H.M.C. Eijkelhof

RADIATION AND RISK IN PHYSICS EDUCATION

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RADIATION AND RISK IN PHYSICS EDUCATION

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RADIATION AND RISK IN PHYSICS EDUCATION

STRALING EN RISICO'S IN HET NATUURKUNDEONDERWIJS

(MET EEN SAMENVATTING IN HET NEDERLANDS)

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PREFACE

The research reported in this thesis began in 1986 following the official completion of the Dutch Physics Curriculum Development Project (PLON). The aim of the research was to investigate further the new approaches to teaching and learning about ionizing radiation which were initially developed in one of the PLON-units for senior secondary education. The work reported here is, therefore, part of a long-term curriculum development and research programme of which the next stage will be the writing and evaluation of new curriculum materials.

During most of the investigations I was assisted by three colleagues: Kees Klaassen, Rudolf Scholte and Piet Lijnse. To acknowledge their contributions I have opted for the term 'we' instead of 'I' throughout the thesis.

I am very grateful for the comments of Piet Lijnse, Robin Millar and Herman Hooymayers on earlier drafts.

1. INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Introduction

This thesis deals with physics education, particularly with the teaching and learning of radioactivity and ionizing radiation. Before outlining the overall aim and the more specific research questions which this study sought to address (section 1.2), we will begin this section by describing the general background to the study. The study itself is a follow up of earlier research and development work in the Dutch Physics Curriculum Development Project (PLON) on a unit called *Ionizing Radiation* (PLON, 1984). The central theme of this unit was the acceptability of the risks of ionizing radiation. A theme of this sort is unusual in physics education. Its aims should be seen against the background of so-called Science, Technology and Society (STS) education. This trend in science education is outlined in more detail in this section. Particular attention is given to those specific problems in STS-education which are addressed in some of our investigations.

Preliminary evaluation of the effectiveness of the PLON-unit showed that pupils appear to have lay-ideas which seem to be resistant to change. A large part of the study reported in this thesis deals with exploring the nature and persistence of these lay-ideas on the topic of radioactivity and ionizing radiation. The way in which our work fits into the recent trend in science education research of investigating pupils' preconceptions and developing strategies for conceptual change is also outlined in this section.

We conclude this section with the background of the PLON-unit, looking at trends in physics education in the Netherlands and at those considerations which played a role in the writing of the unit.

Science, Technology and Society (STS) education

Movements towards Science, Technology and Society (STS) education originated at university level. In the 1960s, among students and staff the role of science and technology in society was a major topic of discussion, principally related to the nuclear arms race, to the war in Vietnam and to environmental problems. Za'rour (1987) summarizes the origin of STS as follows:

> "The limitations and fallibility of science, scientists, and those who apply science could no more be ignored or overlooked. There were cries calling for providing the public with better and more honest information about the pros and cons of science and technology. It was with this fundamental goal that the Science-Technology-Society (STS) movement took off."

As a result of this, a large number of STS-courses were developed at universities, especially in the United States, the United Kingdom and the Netherlands. In 1978 and 1982, lively international conferences were held about STS in Amsterdam (Boeker and Gibbons, 1978) and Leusden (Slaa, Turkenburg and Williams, 1983) in which the main participants were university staff from the UK and the Netherlands. Some participants also came from the field of secondary science education, but they were a small minority. This minority group consisted of people in Europe who were trying to include STS in the school curriculum. It appeared that at school level different approaches were being tried. Lewis and his group developed materials in the project Science in Society (Lewis, 1981), a General Studies course for sixth formers, mainly for those who were not taking a regular science course. The main emphasis in this course was on applications of science and technology in society; a critical view of the role of science and technology in society was absent from this course. Solomon (1983) wrote materials for a similar group of pupils: the SISCON-course. Compared to the previous course, much more attention was paid to reflecting on the role of scientists in society. Mikelskis and Lauterbach (1976) were involved in the construction of an IPN-unit on nuclear power for senior physics education in the Federal Republic of Germany. This unit was written with a problem-oriented view of teaching physics, in which nuclear power is considered to be an important and complex social issue. Eijkelhof, Boeker, Raat and Wijnbeek (1981) of the Free University of Amsterdam wrote a book called Physics in Society, to be used as an optional unit in the Dutch physics education curriculum for pre-university pupils, dealing with complex social issues like energy production and consumption, noise, traffic and nuclear arms, and with reflection on the role of science and technology in developing countries and in industrialized countries.

Later in the 1980s a number of international conferences were held with STS as their main theme. These were organized by the International Organization for Science and Technology Education (IOSTE) in Halifax (McFadden, 1980), Nottingham (Harrison, 1985), Brisbane (Lowe, 1986) and Kiel (Riquarts, 1987) and by the International Council of Scientific Unions in Bangalore (Lewis, 1986). In the Netherlands a summer conference about physics and society teaching was organized by the Dutch Association for Science Education at the Free University of Amsterdam in 1979, in which teachers from some British projects acted as invited speakers. In the United States, annual STS-conferences have been held since 1986 under the heading 'Technological Literacy Conferences'. In the USA, STS-education is promoted by several magazines such as the *Bulletin of Science, Technology and Society* (published by the National Association of Science, Technology and Society, NASTS), the *Newsletter of the Teachers' Clearinghouse for Science and Society Education*, and the *STS Reporter* (published by Pennsylvania State University).

The proceedings of the conferences mentioned above show that STS now covers a wide range of different approaches. Ziman (1980) identifies at least seven approaches:

- making valid science relevant
- the vocational approach
- interdisciplinarity
- the historical approach
- the philosophical approach
- the sociological approach
- the problematic approach.

Others have presented and discussed similar categorizations (Fensham, 1988; Solomon, 1988). Ziman admits his list is not exhaustive. According to him none of these approaches is necessarily exclusive of the others and there is no *ideal* approach. Each has its own rationale, pedagogic advantages and pitfalls. As regards general secondary education, Ziman favours the interdisciplinarity and relevance approaches. The interdisciplinary approach appears also to be favoured by the American NASTS (Pena and Waks, 1989).

In many courses at the secondary level, the dominant STS-approach involves teaching materials which illustrate how scientific knowledge may be useful in understanding new technologies in daily life and how decisions are taken on socio-scientific issues. Only a few courses include reflection on the nature and role of science and technology (Aikenhead and Fleming, 1975; 1990). The place of the PLON-project within this field of approaches will be discussed towards the end of this section.

In view of the developments sketched above, it is not surprising that, in the literature about STS-education, a number of different arguments are given for its importance to adolescents. One is that modern society requires a basic understanding of science and technology by all citizens, as science and technology play such an important role in personal and social life. This is an argument used, for instance, by the NSTA (1982):

> "The goal of science education during the 1980s is to develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision-making. Such individuals both appreciate the value of science and technology in society and understand their limitations."

and the Science Council of Canada (1984):

> "Science should be taught at all levels of school with an emphasis and focus on the relationships of science, technology and society in order to increase the scientific literacy of all citizens."

This so-called 'science for all' argument requires a redefining of the science curriculum, as most of the present curricula have been written for those who are preparing themselves for professions in which advanced knowledge of science is required, although they are a small minority in the population as a whole (Boeker, Eijkelhof, Raat and Swager, 1980; Aikenhead, 1980; McConnell, 1982; Lijnse, 1983; Roy, 1985; Eijkelhof and Kortland, 1985; Yager and Hofstein, 1985; Kortland and Van der Loo, 1986; Bartlett, 1988).

The second argument concerns the low interest in science education courses, for instance in the USA (OTA, 1988), especially in physics (Neuschatz, 1989). It is feared that this could lead to a shortage of professional scientists and technologists. Lewis (1985) feared that pupils were turning away from science, associating it with many of the evils in the world: physics with the bomb, chemistry with pollution and biology with genetic engineering. Others claim that many pupils, including potentially creative scientists and engineers, are discouraged from seeking science careers as they do not wish to work in what they perceive as a boring and irrelevant field (Bondi, 1985). It is argued that more attention to social aspects of science would attract more pupils, especially girls (Sjoeberg and Imsen, 1988).

A third argument claims that more emphasis on STS would relate science education better to the world of the pupils, which would result in better learning of science as pupils are more asked to apply scientific knowledge in familiar contexts and are therefore willing to put more effort into learning tasks (Hogenbirk and Wierstra, 1983; Van der Valk, 1985). In part, this argument is based on dissatisfaction with the learning outcomes in current science education and an expectation that an STS emphasis would make science teaching more effective.

It may be clear from the above that these arguments are rather different. The first aims at a form of science education which could fulfil the needs of all citizens, whilst the second seeks to attract more people to specialize in science and technology. The third refers to pupils who have already decided to take science courses, either for general interest reasons or because they want to be specialists. Questions which arise include:
- are these claims justified? Would different science courses attract more pupils? Would applications-oriented science education be more effective?
- would it really be possible to develop courses which are based on the three criteria: preparation for life, encourage students to study science further and more effective learning?

Questions of this sort are beyond the scope of this thesis. One of the emphases in this thesis is on another problem of STS-education, namely the selection of contents of the curriculum. In traditional physics education there appears to be a general consensus on the content of the curriculum: a large number of topics, concepts, laws, classifications, processes etc. are found in almost all textbooks, even in textbooks from different countries. This may be due to consensus about the structure of the discipline, which had in the past a great influence on the content of physics education in secondary schools. It may also be due to international exchanges between educators.

In STS-education the contents of the curriculum are less agreed upon, partly because of differences in aims, partly because no tradition has been established as yet. Numerous possibilities exist for ways of emphasizing applications of science, technology and social implications. The problem of selection arises when applications and social implications are added to the existing contents of physics syllabuses, as teaching time is limited and many concepts already have to be covered. The problem becomes even greater when STS forms an integral part of the curriculum. Then STS aspects are not simply an addition but a starting point for the selection of content. For instance, when a unit is based on the aim of better understanding of traffic safety through basic knowledge of physics, some concepts are more useful than others. The question then arises: which content is most suitable in the light of the chosen aim of physics education?

This question has been approached in different ways in STS-education. One is to collect as many STS aspects as possible and formulate a syllabus which is based upon this collection. An advantage of this approach is that it provides a teacher with many ideas for topics. A disadvantage is that it may lead to overwhelming the pupils in an abundance of subtopics and content if the teacher tries to cover (large parts of) the syllabus.

A second approach is to write units on the basis of some literature and/or a few consultations with experts. One advantage of this approach is that it quickly leads to a unit. The disadvantage is that the content is subject to the whims of the writers or the consulted experts: it could include a number of less relevant or outdated details, omit more important content elements and stress the teaching of new concepts which appear to be too difficult for pupils. In our view some kind of legitimation of the content of syllabuses is required, which takes into account specific aims of physics education, the expertise of professionals outside the realm of physics education and the results of research on physics learning.

The role of pupils' preconceptions in science education

Studies on children's ideas about natural phenomena date back to the early studies of Piaget around 1930. They only became an important focus of science education research, however, in the seventies.

During the last fifteen years numerous articles and some books have been published on the issue of preconceptions. The term preconception is used along with many other terms indicating more or less the same meaning, such as 'children's science', 'prior conceptions', 'misconceptions','common-sense beliefs', 'intuitive ideas', 'naive beliefs' and 'pupils' representations' or 'notions'. It is not the purpose of this thesis to explore in detail the semantic differences between these and other terms. The epistemological background and the educational implications of the use of these different terms are discussed in various articles (Gilbert and Watts, 1983; Abimbola, 1988; Gunstone, 1988; Hills, 1989). We prefer to use the term 'preconceptions' with the meaning of 'conceptions pupils have formed before instruction' (indicating that the learner forms a mental representation of the world outside him/herself) (Duit, 1987), along with the terms 'pupils' ideas' (indicating rather vague conceptions which pupils could be found to hold before, during or after instruction) and 'lay-ideas' (referring to ideas which can be found among non-scientists, including pupils).

Rich sources of research findings on preconceptions are the proceedings of conferences devoted to this area (Helm and Novak, 1983; Novak, 1987), and books which review the field (Carey, 1985; Driver, Guesne and Tiberghien, 1985; Osborne and Freyberg, 1985). In the Netherlands investigations have also been carried out and reported, for instance on the topics of force and motion (Van Genderen, 1989; Van 't Hul, Van Joolingen and Lijnse, 1989), electricity (Licht, 1987), energy (Van der Valk, Lijnse, Taconis and Bormans, 1989; Lijnse, 1990), light (Wubbels, 1986; Bouwens and Verkerk, 1988) and particulate explanations of chemical reactions (De Vos, 1985).

Not only in the Netherlands but worldwide, many results of studies on pupils' preconceptions are available, especially in physics, for instance on the topics of dynamics, gravity, electricity, light, pressure, heat and temperature, particulate nature of matter and energy. A smaller number of studies has been devoted to topics such as sound, magnetism and radioactivity.

Most of the studies referred to above focus on the existence of particular preconceptions and on the persistence of some of these, for instance by studying pupils' ideas at various stages in education. Less frequent are publications which try to construct 'conceptual frameworks' which refer to inferences about the mental organization of an individual derived from regularities in responses to particular problem settings (Driver and Erickson, 1983; Abimbola, 1988).

A more recent development in this field is a move in the direction of research on strategies which could be applied by teachers in dealing with preconceptions of pupils and in attaining conceptual change (Posner, Strike, Hewson and Gertzog, 1982; Driver and Oldham, 1986; Hashweh, 1986; White, 1986; Licht, 1987; Carr and Kirkwood, 1988; Watts, 1988; Van 't Hul et al., 1989). These strategies are considered to be important by science education researchers, as knowledge of preconceptions and insight into conceptual frameworks does not immediately show the way towards effective teaching and learning. Success of teacher training courses (both pre- and in-service) on preconceptions and conceptual frameworks probably greatly depends on the availability of workable strategies for promoting conceptual change. A recent study by Licht, Eijkelhof, Boschhuizen and Bouma (1989) revealed that in Europe at least there is not much experience of courses on pupils' preconceptions in teacher training.

Most of the preconceptions research so far has focussed on identifying pupils' ideas which might influence the learning of science as such, accepting more or less the existing academic science syllabuses. The results show that the demands set by these syllabuses are not really met by many pupils: some preconceptions seem to be rather resistant to present science education, probably because they are part of general common-sense knowledge in the world outside schools and laboratories.

Towards the end of the PLON-project we developed the idea (Lijnse, 1986; Eijkelhof and Lijnse, 1988) that this problem of the influence of preconceptions on learning would likely to be particularly strong in STS-education, as here the pupils are forced to apply knowledge in often familiar situations, which would evoke exactly those preconceptions which apply to these situations. One might say that STS-education aggravates the problem, as pupils cannot remain within the scientific realm and are deliberately confronted with the outside world and its common-sense ideas. On the other hand, one could also see the more positive side of this: STS-education would provide opportunities to discuss the differences between scientific and life-world ideas. The STS-focus in science education may also lead to the development of criteria to select those preconceptions which are especially worth dealing with in science education, for instance, those lifeworld ideas which may lead to erroneous conclusions with adverse consequences.

Developments in physics education in the Netherlands

In 1974 a national curriculum committee (CMLN, 1975) proposed new physics examination programmes for three existing types of general secondary education in the Netherlands: MAVO, HAVO and VWO (Lijnse and Hooymayers, 1988; Appendix A of this thesis). The philosophy behind these programmes could be characterized as emphasizing the structure of the discipline. In the syllabuses little attention was given to applications of physics and to personal and social implications of physics. Teaching physics in a STS way was not stimulated by these programmes. One of the new points in the proposals was the recognition that VWO teachers should have some freedom to choose topics: one topic taking about fifteen periods should be chosen by the teacher from an officially approved list and should be examined in that part of the examination which is assessed by the school.

The new examination programmes came into effect in the late seventies. The optional topic flexibility was used by a group at the Free University of Amsterdam to develop the topic Physics in Society, which became quite popular among teachers and pupils (Eijkelhof and Swager, 1984). It allowed teachers officially to give some emphasis to the implications of science, technology and society in the physics curriculum.

The PLON-project started in 1972, at the time the CMLN had just about completed its report. The first staff members of the project did not agree with the majority view of the CMLN, which expected the PLON-project to work out the CMLN-syllabus in the form of teaching materials (Van Aalst, 1986). In the view of the project members the main aim of the PLON-project should be to develop new aims for physics education by writing materials and evaluating classroom experiences. These aims should be based on the experiences of teachers and pupils and on social trends. Hooymayers (1986) has outlined which expectations teachers had of the PLON-project at its start. In the first years of the project, the main focus for curriculum development was the improvement of the motivation of pupils to learn physics in junior secondary school. Around 1980 the project decided to include STS aspects in the curriculum with the aim of improving pupils' social decision-making abilities. The approach adopted was less descriptive than in the book Physics in Society and included more pupil activities. In junior secondary education this resulted in four specific STS-units: *Water for Tanzania* (PLON, 1985a), *Stop or Move On*, *Energy in the Future* and *Nuclear Arms and/or Safety* (Eijkelhof, Kortland and Van der Loo, 1984). At senior level it was decided to incorporate STS aspects as far as possible into all the units. So no specific STS-units were developed for upper HAVO and VWO forms but, at numerous places in the units, STS aspects could be identified (Eijkelhof and Kortland, 1988). The STS approach was now widened, not only aimed at promoting social decision-making but also at learning physics which would be useful in daily life and to understand discussion going on in society.

The preconceptions wave rolled on too late to play an important role in the development of the PLON-view of learning physics, as the project officially ended on January 1, 1986. However, during the last years of the project it became clear that preconceptions were not effectively dealt with in the units. This led to the start of research work on several topics, particularly force and motion (Van Genderen, 1989), energy (Van der Valk, 1989) and ionizing radiation.

Early in the 1980s a new national physics curriculum committee (WEN) was set up by the government to work out proposals for new examination syllabuses for MAVO, HAVO and VWO. These syllabuses were to include the results of several innovation projects, including the two mentioned above (Physics in Society and PLON). For senior HAVO and VWO this resulted in syllabus proposals in which the importance of personal and social aims of physics education is emphasized (WEN, 1988) (see also section 2.5 of this thesis). The syllabuses will come into effect in 1993.

Teaching the topic of ionizing radiation

This thesis deals with the topic of ionizing radiation. This topic is relatively new to mankind, as X rays and radioactivity were only discovered to exist less than a century ago. In modern society ionizing radiation plays an important role: it is used in hospitals for diagnosis and treatment purposes, in numerous industrial applications and in agricultural research, and radioactive substances emitting ionizing radiation are used and produced in nuclear power stations and in explosions of nuclear weapons. Some of these fields of application evoke a great deal of public debate (Weart, 1988), for instance about the storage of nuclear waste, the construction of new nuclear power stations, and the deployment of new missiles to transport nuclear arms. Accidents with radioactive sources often lead to headlines. How much emphasis is given in science education to the applications of ionizing radiation and to the questions which arise in these public debates?

In general secondary education, the common approach for teaching about radioactivity and ionizing radiation is rather academic: one starts with the nucleus, with unstable nuclides and with the characteristics of various kinds of ionizing radiation. Applications usually do not receive much attention and the books do not seem to aim at pupils understanding the kind of issues mentioned above.

The typical STS-textbooks mentioned above generally do give attention to nuclear power, describing the pros and cons of this method of generating electricity (Lewis, 1981; Solomon, 1983; Eijkelhof et al., 1981; Mikelskis et al., 1976). Some of these books also deal with the atomic bomb, either focussing on the history of its development (Solomon, 1983) or on the nuclear arms race (Eijkelhof et al., 1981; PLON, 1983a). Medical uses of ionizing radiation have received less attention in STS-courses; one of the exceptions is the Israeli course on physics in medical diagnosis (Ronen and Ganiel, 1984) which includes the subtopics 'X rays' and 'radioactive tracers'.

In 1982 the PLON-project produced a first version of a new unit *Ionizing Radiation* for forms 5 HAVO and VWO which deals with the topics of nuclear power, nuclear arms and medical uses of ionizing radiation. The unit was based on a central theme which may be summarized as 'the acceptability of the risks of ionizing radiation'. The idea was not, as in other STS-units, that the pupils should develop insights into the social decision-making processes around applications of ionizing radiation, but that pupils should be able to use scientific knowledge in assessing the risks of ionizing radiation. So the applications had to function as contexts for scientific knowledge, and not as topics in themselves to be covered fully. A more detailed description of the second version of this unit (PLON, 1984) is provided in section 2.3.

None of the materials mentioned above takes into account the existence of preconceptions among pupils. This may be partly due to the fact that at the time of development of these units not much knowledge was available about pupils' preconceptions, especially not on the topic of radioactivity and ionizing radiation. Perhaps another reason is that STS developers were more occupied with trying to give expression to the aims of STS-education than with the learning effects of their courses.

From a first evaluation of the second version of the unit *Ionizing Radiation* (Eijkelhof and Wierstra, 1986; Eijkelhof, 1986) we learned that preconceptions did exist among pupils, both before and after teaching this topic. Evaluation also showed that pupils did not make much progress in reasoning about the risks of radiation. It looked as if their common-sense reasoning did not alter very significantly.

These results led to the planning of a series of investigations in order to get more insight into the reasons why pupils progressed less than expected in their reasoning about the risks of ionizing radiation and into ways of overcoming these learning obstacles.

In the next part of this chapter we will present a first outline of the general aim, the research questions and methods used in this series of investigations.

1.2 OUTLINE OF THE THESIS

General aim and research question

The point of departure for the investigations reported in this thesis are experiences with the PLON-unit *Ionizing Radiation*, with its specific aim of increasing pupils' ability to assess the risks of ionizing radiation in various fields of application which they might come across, now and in the future. As stated previously, so far this aim has not been achieved satisfactorily, and this leads to questions about why this is the case, how materials should ideally be designed and how teaching could be improved. Therefore, the general research question for the study was:

> Which curricular and other teaching conditions must be fulfilled in order to promote thoughtful risk analysis and assessment as regards applications of ionizing radiation, through physics lessons in senior high school?

The most characteristic feature of this research question is the aim of promoting a thoughtful risk analysis and assessment. The risk perspective was chosen for this study for the reason that risks of ionizing radiation appear very frequently in the everyday world of media reporting; applications of radioactivity are particularly likely to be surrounded by controversy and public debate. If it is seen as important that pupils should understand the points at issue in these debates, it would be difficult to avoid the risk aspects of ionizing radiation. It is also well known that radioactivity and ionizing radiation are, in the perception of the public, strongly associated with matters of hazards and safety. Attitudes are often so strong that scientific knowledge hardly seems to play a role in reasoning about the matter. This makes it particularly challenging to try to teach the subject within a risk perspective. We call our aim an STS-aim as it focusses on the use of scientific knowledge in daily life, assuming that scientific knowledge may be useful in this respect. Of course other focussing points are possible (and indeed much more common) such as learning science for cultural reasons or as preparation for further studies; these latter aims may not lead to curricular and teaching conditions which are in all respects different, but it is likely that our aim will lead to some significant differences from the present approach in teaching this topic.

As an area of education we selected physics education in senior high school; in the Dutch school system this means senior HAVO and VWO classes, in which physics is one of the optional examination subjects (Appendix A). An advantage of this age group is that these pupils are adolescents who generally are more interested in the 'world' than younger pupils. They have also already received three years of physics teaching so that they can study the topic at a higher level. A more pragmatic argument is that, in general, the topic ionizing radiation has not been dealt with in junior secondary education in the Netherlands, so we can avoid various introductory problems which might arise when introducing the topic to younger pupils. In senior high school about fifteen to twenty periods of 50 minutes teaching are available for this topic.

The end point of the present study is a set of recommendations for writing curriculum materials and for teaching strategies with the above mentioned aim. A further study, to be started in 1990, will evaluate the effectiveness of new teaching materials and teaching strategies in reaching this aim.

Separate studies reported

The general research question is rather complex. It encompasses a number of issues, such as:

A. the selection of suitable subject-matter and contexts;
B. taking into account popular and persistent lay-ideas and perceptions of risk, which obstruct risk assessment;
C. considering teaching and learning problems experienced in physics education on this topic;
D. dealing with the attitudes of pupils to risk.

It was therefore assumed that the general research question could not be answered by a single investigation. So it was decided to approach it by a series of investigations, based on more specific research questions. We will now briefly introduce those; a more detailed elucidation will be given in the sections dealing with the studies which seek to find answers to these questions.

A. the selection of suitable subject-matter and contexts

As will be illustrated in chapter 2, the chosen aim is not common in Dutch physics education. Firstly, it is uncommon to formulate an aim which requires pupils to use scientific knowledge outside the classroom. Secondly, the close relationship between scientific knowledge and risk assessment has not been explored in depth in physics teaching. As a consequence, questions arise about the kind of situations in which pupils should be able to assess risks and about the scientific content which should be mastered to reach this aim. As teachers cannot be expected to be specialists in these fields and as the area of applications of ionizing radiation is a rather controversial one, it was decided to consult radiation experts about their views on suitable context domains and scientific content.

This investigation was guided by the following research questions:

1. Which context domains of ionizing radiation are suitable for inclusion in physics education in senior high school?
2. What scientific content should be covered in the physics curriculum in order to stimulate thoughtful risk assessment in the selected context domains?

Answers to these questions were sought by a Delphi-study in three rounds among a group of about 50 radiation experts, reported in chapter 2.

B. popular lay-ideas and perceptions of risk which obstruct risk assessment

As some persistent preconceptions about ionizing radiation were identified in a preliminary study among pupils and as preconceptions of this sort have not yet received much attention in the science education literature, it seemed worthwhile to investigate the nature and incidence of these preconceptions. It is likely that these preconceptions are influenced by lay-ideas in the frequent media reports about radioactivity and ionizing radiation; so we decided to analyze news reports on this matter. Another way to detect popular lay-ideas is to consult radiation experts who have frequent contacts with the general public. These specialists were also expected to be able to contribute to answers to the question of which lay-ideas would present a particular obstacle in assessing the risks of ionizing radiation and which may therefore be important to deal with during the educational process. In addition, they were consulted in order to increase our insight into the differences between the ways of thinking about radiation of lay-people and experts, which is necessary if we are to find ways of bridging this gap.

Analysis of news reports and consultations with radiation experts served mainly as an introduction to our investigations with pupils. We were particularly interested in the nature of pupils' ideas and reasoning about radioactivity and ionizing radiation before instruction, as this may give an indication of what a teacher can expect when starting formal instruction on this topic.

For these reasons the following research questions were investigated:

1. Which specific lay-ideas about radioactivity and ionizing radiation can be detected in reports in the news media?
2. Which specific lay-ideas about radioactivity and ionizing radiation are recognized at a more than incidental level by radiation experts?
3. To what extent are these ideas an obstacle to lay-people in assessing the risks of ionizing radiation?
4. What are the important characteristics of the differences between the ways of thinking about radiation of lay-people and experts?
5. What ideas do pupils have about the origin, propagation, absorption and effects of ionizing radiation in various contexts domains? What meanings do they ascribe to the terms irradiation, radioactive contamination, radioactivity and radiation standards?

Question 1 was answered by an analysis of a large number of news reports, mainly about the Chernobyl accident. Its results are only summarized in this thesis as they have been published in various articles. Questions 2, 3 and 4 are dealt with in part of the Delphi-study referred to above. Question 5 was investigated by a questionnaire (completed by 312 pupils) asking for their ideas about the Chernobyl accident and by fifteen interviews exploring pupils' ideas in five context domains. The results are presented in chapter 3.

C. teaching and learning problems experienced with physics education on this topic

School textbooks illustrate in general terms the content and approach of physics teaching. So we decided to analyze school textbooks to see how they deal with the topic in order to get a better picture of the problems which might be expected when introducing a new approach.

Some teachers already have a range of experiences as a result of teaching ionizing radiation from a risk perspective using the PLON-unit *Ionizing Radiation*. A number of these teachers were approached, mainly to get insights into the methods they have used to deal with the risk approach adopted by the unit and with pupils' ideas about the topic area.

Of course, asking teachers is only one way of getting insight into the learning problems associated with a particular approach. Another, supplementary one is to observe teaching in progress and therefore we observed a series of lessons in a class which used the PLON-unit.

Finally, an indication of teaching and learning problems can be found by studying the "output" of education, for instance by studying the answers on questionnaires completed by pupils after instruction. An interesting question in this respect is what differences there are between those instructed with the PLON-unit and with a traditional textbook.

The studies in this field were guided by the following research questions:

1. How do Dutch physics textbooks deal with the topic of ionizing radiation?
2. What is teachers' experience of teaching the topic of ionizing radiation in a risk context?
3. Which teaching and learning problems can be traced in classroom dialogue during lessons using the unit *Ionizing Radiation*?
4. Which lay-ideas about radiation and related concepts are recurrent amongst form 6 pupils who have studied the topic of ionizing radiation in physics lessons? What differences are apparent in the persistence of these ideas between pupils who have used the PLON-unit *Ionizing Radiation* and those who have used a more traditional textbook?

Question 1 was addressed by analyzing five school textbooks on the way they cover concepts and context domains, on the meanings they attribute to some important concepts and on the way they deal with lay-ideas and with risk aspects. Question 2 was answered by interviewing seven teachers who were experienced in teaching the PLON-unit and question 3 by observing a series of lessons with the unit at one school. Question 4 was dealt with by a multiple-choice questionnaire completed by 138 sixth formers after using the PLON-unit or another, more traditional, book. The results are presented in chapter 4.

D. dealing with pupils' attitudes to risks

Attitudes towards the risks of ionizing radiation appear to be particularly strong in modern society. It might be expected that anxiety about this

kind of radiation will be present on the part of the pupils and may play a role in an educational scheme which has a risk emphasis. In order to get insights into the nature of this anxiety we studied the risk perception literature and included questions about this matter in the Delphi-study with radiation experts and in the interviews with pupils.
These investigations were guided by the following research questions:
1. What are the major reasons for the anxiety of the general public about ionizing radiation and its applications?
2. How do pupils, before instruction, perceive the risks of ionizing radiation in various context domains?
3. Which aspects should be emphasized by teachers when responding to this kind of anxiety amongst pupils?

Questions 1 and 3 were mainly addressed in a third part of the Delphi-study among radiation experts. The results are reported in chapter 5. Question 2 was included in the fifteen interviews with form 4 pupils; the results are reported in chapter 3 and summarized in chapter 5.

Outline of the thesis

The next chapter (2) will begin with a short description of the history of the topic of ionizing radiation in Dutch physics education. It will then present in more detail the contents of the PLON-unit and the findings of preliminary studies, followed by a report of the Delphi-study on the selection of contexts and contents. It ends with a reflection on the recommendations of this part of the Delphi-study.

Chapter 3 deals with lay-ideas about radioactivity and ionizing radiation amongst lay-people and pupils. The results of the news report analysis are summarized, followed by an account of the Delphi-study on the occurrence and importance of lay-ideas. The next section is devoted to pupils' preconceptions, giving an account of the questionnaire and interviews with form 4 pupils, on a variety of contexts. In the final section of this chapter the results of these three studies are evaluated and conclusions are drawn about ideas, frameworks and ways of reasoning.

In chapter 4 the focus is on education itself: it describes some findings on the ways school textbooks deal with risk aspects, class observations are reported, the results of the interviews with teachers are presented and pupils' 'postconceptions' are outlined and discussed.

Chapter 5 begins with an account of some findings from the literature on people's perceptions of the risks of radioactivity and ionizing radiation. It then presents the ideas of radiation experts on how to deal in education with anxiety about radiation. Risk related findings from the studies with pupils are summarized and some conclusions are drawn about teaching radioactivity and ionizing radiation from a risk perspective.

Chapter 6 presents and discusses recommendations for curriculum development, for teaching strategies, for teacher training and for further educational research and development.

2. SELECTION OF CURRICULUM CONTEXTS AND CONTENTS

2.1 INTRODUCTION

It was shown in the previous chapter that the problem of selecting the content of the curriculum is an especially urgent one for STS-education. This chapter focusses on this problem of selection for the topic of ionizing radiation. Answers will be sought to the question:

> Which contexts and scientific contents are appropriate for the aim of promoting pupils' ability to analyze and assess risks of ionizing radiation?

'Scientific contents' include in our view scientific concepts, properties, laws, models and processes, relations between concepts, and explanations of phenomena. 'Contexts' of scientific contents denote schoolish or realistic situations to which these contents are related (Van Genderen, 1989). Examples of such realistic situations are the existence of background radiation in homes, the use of a Geiger counter by a radiation worker and the practice of food irradiation. From the perspective of pupils situations as such are not contexts; they become contexts only if the concepts, laws etc. can be applied by pupils in those situations. The disadvantage of such a perspective is that 'context' becomes a very subjective concept, different for each pupil. From the perspective of curriculum development it is perhaps more useful to use the term 'context' in the meaning of 'situation to which scientific contents should be related in teaching'. In the discussion which follows we will use the term 'context' in this meaning.

As the number of situations and therefore of potential contexts is large, we have decided to cluster some related contexts in 'context domains': collections of related situations which could be used in teaching as contexts for the scientific contents.

In modern teaching of physics, contexts are often selected to function as applications of a given set of scientific contents. Although this may be considered an improvement as compared to traditional ways of teaching in which realistic situations are avoided, such a uni-directional approach of the selection of contexts is not suitable in view of the general aim of our study. This chosen aim is central: in the selection of both scientific contents and contexts this aim should be taken into account. As scientific knowledge and insight should serve this aim, it seems appropriate to start with the selection of realistic situations in which an assessment of risks seems to be an appropriate and feasible aim. From these situations one could then derive those scientific contents which would be important to use in assessing risks in these situations.

In this chapter we start with a short outline of the history of the topic of ionizing radiation in Dutch secondary physics education by describing the aims, scientific contents and contexts of examination syllabus proposals made by various national committees (2.2).

Secondly, the aims, scientific contents and contexts of the PLON-unit *Ionizing Radiation* are specified, followed by a presentation of the main results of some evaluation studies of this unit (2.3).

Thirdly, we present the results of a Delphi-study among radiation experts, in order to legitimate the selection of suitable contents and contexts (2.4).

Finally, we discuss the results of the Delphi-study by comparing these with a new examination syllabus proposal for HAVO and VWO (WEN, 1988) (2.5).

2.2 HISTORY OF THE TOPIC OF RADIOACTIVITY AND IONIZING RADIATION IN DUTCH PHYSICS EDUCATION

Introduction

Many years before the second world war, radioactivity and X rays became accepted as topics in Dutch physics education. The long popular textbook of Gerrits included this topic, at least in its second printing (Gerrits, 1917). The importance of the topic was recognized by the committee which presented a report on physics education in secondary schools to the board of the Dutch Physical Society in 1928, often called the Fokker report after its chairman prof. dr. A.D. Fokker (Fokker, 1928). This is the first report in which a syllabus is suggested for secondary education in physics.

In its introduction several remarks are made about the aims of physics education, such as:

- physics education should lead to knowledge of the most important theories, familiarity with the most important applications of physics in daily life and in technology, and insight into the historical development of some problems;
- education should be related to the pre-scientific knowledge of the pupils in order to raise their level of interest.

So already in this early report emphasis is given to the importance of applications of physics in daily life and technology and to the existence of prescientific knowledge, the latter to raise the level of pupils' interest.

In the syllabus proposal itself, under the heading 'Atomistic Electricity', a number of concepts in the field of X rays and radioactivity are mentioned (Table 2.1). These refer almost exclusively to scientific contents. Only the 'application of X rays' and the 'experiments of C.T.R. Wilson' refer to context. Topics in the left-hand column were mentioned in a circular sent to schools in July 1930 by the Board of Inspectors. The circular listed the minimum requirements for the physics examination at the end of the HBS (a five-year school type preparing pupils for tertiary education) and stated that the examination questions would remain within the boundaries of these minimum requirements.

Table 2.1 Part of the earliest proposed syllabus for Dutch physics education (Fokker, 1928)

core topics	*optional topics*
X rays: properties application nature origin	X-ray spectra
radioactive radiation: alpha- beta- gamma-radiation	emanation helium-atom as alpha-particle radioactive crumbling [sic] of an atom energy of radioactive radiation
ionization of gases	ions as nucleating sites experiments of C.T.R. Wilson
	Bohr's atomic model structure of matter periodic system of elements isotopes hydrogen nucleus as building block of the nuclei of other elements

In order to get some insights into the development of ideas in Dutch physics education, we studied the reports of other committees of the following decades: Groosmuller (1938), Houdijk (1948), Rekveld (1966a,b), CMLN (1975) and most recently WEN (1988). We were particularly interested in the aims stated in these syllabus proposals and in the contents and contexts which were included, either as basic knowledge items or as optional topics, and in the reference made to the risks of ionizing radiation. This may give us some clues as how strong certain traditions are, how difficult it might be to get proposals for change accepted by Dutch physics teachers, or, conversely, in what longstanding tradition new proposals might be seen.

In the following section we will look at trends in the proposals from 1928 until 1975 (the proposal which lead to the examination syllabus which is currently operative).

Trends in syllabus proposals

Most of the proposals of the committees mentioned above led to new examination programmes on which the national examinations were based and consequently had great influence on textbooks. Such influence is already visible in the textbooks published around 1930: Gerrits (1931), Moll and Burger (1928) and Reindersma and Van Lohuizen (1931). These all contain the topics in the Fokker proposal with only a few additional topics. In these extra topics some differences between the books appear, both as regards the way they deal with the risks of ionizing radiation and in the way certain concepts (half-life, structure of the nucleus and radioactive decay) are treated:

a. Gerrits mentions as a property of X rays their curative effect on the human organism, Reindersma the causation of very malignant skin disorders but Moll neither of those properties;
b. only Gerrits mentions physiological effects of radioactive rays and radioactive substances: used for the curing of skin disorders and cancer; he refers to the use of spring water and mud which contain small amounts of radium emanation;
c. as an addition to the national syllabus, the term 'half-life' is used by Moll and Reindersma; Gerrits uses the expression 'characteristic time of an element';
d. Gerrits and Moll explain that nuclei consist of protons and electrons (the neutron was only discovered in 1932);
e. radioactive decay is described using terms such as "falling apart" (Gerrits), "splitting" (Gerrits), "bursting apart" (Moll) and "crumbling" (Reindersma) of atoms; at that time no confusion with fission is possible as nuclear fission was only discovered in 1939.

The topic 'atomistic electricity' was not often examined in the thirties. In 1932 a question was asked about X rays: pupils had to describe an apparatus which produced these rays, explain their origin and mention some of their properties.

The Groosmuller committee (1938) declared in the introduction to its report that in its view no fundamentally different contents were necessary, as compared to the existing syllabus. This view is reflected in the contents of that part of the syllabus with the heading 'atomic structure and radiation': its contents were not very different from the Fokker report. New features were the terms 'radioactivity', 'transmutation', 'neutrons', 'positrons' and 'deutons'(!). On the other hand the terms 'radioactive radiation' and 'emanation', and the subtopics 'applications of X rays', 'energy of radioactive radiation' and 'X-ray spectra' were no longer mentioned. So the only reference to context was to 'experiments of C.T.R. Wilson'.

The Houdijk report (1948) contains a full chapter on the aims of physics education. It starts by quoting the aims of physics education set by Fokker (1928) but takes the view that these aims need additions and extensions. Reference is made to developments during and after the war, such as the atomic bomb. It is stated that because of these developments the social importance of physics is now felt by large numbers of people. The report concludes that physics education should refer to technological developments made possible by physics. So the physical side of some technical - and therefore often economical - problems should not be omitted. It agrees with the Fokker report that a physics teacher should not hide behind arguments about lack of time, in order not to answer pupils' questions about new phenomena in daily life and in technology; where possible he should point out the relation between these.

In the syllabus proposal we find X rays mentioned under the heading "electricity" in the list of topics for forms 2 and 3 of the HBS. The syllabus-proposal for the upper forms includes the topics listed in Table 2.2.

Table 2.2 Part of the first post-war syllabus proposal for Dutch physics education (Houdijk, 1948)

core topics	*optional topics*
radioactivity	
scattering experiment (Rutherford)	
atomic models of Bohr and Rutherford	
Wilson cloud chamber	Geiger counter, ionization chamber
X rays: spectra, tubes, interference (materials-research, structure of crystals, therapy)	explanation of the periodic table
radioactive series	
mass spectrograph, isotopes	
nuclear physics	artificial radioactivity

It is remarkable that α-, ß- and gamma-rays are not mentioned, perhaps because they are considered to be included in 'radioactivity'. Also the concept of half-life is still not included in the list, although as we saw above, this concept was already dealt with in the textbooks around 1930.

The radioactive series is a new addition. No mention is made of the topic of nuclear fission, nor of the effects of radiation. This is striking as the committee refers in its introduction to the syllabus to the atomic bomb as an example of the revolutionary influence of physics. Some more STS aspects might have been expected from the aims which were declared.

Compared to the previous proposal a few more contexts are included: Rutherford's experiments and some applications of X rays. Some other elements of the syllabus, such as Geiger counter, ionization chamber and mass spectrograph, refer to apparatus which could be easily related to contexts by dealing with the use of these. Except 'therapy with X rays', all these elements refer to contexts which can be labelled as 'scientific research'.

In view of the restructuring of Dutch secondary education in the 1960s, the Rekveld committee formulated proposals for the physics syllabus of HAVO and VWO (Appendix A). In the HAVO-report (Rekveld, 1966a) the committee mentioned the following aims for physics education in HAVO-schools:

a. contributing to pupils' general education;
b. making pupils familiar with the principles and basic concepts of physics;
c. providing insight into the development of physics since 1900;
d. preparing pupils for higher vocational training.

In the VWO-report (Rekveld, 1966b) no aims of physics education are mentioned. Table 2.3 lists the topics in the field of radioactivity, ionizing radiation and nuclear reactions in the VWO-report.

Table 2.3 Part of the first proposal for a physics syllabus for VWO (Rekveld, 1966b)

core topics	*optional topics*
	explanation of X-ray spectra
natural radioactivity: types of radiation, properties	disintegration law, half-life; description of α- and ß-radioactivity
demonstrating radioactive radiation (a.o. with Wilson chamber, Geiger tube)	neutrino (energy-spectrum of ß-particles)
artificial radioactivity, tracers	radioactive series
structure of the atomic nucleus: proton, neutron (nucleon)	cyclotron; nuclear reactions resulting from bombardment
isotopic nuclei	
$U = m.c^2$; binding energy per nucleon; dependence of atomic number	
nuclear fission; nuclear reactor (purpose, principle)	nuclear fusion in a plasma; solar energy; gamma-radiation; energy-levels of the nucleus; radiation dosimetry; curie; röntgen

As compared with the HBS-proposals of previous committees, less emphasis is given to X rays and many more topics are included in the field of nuclear reactions. New items in the list of core subtopics are the equivalence of mass and energy (Einstein's equation), binding energy and nuclear fission. References to contexts are Wilson chamber, Geiger tube, nuclear reactor, cyclotron, tracers and radiation dosimetry. Again, scientific research appears to be the main characteristic of these contexts.

The HAVO-proposal differs only slightly from the syllabus proposed for VWO. In the scientific contents list it gives less emphasis to energy aspects of nuclei and radiation. As regards contexts it is similar to the VWO-proposal, except that it includes 'dating method' and omits 'radiation dosimetry'.

The last proposal we deal with in this section is the CMLN-report (1975). This report makes proposals for syllabi for various types of secondary education. In its HAVO-section, a few lines are devoted to the aims of physics education at HAVO. According to the committee the aim is to prepare pupils for a future role in society, which includes that pupils should be able to use physics directly if required; indirectly it means that physics should be part of the general education of pupils. It is further stated that pupils therefore should become familiar with basic concepts of physics and with the way in which a physicist approaches problems. In its VWO-section, no statement is made of the aims of physics education.

In the VWO-syllabus itself no big changes, as compared to the Rekveld syllabus, can be reported. This report is the first to make no distinction between core and optional topics throughout the VWO-syllabus. Some larger optional topics were proposed but these topics did not relate to atomic and nuclear physics.

In the CMLN-proposal for VWO the following elements are deleted: radioactivity, radioactive series, artificial and natural radioactivity, cyclotron, dosimetry, curie and röntgen. Scientific contents added are atomic and nuclear mass, (un)stable nuclei, mass defect, annihilation and creation of material particles, and mass as function of velocity. As contexts are added mass spectrometer, dating method, and dangers of radiation.

The CMLN-proposal for HAVO differs only slightly from the Rekveld-proposal. The present HAVO- and VWO-syllabi (O&W, 1976) are based on these CMLN-proposals and are presented in Table 2.4 (page 22).

In Table 2.4 no contexts are included; only four elements, 'mass spectrometer', 'cloud chamber', 'GM-counter' and 'nuclear reactor', refer indirectly to contexts. No reference is made to the risks of ionizing radiation in these syllabi.

The aims and contents of the most recent proposal for an examination syllabus (WEN, 1988) will be presented and discussed in section 2.5, as the origin of these proposals can be better understood after a description of the PLON-unit *Ionizing Radiation*.

Table 2.4 Part of the present physics syllabus for HAVO and VWO (O&W, 1976) (*: only required for VWO)

*	-	X rays (line spectrum)
	-	structure of the nucleus; proton and neutron; atomic and mass number
	-	number of nucleons depends on atomic number; isotopes
*	-	nuclear mass; atomic mass unit
	-	mass spectrometer (deflection in a magnetic field)
*	-	energy levels
(*)	-	stable and unstable nuclei; α, (*) ß+, ß- and gamma-radiation
*	-	exponential disintegration law
	-	half-life
	-	demonstrating radioactive radiation with cloud chamber and GM-counter
*	-	nuclear reactions
	-	$E = \Delta mc^2$ (no derivation)
*	-	annihilation and creation of material particles
*	-	mass defect and binding energy of nuclei
(*)	-	nuclear fission and (*) fusion
	-	nuclear reactor (principle)

Conclusions

The history of Dutch physics syllabus proposals for HBS and later for VWO and HAVO shows that until recently, the aims of physics education are not always discussed explicitly in the reports. It appears to be assumed that these were not problematic and were sufficiently agreed upon implicitly by the community of physics educators. In only two of the reports, STS aspects are declared to be important in the introductory sections dealing with the aims of physics education. However, these aims seem to be formulated from a concern with the public image of physics and from the view that knowledge of physics concepts would be sufficient for pupils to use physics in daily life and to understand developments in society. In all syllabus proposals the number of contexts is limited. They are not distinguished from the scientific contents of the syllabuses. Those contexts which are included refer almost exclusively to scientific research (famous experiments, scientific instruments, types of research) or to an idealized technological prototype (such as the principle of a nuclear reactor). The scientific contents of the syllabuses seem not to be derived from contexts but based on an agreed, though not well articulated, view of what pupils should know at the end of secondary education in physics. Risk aspects are generally absent from these proposals. Only the CMLN-proposals mention 'dangers of radiation' but this item was not included in the resulting examination syllabus.

We may conclude, therefore, that the aim of risk assessment has not been considered by the various curriculum committees as an aim for physics education on the topic of ionizing radiation. Not surprisingly, the examination syllabuses published to date, including the present one, appear not to be suitable for a teacher who wishes to strive for this aim.

2.3 SOME INNOVATIVE CURRICULUM MATERIALS ON RADIO-ACTIVITY AND IONIZING RADIATION

Introduction

As outlined in chapter 1, in the 1970s two curriculum projects were initiated in the Netherlands in which the relation between physics and the world outside did play an important role: the PLON-project and the project Physics in Society.

During the life time of the PLON-project (1972-1986), a large number of units were produced for junior and senior secondary education. The units dealt with a wide range of topics. The topic of radioactivity and ionizing radiation was covered in two units:

1. *Nuclear Arms and/or Security*, for lower forms;
2. *Ionizing Radiation*, for senior forms.

The first unit is described in Eijkelhof, Kortland and Van der Loo (1984) and is less relevant to this thesis as it is written for pupils in the junior secondary school. The second unit will be described in more detail later in this section.

The book *Physics in Society* (Eijkelhof, Boeker, Raat and Wijnbeek, 1981) deals with various controversial issues. Those which relate to the subject of this thesis are issues such as the nuclear power controversy, risk analysis of nuclear reactors, and the history and development of the nuclear arms race.

Reactions of pupils and teachers were in general favourable (Eijkelhof and Swager, 1984). An advantage of the book was that it could be used in addition to any other physics textbook. This supplementary character was on the other hand also a disadvantage, as no integration was possible between the pure physics and the related applications, and as the contents might be seen as interesting but of a lower status than the topics to be studied for the national examination. The later PLON-units, such as *Ionizing Radiation*, might be seen as a further step towards integrating physics and society.

As this unit is the only Dutch physics textbook for senior secondary education in which the topic of ionizing radiation is dealt with from a risk perspective, as much of the research described in this thesis originated from evaluation studies of this unit, and as some of the studies reported in the following chapters are closely related to the use of this unit, we will describe in the following section in more detail the contents of the present version of this unit. This description is preceded by a short outline of the history of the unit to illuminate the origin of the present contents. It is followed by a section presenting the main findings of a first evaluation study on the effects of the use of this unit, leading towards a rationale for further studies.

The PLON unit Ionizing Radiation

In planning the PLON-curriculum for the two senior forms of HAVO, it was decided that the topic of radioactivity should be dealt with in one of the ten units. The general argument was that this is an important topic, both for those who prepare for science-related tertiary studies and for those who chose the subject physics without any particular vocational need, but as form of general education.

In trying to devise a blueprint for this unit it was argued that for many people the topic of radioactivity is relevant because of the possible effects of radiation. The curriculum team had observed that all traditional approaches to the topic focussed on the source of the radiation (nuclear processes) and on the physical properties of the radiation emitted. By largely ignoring the possible effects of radiation, one might maintain a gap between what was learned in physics lessons and what interested ordinary citizens. One perceived limitation of a modern issues-based approach such as Physics in Society was that the book contained many aspects from other discliplines (history, economics, social science) and that only highly controversial issues were included. These considerations led to the following basic decisions preceding the design of a new unit:

1. emphasis should be given, not only to the source and the nature of the radiation but also to the effects of radiation;
2. the unit should not focus on one or two complete issues but on ionizing radiation itself;
3. ionizing radiation should be applied in a variety of practical situations.

Following these decisions, the acceptability of the risk of applications of ionizing radiation was chosen as central theme of the unit. The aim of the unit was that pupils should learn to use scientific knowledge in situations in which risks of ionizing radiation have to be assessed. Contents were selected using questions deduced from this aim:

a. what is the origin of this radiation?
b. what are the properties of the radiation?
c. how can the radiation be detected?
d. what are the effects of the radiation on the human body?
e. what uses can be made of the radiation?
f. how can one protect oneself against radiation?
g. how can the risks of radiation be evaluated?

In order to prepare the unit, a review of literature was undertaken and interviews were held with some experts: radiation experts in the Ministry of the Environment (who deal professionally with a large number of applications of ionizing radiation), a specialist on nuclear matters in the national civil defence organization, and two medical consultants (familiar with the use of X rays and radioactive substances in hospitals). More experts could not be consulted due to time constraints.

A trial version of the unit *Ionizing Radiation* was developed in 1982. The unit dealt with types, effects and sources of radiation, in a section to be studied by all pupils. Optional chapters were added about nuclear energy, nuclear arms and health applications. Pupils' opinion about this version of the unit was evaluated in ten classes by Wierstra (1984). Questionnaires were completed by 172 pupils. Analysis of the answers resulted in the following conclusions:

a. pupils judged the unit to be useful, instructive and interesting: they mentioned the topicality of the theme, the insights gained into the nature, applications and effects of radiation, and into the positive and negative aspects involved;
b. the unit did not cause depressive feelings amongst the pupils; in reactions to some lectures about this unit, the point of possible depressive feelings amongst pupils because of the risk approach had been raised;
c. the unit was judged to be neither difficult nor easy by most of the pupils, but the variety of lessons was not seen as optimal;
d. girls tended to find the unit more instructive and more difficult than boys; after the unit they were more critical about radiation than boys; the optional chapter on medical applications was very popular among girls.

These results, and oral reports from teachers, were discussed by members of the project team and led to some amendments of the unit, for instance the inclusion of more pupil activities, the removal of the introduction of nuclear fission from optional chapters to a section to be studied by all pupils, the addition of a short introduction about the concept of risk, and the use of SI-units throughout, even though the old units curie, rem and rad are more common in many external publications.

As the second version of the unit (PLON, 1984) plays an important part in this thesis we will describe its contents in greater detail (see also Appendix B). Teaching the unit requires about twenty periods of 50 minutes each.

The unit starts off with an *orientation*, which includes the following:

- introduction of the concepts 'X rays', 'nuclear radiation' and 'ionizing radiation';
- an activity in which pupils discuss their experiences of a number of everyday life situations in which ionizing radiation is involved, such as being X-rayed, viewing TV-programmes about nuclear issues or meeting cancer patients who have been irradiated;
- a section on small and large risks, including the relation between risk components such as 'chance' and 'effects', the difference between micro-, meso- and macro-effects, and exercises about the risks of free-

riding on public transport, about the risks of traffic accidents for cyclists and about examples of risks with low or high probability and slight or serious consequences.

The next part (chapters 2, 3 and 4) contains *basic information* and skills about the nature, effects and sources of X rays and radiation from radioactive substances. Concepts important in risk assessment are introduced, such as the characteristics of various kinds of ionizing radiation, 'half-life', 'activity', 'dose equivalent', 'external' and 'internal exposure to radiation', and 'acute' and 'delayed' effects of radiation. Pupils become familiar with dose limits recommended by international bodies such as the International Commission on Radiological Protection (ICRP). Sources of radiation in nature, in nuclear reactors and nuclear bombs, and in medical applications are studied. All exercises in this section deal with real-life situations. One of them requires a rough calculation of the annual radiation doses of the pupils themselves and a comparison of these doses with the established standards.

The next part of the unit (chapters 5, 6 and 7) contains three *options*: nuclear energy, nuclear arms and health. Small groups of pupils work on one of these options. The unit contains background information on risk and safety aspects of each of these areas of application. So emphasis is given to risks in the nuclear fuel cycle, the safety of nuclear power stations, the immediate and delayed effects of nuclear arms explosions, protection by nuclear shelters and the use of X rays and radioactive sources for diagnostic and treatment purposes. Pupils study this information and also visit places where ionizing radiation is used, such as radiotherapy and medical physics departments of hospitals, dentists' and vets' surgeries, nuclear power stations and nuclear shelters. Answers have to be found to a selection of questions about radiation risks of, for instance, uranium mining, reprocessing nuclear waste, fast breeding, accidents such as at Three Mile Island, explosions of nuclear weapons, being X-rayed, working with nuclear medicines and irradiating cancer patients. In several lessons pupils report their findings to other groups in class.

The last part (chapter 8) might be labelled *broadening and deepening*, and deals with procedures for analyzing and evaluating personal and societal risks. A framework for evaluating risks is presented through a series of questions, such as:

a. what are the advantages to you of using ionizing radiation?
b. what are the advantages to others?
c. what are the risks to you in the short and long term with, and without, the use of ionizing radiation in this particular application?
d. what are the risks to others?
e. is it possible to reduce the risks associated with the radiation?
f. are there any alternatives which achieve the same objective with less risk?

Examples are used such as being prescribed a brain scan, working professionally with radioactive materials or X rays, or the dumping of radioactive waste into the ocean. Pupils are expected to use the knowledge acquired from the unit in answering the six questions, especially c, d and e.

A limited number of schools (twelve) obtained permission from the Ministry of Education and Science to use a special PLON-examination syllabus for HAVO (PLON, 1983b), pending the preparation of a new national syllabus for HAVO by the WEN. This PLON-syllabus covers most of the contents of the PLON-unit *Ionizing Radiation* (Table 2.5).

Table 2.5 Part of the PLON-syllabus for HAVO (PLON, 1983b)

- properties of X rays
- number of nucleons depends on atomic number; isotopes
- stable and unstable nuclei; α-, ß- and gamma-radiation; origin of unstable nuclei by bombardment; half-life
- demonstrating ionizing radiation with cloud chamber and GM-counter
- activity, dose
- cosmic rays and other forms of natural radiation
- biological effects of ionizing radiation
- radiation protection
- medical applications of ionizing radiation
- nuclear fission and fusion
- $E = \Delta mc^2$
- principle of a nuclear reactor
- nuclear fuel cycle
- types of radioactive waste
- nuclear arms: principles of operation, effects

Table 2.5 shows that the PLON-syllabus referred to a number of contexts for the topic of ionizing radiation, such as radiation protection, background radiation, medical applications, nuclear reactor, fuel cycle, radioactive waste and nuclear arms. Related to these contexts, activity, dose and biological effects of radiation were added to the scientific contents of the current HAVO-examination syllabus (Table 2.4).

Then the question arose of how the unit would operate in class. Would the unit be welcomed by pupils and teachers? Would teaching result in pupils being able to assess the risks of ionizing radiation in a number of contexts?

Evaluation of the second version of the unit Ionizing Radiation

The second version of the unit was used in 25 classes in the school year

1984/85. In an evaluation study (Eijkelhof and Wierstra, 1986; Eijkelhof, 1986), pupils from eight classes completed questionnaires before and after the unit was taught. The study focussed on the interests of pupils in specific topics, the attitude of pupils towards radioactivity and X-rays and the increase in pupils' abilities to use scientific knowledge in assessing the risks of applications of ionizing radiation.

In the pretest the pupils were asked to indicate how much they knew about thirteen named topics and how much they wanted to know about these topics. The results show that pupils were especially interested in the effects side of ionizing radiation: the most popular topics were health protection, radiation risks and radiation effects. These were not the topics pupils claimed to know least about: half-life, ß-radiation and radiation measuring. One might conclude that the emphasis given in the unit to the effects of ionizing radiation at receiver end accords well with the interests of the pupils before the unit is taught. Boys and girls did not differ much in their pre-interests. However, most of the girls opted for the health chapter when working on the unit, while boys chose the chapters on nuclear energy and nuclear arms. The same kind of differences between boys and girls showed up in the question, posed in the post-test, about which of seven named video-programmes they would like to see in addition to the unit. Boys tended to be more interested in more technical programmes about nuclear arms and nuclear energy whilst the girls preferred programmes on cancer therapy and on the views of a cancer patient. However, both groups expressed interest in seeing the film 'The Day After', which is about the effects of a nuclear war.

Answers on a semantic differential test both before and after the unit showed that pupils had a significantly more positive attitude towards X rays than towards radioactivity. A slight positive change in the attitude towards the latter concept was detected, especially with the girls.

Finally, the pupils were presented with statements regarding the risks of applications of ionizing radiation and asked to comment on these. Examples of these statements are:

A. "the disposal of radioactive waste in sea is not a very serious problem";
B. "food which has been irradiated by a radioactive source in order to preserve it should be banned in the Netherlands".

Neither topic is dealt with in the unit. This indeed was part of the basis for their choice, so that pupils' answers could not simply be a repetition of ideas in the unit, but should rather be based on independent reasoning.

Around 80% of the pupils disagreed with the first statement, both before and after the unit. Their reasoning did not show a change in any very obvious direction. They did not know much detail related to the issue and fitted little of the basic knowledge from the unit into their arguments. Instead, these were mainly of a common-sense nature, such as:

"this is bad as it could be harmful to the environment"
"very bad, if just one of the containers starts leaking it will be a disaster for the whole world"
"the hazards of this dumping show up only years later"
"very bad, we must find a way to make the substance no longer radioactive"
"bad: the containers will decay and that rubbish will get into the sea"
"bad, but you have to put it somewhere; if the vessels are strong, it might be done".

Only very few pupils used afterwards some knowledge from the unit:
"it should only be allowed if the half-life of the substance is short"
"bad, as the life span of the containers is shorter than that of the radioactive waste".

It is noticeable that responses to the second statement show a greater shift towards a tolerance of radioactivity, and an increase in reasoning ability compared with the first statement, though the physics was not always used in a correct way:
"I agree, as this will increase the amount of radioactive waste"
"no problem, as no radioactive waste remains"
"as long as the radiation remains below our daily intake"
"no problem: it kills bacteria and the dose is not dangerous"
"I don't know, if the food itself does not become radioactive it is not a problem"
"if the risk and hazard of rotten food is greater than the risk and hazard of the radiation, than irradiation of food is useful and should be permitted".

This difference between the comments on both statements may be due to the fact that the former case has received much more attention in the news than the latter one, so the opinions of the pupils regarding food irradiation may be less fixed and more easily influenced by instruction.

Finally, in the comments on these and other statements, examples were found of lay-ideas about the concepts of radiation, radioactivity and irradiation; for instance we found the following remarks in the answers to the questions in the post-test:
"it might be dangerous if the radiation is released after the food is consumed"
"the food is irradiated with a radioactive substance with a short decay time; when the food reaches the consumer it is not dangerous anymore"
"radioactivity is too dangerous to put into our food".

Possible directions of improving the unit Ionizing Radiation

The results of this study show that the aim of increasing the reasoning ability of pupils by including knowledge from the unit has not been obtained satisfactorily. Several reasons for this might be hypothesized, such as:

a. the questions asked in the pre- and post-tests evoked ready answers from the lifeworld which were evident in the eyes of the pupils; in this case there was no need felt to apply scientific knowledge;
b. the contents of the unit are not suitable: perhaps some important concepts are missing, or concepts are not well enough applied in suitable contexts, or perhaps too many less important concepts and contexts are included which hinder learning of the important ones;
c. lay-ideas about ionizing radiation and radioactivity may influence the learning of scientific concepts and/or the use of these scientific concepts in real-life situations;
d. the teachers are not familiar with some of the contents of the unit: they may not teach topics such as radiation protection and radiation risk properly;
e. the aim of the unit is too ambitious: perhaps the complexity of the topic and the available time are such that the aim of the unit should be reformulated.

Another possible hypothesis, namely that the interest of the pupils might be too low, was discarded, as studies by Wierstra (1984), Eijkelhof and Wierstra (1986) and Jörg and Wubbels (1987) demonstrated that most of the pupils showed great interest in the way the topic is approached in the unit.

Reasons a and c would require greater insight into the ways pupils reason about the risks of applications of ionizing radiation, before, during and after education on this topic (chapters 3 and 4). Reason b might be revealed by consulting radiation experts (section 2.4). For reason d we need to interview teachers (chapter 4). Reason e could not be checked by any single research method but it is expected that insight into the complexity of the topic and the feasibility of the aims will have increased by the end of our series of studies (chapter 5).

2.4 A DELPHI-STUDY AMONG RADIATION EXPERTS

Introduction

In the previous section the contents of the PLON-unit *Ionizing Radiation* were described. Although scientific contents and contexts were selected with a particular aim in mind which was different from the aims on which examination syllabi had been based in the past, the selection itself was made rather intuitively, after discussions with a few experts in their particular fields and studying the literature. Criteria for choice remained implicit and the list of contexts and concepts to be dealt with in view of the chosen aim was not well legitimated by radiation experts. Such a selection approach is rather pragmatic. Although it is likely to lead to choices which are acceptable to pupils and teachers, it might well be that the selection is not optimal for the chosen aim, with the result that important contexts and concepts are missing, or that non relevant concepts are included.

In our view this problem is certainly a pressing one if the aim of education on this topic is to promote pupils' ability to analyze and assess the risks of ionizing radiation for the following reasons:

1. this kind of radiation is, by choice, by nature or by accident, involved in many spheres of life and work; curriculum developers and teachers cannot be expected to be familiar with such a variety of spheres and to be able to assess which concepts are appropriate for assessing the risks in such a diversity of contexts;
2. some applications of ionizing radiation are rather controversial (even between experts) and discussions are dominated by an apparent general fear of radiation among the public; in the process of selecting contents of education on this topic, one might have opposite aims in mind, such as reassuring the pupils or demonstrating how risky certain applications are.

Therefore, in order to legitimate the selection of subject-matter and contexts based on a risk perspective, it was decided to consult people who are professionally involved in the field of applications of ionizing radiation and radiation protection. It was expected that they would have a thorough knowledge of the applications in their own field of work and of general principles of radiation protection, and be familiar with the requirements for radiation risk assessment. These radiation experts were approached in order to discuss with them in a systematic way the problem of what a physics curriculum should include regarding contexts and concepts if it is to make a contribution to pupils' ability to assess the risks of applications of ionizing radiation.

In the following sections we will describe how the study was organized and present and discuss the main results.

Choice of research method

In the selection of research method several constraints had to be taken into account.

Firstly, as the number of applications of ionizing radiation is quite large, we had to involve a considerable number of radiation experts in order to cover the whole field.

Secondly, the number of radiation experts with the knowledge and experience we were looking for is quite small in the Netherlands, estimated to be around 500, and these people have in general rather responsible work and are very busy. So their time is limited.

Thirdly, as stated above, the field of ionizing radiation has many controversial aspects. As an example we mention that in the past some unpleasant clashes have taken place between experts with different views on, for instance, nuclear energy, nuclear waste disposal and radiation norms. In these clashes personal feelings were injured and so we judged that meetings of radiation experts would be dominated by events of the past and not by the issue which we wanted to be discussed.

Finally, the issue of what contents and contexts to select from a risk assessment perspective is so complex and so new, that a single contact with the group of radiation experts did not seem appropriate.

Therefore we had to look for a research method which would allow us to contact a relatively large number of radiation experts more than once, in an anonymous way, with a limited time investment by the participants.

The Delphi-method seemed to meet all our requirements. In their standard work on techniques and applications of the Delphi-method, Linstone and Turoff (1975) define it as:

> "a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem".

To accomplish this 'structured' communication provision is made for some feedback of individual contributions of information and knowledge, some assessment of the group judgment or view, some opportunity for individuals to revise views and some degree of anonymity for the individual responses. From the seven properties of situations in which the Delphi-method is suitable according to Linstone and Turoff, the following five apply to our case:

a. participants represent diverse backgrounds with respect to experience or expertise;
b. more individuals are needed than can effectively interact in a face-to-face exchange;
c. time makes frequent group meetings infeasible;
d. disagreements among individuals are so severe or politically unpalatable that the communication process must be refereed and/or anonymity assured;
e. domination by quantity or by strength of personality must be avoided.

In the literature (Linstone and Turoff, 1975; Van Houten and Van der Zee, 1980) a distinction is made between conventional and real-time Delphi-studies. In the second type often use is made of the computer with the advantage that the rounds can happen in quick succession. A disadvantage of this real-time Delphi-study is that the process of communication has to be fixed in advance which restricts the process of constructive analysis and synthesis. In our case, with a novel research issue and therefore unpredictable answers from the participants, we took the view that a conventional Delphi-study would be more appropriate.

Research design

For this Delphi-study the following research questions were formulated:

1. Which context domains of ionizing radiation are suitable for inclusion in physics education in senior high school?
2. What scientific contents should be covered in the physics curriculum in order to stimulate thoughtful risk assessment in the selected context domains?

The first question focusses on context domains and not on contexts. In our field of study such a context might be the use of X rays by a dentist for diagnostic purposes. However such a context would be, in our view, too specific to be included in a syllabus as it would limit a teacher too much in his or her choices for classroom teaching. Therefore we decided to aim at legitimating context domains (sets of contexts which are related, both socially and scientifically, e.g. the use of ionizing radiation for diagnostic purposes).

The second question illustrates our intention to legitimate the scientific contents (or subject-matter) which should be covered in order to promote our general aim: learning to assess risks in situations in which ionizing radiation is applied.

The Delphi-study was originally planned to find answers to the two research questions mentioned above. During its preparation it was decided to add questions on other topics within the general aim of our research efforts, for instance about the incidence and importance of lay-ideas and about ways of dealing with radiation anxiety. The results of these other parts of the Delphi-study will be reported in sections 3.2 and 5.3 of this thesis.

The study was held in three rounds. In each round the participants received a questionnaire which they were asked to return within three to four weeks. If we did not receive the completed questionnaire within this period, a reminder was sent. The questionnaires from each round were analyzed independently by two researchers. The results of both analyses were discussed with two other members of the research team. The questions for the following round were then formulated and discussed by the team.

We will now briefly describe the nature of the questions in the three consecutive rounds.

The function of the first round was to orient the participants towards the aim of the study and to make a first inventory of opinions. This orientation was necessary as most participants were not familiar with teaching physics in senior high school and with new developments in physics education at that level. So we had to clarify what we meant by contexts and by subject-matter related to the aim of risk assessment, using examples.

In this first round we started off with specific contexts, in order to be able in a later phase to group these contexts into context domains. A list of eighteen contexts was presented to the participants who were asked to judge the importance of these contexts for physics education and to add important contexts which were not mentioned in the list. They also received a set of subject-matter items, taken from a draft-proposal for a new examination programme (WEN, 1986). Participants were invited to indicate for three contexts, identified by them as important, which of the items were required in order to be able to assess the risks of radiation in these contexts, and to add items which were also essential in this respect.

In the second round we presented a list of ten contexts which had been composed by the research team based on a large number of additions from the participants. These were now asked to judge the importance of these new contexts and to formulate criteria for drawing up a suitable set of contexts.

As regards subject-matter we asked the participants in this second round to judge the importance of items which had been added in the first round and to comment upon some those items on which the opinions appeared to differ strongly in the first round.

As a broad consensus on subject-matter was reached after the second round, we decided to leave this topic out of the third round. Based on the answers of participants in the second round, we were able to formulate two sets of context domains: one set we labelled as 'very important', the other as 'fairly important'. These sets were presented in the third round, together with four criteria for selection which the research team had formulated, based upon the criteria from the participants in the second round. The question now asked was:

> How suitable are these four criteria for selecting a set of context domains for physics education, and to what extent are the two given sets grounded upon these criteria?

Through this organization of the three rounds, an attempt was made, on the one hand to collect as much new information from the participants as possible, on the other hand to look for consensus in order to legitimate a final set of context domains and list of subject-matter items as suitable for the aim of learning to assess risks.

The participants

In order to select the participants the following criteria were set:

a. the group should consist of experts from four fields in which ionizing radiation is applied: health care, electricity generation, defence and industry;
b. in the group the diversity of opinions about risks of ionizing radiation should be represented: not only people who are convinced that most of the public outcry on applications of ionizing radiation is exaggerated, but also those who take the view that this outcry is generally justified;
c. each participant should have experiences on instructing or should have contacts with lay-people: we preferred people who would have some notion of what one could expect lay-people to know and to be able to understand;
d. each participant should have at least four years of relevant working experience in the field;

e. each participant should be prepared to participate in at least two rounds in order to limit the number of people who might leave the study after the first round.

The process of setting up the panel was initiated by consulting a board member of the Dutch Association for Radiation Protection, local radiation experts and experts from environmental organizations. Based on this advice a list of 80 potential participants was drawn up. These people then received a letter which explained the aim and design of the Delphi-study and in which we asked them to participate.

Nearly 80% of the experts we approached (i.e. 63) agreed to participate in the study, which originally was planned to cover two rounds. The need for a third round was began to be felt when preparing the second questionnaire; therefore we asked participants explicitly if they would be prepared to answer a third questionnaire.

Table 2.6 gives some information about the participants, the number of actual respondents in the three rounds and their experience of instruction or contacts with lay-people in various areas, the most important ones being health care, nuclear energy, nuclear arms and industry.

Table 2.6 Fields of activities of the participants *

	rounds		
fields of activities	I N=55	II N=49	III N=35
health care	26	24	17
nuclear energy	26	23	19
nuclear arms	11	10	7
industry	26	24	18
other areas	9	8	7

* participants were allowed to cross one or more fields

Table 2.6 shows that the diversity of fields of activities remained much the same during the study. So selection criterion a was fulfilled throughout the study. From the answers in all rounds it was also clear that criterion b (about the representation of a diversity of opinions) was fulfilled. We also compared the answers in the first and second rounds of the 35 remaining participants, with the answers of those who decided not to participate in the last round. No noteworthy differences were found. Therefore we may conclude that the decline in response did not represent a shift in the balance between the various groups of participants.

Results on contexts

In the first round the question of the importance of eighteen specific contexts for physics education yielded the following results, presented in Table 2.7.

Table 2.7 Recommendations on contexts for ionizing radiation in physics education by participants in the first round of the Delphi-study (1 = unimportant, 2 = fairly unimportant, 3 = fairly important, 4 = important)

contexts	score	s.d.
background radiation	3.6	0.6
diagnostic use of X rays in health	3.5	0.7
diagnostic use of nuclear radiation in health	3.2	0.9
emission of radioactive substances after an accident in a nuclear power station	3.1	0.8
storage of nuclear waste	3.0	0.8
radioactive fall-out	3.0	0.8
emission of radioactive substances by a nuclear power station in normal circumstances	2.9	0.9
therapeutic use of nuclear radiation in health	2.9	1.0
therapeutic use of X rays in health	2.9	1.0
radon emission in homes	2.7	0.9
direct consequences of a nuclear explosion	2.7	1.0
irradiation of food	2.3	0.9
decommissioning of nuclear power stations	2.0	0.8
measurement of thickness in industrial processes	2.0	0.9
dating of archeological finds (C-14 method)	2.0	1.0
radioactive fire-alarms	1.9	0.7
accidents in a reprocessing plants	1.9	0.9
production of medical radioactive sources	1.7	0.8

This table shows that the contexts rated as most important were health applications, background radiation, fall-out from nuclear power stations and from explosions of nuclear arms, and the storage of nuclear waste. A currently popular context such as the dating of archeological finds (cf. section 4.2) is rated much lower.

Furthermore 66 new contexts were added to the list, for example radiography, neutron activation, measurement and control engineering, use of radioactive substances in industrial products, the use of tracers in scientific research and the transport of nuclear materials. These contexts were clustered in ten groups. These ten groups were presented to the participants in the second round. As a result some scientific and industrial applications were rated as important in physics education: tracers in scientific research, non-destructive materials research, sterilization, radioactivity from coal-fired power plants and measurement and control engineering.

As time available for covering the physics curriculum is limited we were not only interested in the recommended contexts as such (their number might be too large to fit into the curriculum) but also in the grounds for the recommendations. So we asked participants in the second round to give criteria for the selection of contexts. Based on their answers we presented in the third round the following list of criteria for the selection of a set of context domains:

1. a large part of the total collective dose should be covered by the set;
2. contexts which are most likely to be encountered by citizens should be included;
3. the set should reflect the variety of applications in society;
4. the applications with the most important social implications should be included.

The participants were quite unanimous in their approval of these criteria: 93 % agreed with the list.

Again using the results of the first two rounds we also presented in the third round a list of important (category I) and fairly important context domains (category II) (Table 2.8). The participants were asked to assess whether this list would meet the four selection criteria.

Table 2.8 Recommended context domains for a physics curriculum

category I (important)

1. Background radiation: from the cosmos, food, rocks, building materials etc.
2. Medical applications: diagnostic and therapeutic uses of X rays and nuclear radiation.
3. Nuclear energy: emission of radioactive substances, normally and after an accident.
4. Storage of nuclear waste: underground, above ground, on the ocean-floor.
5. Fall-out (as a consequence of nuclear weapons explosions).
6. Some applications of ionizing radiation in scientific and industrial research (e.g. tracers).

category II (fairly important)

7. Other industrial applications (materials research, sterilization, measurement and control).
8. Immediate consequences of nuclear weapons explosions.
9. Radioactivity from coal fired power plants.

This table has a ranking order from 1 to 9, 1 being rated the most important. It should be noted here that the context domains are not all equivalent due to the fact that some (e.g. number 9) are too specific to group with others.

Many contexts which were suggested in the first round by the research group or by the participants did not receive sufficient support to be included in categories I and II, such as transport of nuclear materials, dating methods, production of radioactive sources for medical use, accidents in a reprocessing plant, decommissioning nuclear power plants and fire-alarms containing radioactive sources.

All participants except one agreed that Table 2.8 meets most or all criteria. Some participants suggested moving context domain 6 from category I to II.

There appears to be no remarkable difference in the answers of participants from the various fields of activities, as listed in Table 2.6.

In a final question relating to this issue of the importance of context domains, we asked participants to indicate what they would prefer in the event of time limitations: to deal with only some of the most important context domains in depth or to treat all nine fields more superficially. The experts were divided about this question: no clear preference resulted.

Results on subject-matter

In the first round participants were given a list of 32 subject-matter items taken from an early version of a proposal for a new examination programme for the pre-university stream (VWO) from the Advisory Committee for Physics Examination Programmes (WEN, 1986). The nuclear physics section of that proposal differed considerably from the current examination programme as it gave much greater emphasis to radiation effects and safety aspects. The resemblance to the contents of the PLON-unit Ionizing Radiation is striking.

Of these 32 items, 26 were seen as necessary basic knowledge for risk assessment in the various contexts. Of course some elements are context specific (such as nuclear fission and the basic structure of a nuclear reactor) but most items were seen as important for all contexts.

Of the six other items, two were seen as unimportant for risk assessment, namely 'mass spectrometer' and 'materials research'. On the importance of the remaining four items, the opinions varied. These were 'mass defect, binding energy', 'equivalence of mass and energy', 'annihilation and creation of elementary particles' and 'nuclear fusion'.

Most of the participants added some items to the list of 32: in total 135 suggestions were given. These were able to be classified under four headings: human body and the environment (33%), advanced physics (40%), risk (17%) and knowledge from other disciplines (5%).

In the second round the number of questions on subject-matter was limited to two. In one question we asked for arguments in favour of or against inclusion of the four elements on which no consensus was reached in the first round.

A majority of the participants was not in favour of including the four elements in the list, arguing that these topics were too advanced for secondary education, too futuristic (fusion) and not contributing to risk assessment. Those who were in favour did not claim that the items were of importance for risk assessment but that they would not like to oust these topics for other reasons (e.g. "it is standard physics knowledge").

In the second question we presented seventeen groups of new items, based upon the additions suggested by the participants in the first round. The items were grouped in order to reduce the total number of items to be assessed and to limit overlap between the suggestions of the participants. All suggestions were able to be included in the groups. Participants were now asked to indicate which of these groups they saw as most important for learning to assess risks of ionizing radiation.

Of the seventeen groups of new items, five were seen as most important for risk assessment:

a. early effects of high radiation doses;
b. genetic effects of radiation;
c. dispersion of radioactive substances in the environment and food chain;
d. behaviour of radioactive substances in the human body;
e. biological effects of low radiation doses.

Rated as fairly important were risk comparisons, risk perception, principles of risk analysis and knowledge of cellular processes. The other eight groups were given low priority. Most of these groups contained elements of advanced physics (e.g. interaction of radiation with matter, gamma spectra) or of other disciplines (e.g. legal aspects).

In Table 2.9 (pag.40) we have displayed the subject-matter items which were recommended by the participants as being important for learning to assess the risks of radiation in various context domains. In this table we have not included aspects of risk analysis, such as risk comparisons. The opinion of the radiation experts on this specific point will be dealt with in section 5.3.

Conclusions and discussion

This part of the Delphi-study was designed to find answers to two research questions. The first was to legitimate the selection of context domains of ionizing radiation. There appeared to be general agreement among the participants about the importance of sets of context domains (Table 2.8) and about the criteria on which the selection of these sets should be based: contribution to collective dose, variety, personal and social significance.

The second research question dealt with the selection of subject-matter. Most of the items of the draft WEN-proposal were seen as important. Some concepts were added to this list, dealing with the possible effects of radiation, with the spreading of radioactive substances in the environment and the human body, and with risk assessment.

Table 2.9 Subject-matter items recommended by radiation experts

A. Basic knowledge about atomic and nuclear physics
- *structure of the nucleus*: nucleon, proton, neutron, atomic number, mass number, (Z,N)-diagram, isotope, atomic mass unit;
- *radioactive sources*: stable and unstable nuclei, energy levels of a nucleus, disintegration, activity [Bq], radioactive decay curve, half-life;
- *ionizing radiation*: alpha-, beta-, gamma- and neutron-radiation, X rays, nature and properties of these types of radiation, X-ray spectrum;
- *detection of radiation*: Geiger counter, photographic plate, cloud chamber;
- *nuclear energy*: nuclear reactions, nuclear fission, chain reaction, principles of a nuclear reactor.

B. Basic knowledge about radiation protection
- *irradiation*: absorption, dose [Gy], interaction with living matter, dose equivalent [Sv], influence of distance and medium;
- *contamination*: spreading of radioactive substances in the environment and in the human body;
- *effects of ionizing radiation*: early and late effects of low and high doses, somatic and genetic effects;
- *safety aspects*: film badge, lead apron, radiation norms, ALARA-principle, safety measures.

If we compare Table 2.9 (recommended subject-matter items) with Table 2.8 (recommended context domains) than it is clear that the newly added item 'spreading of radioactive substances in the environment and in the human body' is an important element in many of the most recommended context domains. It plays a role in 'background radiation' (radioactive substances in food and radon from building materials), in 'medical applications' (diagnostic and curative use of nuclear radiation), in 'nuclear energy' (emission of radioactive substances), in 'storage of nuclear waste', in 'fall-out' (from a nuclear explosion) and in 'applications in scientific research' (tracers). In short it might be concluded that 'contamination' should occupy a prominent place in a curriculum which claims to promote learning to assess the risks of ionizing radiation.

Early in this section we mentioned some specific considerations which led to the choice of the Delphi-method for our research purpose: diversity of backgrounds, limited time of the participants and severe disagreements among them. From the job-descriptions of the participants, the variety of areas of activity appeared to be large indeed. On several questionnaires remarks were made illustrating the time restrictions of the participants; time was often mentioned as an argument for not continuing in the third round. And anonymity appeared to be justified in the light of the strong opinions which were sometimes given. Only as a result of anonymity were suggestions of some individuals able to become important elements of the end results of this study.

On the other hand, an important disadvantage of the Delphi-method became apparent during the study. It is a very time consuming method, especially when the participants are asked to answer open questions. Looking back upon this study we would conclude that a slightly smaller number of participants (about 40) would have been sufficient, provided that more time was spent on the selection of the participants and on maintaining the original group of participants.

However, in our view the Delphi-method is a suitable method for providing information on which curriculum development can partly be based. A necessary condition is that the participants are asked questions which relate to their specific expertise, which could not be answered by people with other backgrounds and which do not go beyond their expertise. However, due to its time-consuming character, application of this method should be limited to topics:

- in which a large number of context domains is involved;
- which are in a state of flux;
- which have a controversial character.

For example, the topic of solid state physics would not require a Delphi-study among experts in this field. On the other hand, in the case of a curriculum which aims to facilitate pupils' learning to assess the risks of toxic substances a Delphi-study is probably justified.

The results of this Delphi-study should not be seen as prescriptive for the contents of a physics curriculum with the chosen aim. The main reason for this is that none of the participants was directly involved in physics teaching at secondary school level. So they cannot be seen as experts about the learning and teaching problems associated with ionizing radiation for the 16-18 year age group. In defining the contents of the curriculum other aspects have to be taken into account, such as the available time and the learning difficulties of pupils. These aspects can be deduced from other professional groups who are more familiar with physics teaching to secondary school pupils, such as teachers and physics education researchers.

On the other hand, radiation experts have a great deal of experience with contexts of ionizing radiation which is not held by either of the other professional groups. The results of this part of the Delphi-study show that they have some original, well argued ideas regarding the curriculum which might play an important role in discussions about possible reforms in physics education towards the aim of risk assessment. Of course some amendments to the list of recommended subject-matter might be expected from the physics education community. However, the main results of this Delphi-study cannot be disregarded.

In the following section we will evaluate how novel the Delphi-recommendations are by comparing them with the final WEN-proposals.

2.5 EVALUATION OF THE RECOMMENDATIONS ON CONTEXT DOMAINS AND SUBJECT-MATTER

Introduction

In the early sections of this chapter we presented a description of the contents of proposals for examination programmes and of some books used in physics education around 1930. Some general trends were illustrated such as the inclusion of more concepts related to nuclear physics and hardly any attention to applications of ionizing radiation other than in the sphere of scientific research. In a later section the content of the PLON-unit *Ionizing Radiation* was described. No detailed comparison was made with the new physics examination syllabus.

In order to facilitate the interpretation of potential implications which the recommendations of the Delphi-study might have, we now focus on a comparison between these recommendations and the WEN-proposals.

Comparison with the WEN-proposals

The Werkgroep Examenprogramma's Natuurkunde (WEN) is an advisory committee of the Ministry of Education and Science regarding examination syllabi. After preparing advice on a new syllabus for MAVO, the WEN started its work on syllabi for HAVO and VWO in 1985. An early draft of the proposals for VWO (WEN, 1986) was used in formulating the questions for the first round of the Delphi-study (section 2.4). In December 1987 the WEN presented its proposals to the Minister of State for Education. In this section we will make use of what is called the final proposal (WEN, 1988) in which comments of teachers and organizations (such as the Dutch Association of Science Teachers, the NVON) have been incorporated. Recently, this final proposal of the WEN has been accepted by the Ministry of Education and Science as the new examination syllabi for HAVO and VWO from August 1, 1992 onwards (O&W, 1989).

To a greater extent than any previous committee, the WEN has given attention to the general aims of physics education. The WEN mentioned in its final report for HAVO and VWO (WEN, 1988) the following four general aims:

1. Introduction in science and technology.
   Reference is made to knowledge of and insight into physics and its methods, to historical and philosophical aspects, and to use of knowledge of physics in technical applications, in the life-world, in society and in relation to other disciplines of science.
2. Preparation for further study and vocation.
3. Preparation for being a concerned citizen.
   Factors mentioned are consumers' behaviour, coping with a technical environment, a critical view on social problems with physical and technological aspects, and insight into the interaction between science, technology and society.

4. Personal development.
   Reference is made to knowledge and insight into pupils' environment, to a critical and investigative attitude, and to ability in communication and other social skills.

Aims like these are much broader than the aim of physics which is central to our study, but this latter is certainly incorporated in the WEN aims.

The final WEN-proposals for HAVO and VWO do not differ much from each other on the topic of radioactivity and ionizing radiation. The main differences are in the field of nuclear physics: in the VWO-proposal additional coverage is given to 'nuclear energy-levels', 'K-capture' and 'annihilation and creation of elementary particles'. We will compare the VWO-proposals of the WEN with the recommendations of the radiation experts.

Table 2.8 presented the context domains recommended by the participants in the Delphi-study. In Table 2.10 we summarize these context domains and list alongside the items of the WEN-proposal which refer to these context domains. The WEN labels most of these items as "contextual concepts": these are items which could be included in examination questions without further clarification; in the case of apparatus only the function should be known, not the physics which explains its operation (e.g. the Geiger counter). In Table 2.10 we have italicized the only item for which the WEN-syllabus states that more than simply its function should be known.

Table 2.10 The Delphi-study context domains versus the WEN-proposal

Delphi-context domain	WEN-proposal
1. Background radiation	*background radiation*
2. Medical applications	medical diagnostics with X rays radiotherapy radiodiagnostics, tracers, detection of tumours, internal tomography, scintigrammes
3. Nuclear energy	principle and structure of nuclear reactor, moderator, control rods critical reactor
4. Storage of nuclear waste	various types of nuclear waste regarding life span
5. Fall-out of nuclear arms	nuclear bomb, nuclear explosion
6. Scientific research	use of radionuclides linear accelerator of particles
7. Industrial applications	use of radionuclides
8. Direct effects nuclear arms	nuclear bomb, nuclear explosion
9. Radioactivity of coal	-

The main conclusion to be drawn from this table is that the recommended context domains are, in general, congruent with the WEN-proposal. The WEN-proposal is much more context-directed than the syllabi discussed in section 2.2. With the new syllabus a teacher could draw attention to almost all context domains. However, some differences between the recommendations of the Delphi-participants and the WEN-proposal are noticeable:

- in the WEN-proposal, it is not clear which aspects of background radiation should be dealt with: only its existence or also its various sources, such as building materials, food, cosmos and rocks?
- in the field of nuclear energy, the WEN-proposal focusses on the principles and structure of the nuclear reactor, not on the production of certain nuclides and the emission of radioactive substances in normal and accidental circumstances;
- a similar comment might be made about nuclear arms: the focus of the WEN-proposal is on the bomb and the explosion, not on direct consequences and fall-out;
- regarding nuclear waste, in the WEN-proposal only the life span is mentioned as characteristic of different types of waste, not 'activity' which in practice is the most important feature to distinguish between different types of waste;
- in the WEN-proposal, the contextual concept 'use of radionuclides' is very wide: this leaves teachers with the problem of what to include.

In Table 2.9 we have presented the subject-matter items which were recommended by the radiation experts for teaching pupils to assess the risks of applications of ionizing radiation. If we compare this table with the subject-matter items in the WEN-proposal for VWO, the following conclusions might be drawn:

- all items in part A of Table 2.9 (basic knowledge about atomic and nuclear physics) are included in the WEN-proposal; in addition to these items, the WEN-proposal contains the items: K-capture, half-thickness for gamma- and X rays, bubble chamber, mass defect, binding energy, equivalence of mass and energy, annihilation and creation of elementary particles, and nuclear fusion. All of these items, except half-thickness, might be regarded as advanced nuclear physics; several of these items were not seen as essential for risk assessment by the participants of our Delphi-study; this is not surprising as the WEN did use broader selection criteria than our risk perspective;
- most of the items in part B of Table 2.9 (basic knowledge about radiation protection) are also included in the WEN-proposal; exceptions are the concepts 'irradiation' and 'contamination', the ALARA-principle and safety measures, which are not found in the WEN-proposal; another difference is the kind of emphasis given to the effects of radiation: the radiation experts recommended the distinctions between early/late and somatic/genetic effects of ionizing radiation, the WEN-proposal refers only to the effects of different types of radiation on human tissue.

From our risk assessment viewpoint the most important differences in subject-matter items are:

- the absence of the concepts 'irradiation' and 'contamination' in the WEN-proposal: as we illustrated in section 2.4, in many context domains of Table 2.8 'contamination' plays an important part;
- the strongly physics-oriented approach of the effects of radiation in the WEN-proposal: from a risk perspective, given the dose equivalent, the type of radiation is no longer important, as the effects of these radiations are incorporated in the dose equivalent concept;
- the absence in the WEN-proposal of some safety aspects such as the ALARA-principle and safety measures: the ALARA-principle is important for understanding the meaning of radiation norms, and the safety measures offer the opportunity to draw attention to ways of reducing the dose equivalent in the case of both open and closed sources.

If one adds some items dealing with the last three points to the new WEN-syllabus and some risk analysis aspects (to be dealt with in chapter 5), it seems to be feasible in principle to teach the topic of ionizing radiation with the aim that pupils will be able to assess the risks of ionizing radiation in various context domains. The question of how this should be done, however, has not yet been answered. This would require, among other things, insight into learning difficulties in this field of physics. The next two chapters are devoted to this issue.

3. LAY- AND PUPILS' IDEAS ABOUT RADIOACTIVITY, RADIATION AND RISK

3.1 INTRODUCTION

Lay-ideas about radioactivity, radiation and risk

X rays and radioactivity have always been around but were discovered only about a century ago by mankind. Other phenomena, such as gravity, electricity, magnetism, light and sound, already had a long history of physical research and public interest. This is not surprising as many of these phenomena can be detected by our senses. Ionizing radiation, however, can only be detected by specific instruments. That seems to be a basic reason why it took mankind so long to discover X rays and radioactivity.

In the first few years after their discovery, the existence of radioactivity and X rays became quickly known among the general public. For instance cartoons appeared in which it was suggested that X rays could reveal anything, not only bone-fractures but also maids listening behind the door of a lodger. Some advertisements even promised X-ray-proof underwear. These cartoons and advertisements suggest that the public thought that X-ray photographs were made in the same way as flashlight pictures, incorporating the ideas that the X rays were emitted by the camera and reflected by the object. This is certainly different from what scientists at the time believed to be the case.

A second characteristic of early public ideas about ionizing radiation is that knowledge and concern about its harmful effects was lacking. This lack of concern was shared by the scientists who were, in the first decade, rather careless in handling X-ray tubes and radioactive materials and often indeed recommended X rays' health promoting capabilities, until some scientists themselves were seriously affected by ionizing radiation (Weart, 1988).

The latter characteristic certainly no longer applies to public thinking about radioactivity. The opposite is true: any accident with nuclear material is likely to be announced on the front page of newspapers all over the world. The general fear of radioactivity has even influenced the choice of names for new medical techniques. For instance, a new medical diagnostic technique which makes use of nuclear magnetic resonance (NMR) is now called magnetic resonance imaging (MRI) to avoid any associations with nuclear issues. Risk perception studies (Slovic, Lichtenstein and Fischhoff, 1979; Slovic, Fischhoff and Lichtenstein, 1981; Van der Pligt, Eiser and Spears, 1986) confirm that many people today hold strong beliefs about the danger of anything nuclear. Weart (1988) claims that public ideas in this field are based on a complex web of social and political associations, on old myths about pollution, cosmic secrets, mad scientists and apocalypse, and on the threat of nuclear war.

The former characteristic of public thinking on ionizing radiation, however, namely the existence of lay-ideas which are different from common scientific ideas, has been less frequently studied than the attitude of lay-people towards nuclear issues. Recently Lucas (1987,1988) has explored the public's knowledge of elementary physics using direct interviews in the street or on doorsteps about isolated scientific facts. A few questions were asked about the topic of radioactivity. He found low levels of understanding of the term 'radioactivity' and widespread lack of clarity about the periods of time for which radioactive waste might continue to be hazardous. Durant, Evans and Thomas (1989) reported similar results from a British survey of the public understanding of science. Only 65% of the respondents disagree with the statement "Radioactive milk can be made safe by boiling it" and only 34% said nuclear power stations do not cause acid rain. In education the existence of lay-ideas among pupils is of particular importance as these might influence the learning of scientific concepts.

It seems likely that the sources of lay-ideas on the topic ionizing radiation are not so much of a visual and/or kinaesthetic character (Driver, 1988), as they are, for example, in the field of mechanics, but are more semantic and social in nature (Ogborn, 1985; Solomon, 1987). In society topics related to ionizing radiation (e.g. accidents with nuclear power stations, nuclear weapons, radiation in hospitals, food irradiation and nuclear waste) are often talked about. We expect that pupils often acquire their ideas from these kind of discussions. More knowledge about these sources of ideas we consider to be important for several reasons:

1. it would be useful to know more about possible lay-ideas before studying the particular notions of pupils as it would prepare us for the kind of notions which might be expected;
2. it would be important to know which lay-ideas exist in order to get insight into the potential contribution of social influence to the persistence of some ideas.

Therefore we decided to investigate first what kind of ideas about radioactivity and ionizing radiation pupils might meet in communication situations. Studying these ideas was not an aim in itself but served as an orientation on the study of pupils' ideas and of learning processes. Because of time constraints, we did not study lay-ideas about radiation in a direct manner e.g. by interviewing members of the public. Instead we opted for more indirect methods of studying lay-ideas, firstly by examining news-reports about nuclear issues, and secondly by consulting radiation experts about their experience of lay-ideas in a variety of practical situations. The latter study is reported in section 3.2. The former study focussed on the use of radiation terms in Dutch and English newspapers, and on Dutch radio and TV, in the context of the Chernobyl incident. As the results of this study have been published elsewhere (Eijkelhof and Lijnse, 1987; Eijkelhof and Millar, 1988; Lijnse, Eijkelhof, Klaassen and Scholte, 1990), we confine ourselves here, in the section which follows, to a summary of these results.

Lay-ideas in the newspapers

One of the most prominent features found in newspaper reports about Chernobyl is the lack of differentiation, bordering on confusion, between the terms 'radiation', 'radioactivity' and 'radioactive matter'. This lack of differentiation has been noted in a large number of quotations, dealing with what happened at the reactor site, in Western Europe and in between. Very often the term 'radiation' is used in cases in which a scientist would use the term 'radioactive material' or 'radionuclide'. Similarly, the term 'radioactivity' is often used in the scientific meaning of 'radiation' or 'radioactive material'. As a result of this it is often not clear in the quotations if people, animals, plants, water and soil are understood to have been exposed to radiation (in the scientific sense: being 'irradiated') or to have ingested, inhaled or been polluted with substances containing radionuclides (in the scientific sense: being 'contaminated'). This makes it difficult for all readers, whether experts or lay-people, to interpret the given information.

Secondly, in many reports about Chernobyl the newspapers presented the readers with numerical information. These figures were generally meant to quantify the extent of danger to the population. For this information the term 'dose' was most commonly used; the term 'activity' scarcely appeared in the newspapers. The already rather subtle distinction between radiation absorbed dose (SI-unit gray) and dose equivalent (SI-unit sievert) is further complicated by the widespread use of pre-SI units, such as rad and rem. In addition, units such as becquerel and curie were used. All of these units plus the derived ones, such as becquerels per litre, per kilogramme or per square metre, and milli-rems or microsieverts, per day and per year occur in various press reports.

It appeared from the reports that a fundamental lack of distinction exists between 'activity' and 'dose (equivalent)'. Both types of concept and their units seem often to be used to indicate a quantity of radiation which is contained by food, water, air or the human body and therefore to refer to the 'strength' or 'dangerousness' of the situation. This is another manifestation of the undifferentiated radiation/radioactivity/radioactive material concept.

Thirdly, we found a number of quotations in which the term 'half-life' seems to be seen as either the active period (life-time) during which the substance retains its 'radiation' or 'radioactivity', or as the period in which the activity is constant at its maximum level, after which it is seen to decrease. This alternative interpretation of the concept of half-life could be expected from people who are not familiar with the process of radioactive decay and may have been reinforced in the Netherlands by the fact that after eight days (the often mentioned half-life of iodine-131) Dutch cattle were allowed to graze outside again.

Fourthly, a number of quotations were selected which revealed the public's association of danger with radiation and radioactive matter. The effects of radiation were often associated with those of poison. Words such as "deadly" and "lethal" were often used as qualifying terms. The risks to infants were generally seen as much higher than those to adults.

Fifthly, from many quotations one could easily get the impression that a safety level exists below which nothing will happen but above which the consequences are really serious. Some further confusion is added by the use of different reference levels in the quotations, such as the normal background level (2 mSv), the public dose limit (5 mSv), dose limit for radiation workers (50 mSv), the emergency level (500 mSv) and the dose at which half of those exposed would be expected to die of acute radiation sickness (5000 mSv). In a culture in which fear of radiation is very strong, reassuring arguments, such as reference to emergency levels, may be counterproductive as many people will not understand why safety measures are being taken while it is said that the radiation levels are far below the danger levels. A particularly interesting case is the outcry about remarks made by John Dunster of the British National Radiological Protection Board (Millar and Wynne, 1988). One evening he said that the chances of dying because of the extra radiation dose from the Chernobyl fall out would be very small for Britons. The following day he estimated that some tens of extra deaths would occur in the United Kingdom over the next 30 years because of Chernobyl. During the following days he had to spend a great deal of time explaining that these two answers are equivalent.

Clearly these problems have to do with a lack of understanding of some basic health radiation conceptions. One is the stochastic nature of long term radiation effects such as cancer. One cannot predict who will get cancer as a result of a certain radiation dose or at which dose an individual will develop radiation-induced cancer. One only knows that the chances increase with larger doses. A second point is the difference between the risk to one person and the risk to the population as a whole. A government would in general decide to take action long before the individual needs to be worried about the risk to himself and his family.

Finally, many reports dealt with safety measures taken at the governmental level. In these reports we found various incorrect ideas which might have influenced the public's thinking, such as the effectiveness of boiling or purification of water, the neutralization of radiation in the soil and the absorption of radioactivity by a liquid. In several reports iodine is portrayed as therapeutic, rather than preventative: it would act as an antidote and counter radiation poisoning or the effects of radiation in general. In this way people are stimulated to take iodine tablets *after* contamination has taken place. In fact, taking iodine tablets is only useful *before* exposure to radioactive iodine, and would not be of any use in the event of possible contamination with other radionuclides.

One could argue that the reports in the days following the accident at the Chernobyl nuclear reactor were written up in haste, that the lack of

Table 3.1 Quotations from the news media about other nuclear incidents

1. *radiation/radioactive matter*

"There was a slight radioactive gas release. The televised CBS Evening News labeled it deadly radiation." [TMI] (Trunk & Trunk, 1983)

"Radiated crops would not be salable..." (id.)

"Releases of radiation are being confined..." [TMI] BBC, 9 o'clock news, 2-4-1979, quoted by Ryder (1982)

"During an incident at an American nuclear test in the Nevada-desert, experts had to release radioactive radiation" (Utrechts N., 15/5/86)

"clothing that protects against radiation" [picture showing gas-masks] (Volkskrant, 4/11/87)

"The Nuclear Energy Commission is seeking to assure people that the radiation is confined to one area and that it has not escaped into the atmosphere or into the water supply" [Goiania]
(New Scientist, 25/10/87)

"the radiation spread out across the country, with much of it settling on northern Britain, and traveled as far as Scandinavia" [Windscale fire, 1957] (Time, 31/10/88)

"In case of a nuclear disaster our waterpurifying installations could only remove 30 to 50 percent of the radiation" (Utrechts N., 24/4/87)

"During a fire in a nuclear research centre, 48 km south of the Australian city Sydney, on Wednesday radioactivity reached the open air; two workers were contaminated with radiation" (Utrechts N., 19/3/87)

"No precautions were taken to avoid leaking away of radioactive radiation" [contaminated well in China] (NRC-H, 23/5/86)

2. *danger and risk*

"...radiation inside the plant is at eight times the deadly level, so strong that after passing through a three-foot-thick concrete wall, it can be measured a mile away." [TMI] Walter Cronkite in CBS-news, 7.00 p.m., March 28, 1979 (McDermott, 1981)

"...Radiation penetrated through walls that were four-feet thick and it spread as far as 10 to 16 miles from the plant." [TMI]
NBC (McDermott, 1981)

"We know today that people still equate nuclear reactors with atomic bombs." [TMI] (Trunk & Trunk, 1983)

"Two local medical doctors were advising their patients that if they were nauseous or had stomach aches or sore throats, there was a good chance they had radiation poisoning." [TMI] (Trunk & Trunk, 1983)

"In certain ill-defined and perhaps unknown quantities, radiation in the air, soil and water can, of course, be deadly. Some of its forms may persist for many centuries." (Time, 31/10/88)

openness of the Soviet authorities encouraged speculation and that the general panic caused reports to be less accurate than they would normally be. In order to check on these points we have identified some reports about other incidents involving nuclear installations:
- the accident in the nuclear power station at Three Mile Island (USA);
- the disposal of nuclear waste at some U.S. military installations;
- the contamination of people with caesium-137 in Goiania (Brazil);
- some other incidents in the UK, China and Australia.

We collected quotations not only from newspapers but also from magazines. No great efforts were required to collect these quotations. Only for the Harrisburg accident did we have to rely on secondary sources for examples of media coverage. Table 3.1 presents a selection of quotations about these incidents.

From Table 3.1 it is clear that lay-ideas are not confined to the Chernobyl-issue. In particular, the use of the term 'radiation' with the meaning of 'radioactive material' occurs in reports about a number of nuclear incidents and in different journals and magazines. Also the lack of distinction between contamination and irradiation is illustrated in several quotations. Similar results have been reported by de Souza Barros (1989) in an analysis of Brazilian newspapers on the Goiania accident (IAEA, 1988).

The 'danger and risk' quotations contain a possible explanation for the idea that radiation spreads across large areas: the radiation is seen as very strong, passing through concrete walls of about 1 metre thick. Other quotations under this heading illustrate aspects of doom.

Lay-ideas related to 'dose', 'activity' and 'half-life' concepts were found less often. This might be due to the fact that in the Chernobyl period much more quantified information was given about activity limits, dose limits and half-life. The information about the other incidents is of a more qualitative nature.

Pupils' ideas in the science education literature

In chapter 1 (section 1.1) we referred to research on pupils' ideas related to scientific phenomena, processes and concepts. It was shown that pupils' ideas on ionizing radiation have been much less studied than those in several other areas of physics.

The oldest study found in the literature is that of Riesch and Westphal (1975) in the Federal Republic of Germany. As it is written in German and therefore less accessible to many readers we will summarize their results more fully. They based interviews with 59 pupils of about age 15 on the following research questions:

1. Do pupils at the end of Sekundar Stufe I relate the concept of radioactivity with the idea of a transportation process?
2. If so, does this idea relate to a particular physical theory?

Some of their findings give information about the ideas which pupils have

about the propagation of ionizing radiation. Nearly all pupils assume that the radiation has a certain starting point, that its intensity could vary and that the radiation becomes stronger near the source. The speed of the radiation is generally considered to be high, at least higher than the speed of vehicles in traffic. About one third expects that air or another medium is required for the propagation of radiation.
A majority has the following ideas about the propagation itself:

a. the radiation does not move in a straight line and can go partly or wholly around obstacles;
b. the radiation can be reflected, repelled or "sucked in" by substances;
c. the radiation could build up in front of obstacles.

The most dominant transportation model is 'current/flow'. Typical comparisons are with a stream of water and with pressure. A minority seems to use an 'equilibrium' model to explain transportation. They illustrate this by referring to the radiation being blown by the wind, moved by air particles, released into the environment or slowly given off by objects that have previously received radiation.

Only a few pupils use a 'particle' model: they note that the radiation is moving too fast to go around a corner, that it is slowed down by air or is destroyed by "moving energy molecules".

In the final part of their paper the authors note that pupils seem to confuse ideas about the transport of radioactive sources with those about the propagation of radiation: everything is brought under the name of 'radiation'; e.g. the expressions "radiation develops into a smoke plume, blown by the wind", "radiation attaches itself to objects", "radiation is hanging in the air" are correct if by radiation is meant 'radioactive nuclides'; other sources of incorrect representations - apart from wrong information - could also be such terms as 'radioactive contamination'.

In the Netherlands, Eijkelhof and Wierstra (1986; Eijkelhof, 1986) studied 17 year old pupils' use of scientific concepts in a real life context. Their results have been summarized in section 2.3.

In the United States, Showers (1986) studied the effects of informational and persuasive messages on the attitudes of high school pupils toward the use of nuclear energy. As part of his study he asked questions to assess the level of knowledge of 232 pupils in grades 10 to 12 who had not studied nuclear energy in any of their classes. In these questions he included some of what he calls "nuclear myth questions". About half of the pupils agreed with the following statement: "Although it is unlikely, a nuclear power plant can blow up like a nuclear bomb". About 40% assumes that man-made radiation is more dangerous than natural radiation and about 70% that "being exposed to radiation will make you radioactive". Showers also found that about 50% of the pupils have the idea that nuclear power plants more or less contribute to the amount of acid rain in the United States.

Also in the United States, Kaczmarek, Bednarek and Wong (1987) surveyed 'misconceptions' of second year medical students with no previous radiological training (the precise number is not stated). Almost three-quarters of the students believed that objects within a radiography room emit radiation after the completion of a diagnostic examination and 37% of them thought intravenous contrast materials were radioactive. They also noticed that students did not equate gamma-rays and X rays and that more than 30% of the students assume that radioisotopes have the potential to explode. They conclude from their survey that it demonstrates that medical students have significant misconceptions about radiological physics.

From this survey of the literature we might conclude that in several studies the existence of lay-ideas about radioactivity, nuclear energy and ionizing radiation among pupils and students has been noted. However the scope of these studies has been limited. Riesch and Westphal focussed on the transportation process and tried mainly to establish which physical model the pupils were using. Eijkelhof and Wierstra's findings of lay-ideas were more or less accidental. Showers' findings were the result of a field study with only five relevant questions. Finally, Kaczmarek and colleagues reported their findings in a letter to the journal *Health Physics* without much detail about the research procedure.

Having gained some insight into the nature and incidence of lay-ideas in this field, questions arose such as: Which meanings do pupils ascribe to terms? How do they interpret safety measures? What are their ideas about the risks of radiation? It is not likely that their ideas will differ radically from what we found in the newspapers and from what is reported by radiation experts (section 3.2). However it might be that some ideas are more prevalent than others. As the final aim of our series of studies is to contribute to the improvement of physics education it seemed necessary to involve pupils in our investigations.

In the study reported in section 3.3, pupils' ideas about Chernobyl were investigated: one particular context which got a great deal of public attention in recent years. In another study (section 3.4) 33 pupils were interviewed about a variety of contexts in which ionizing radiation is involved. In the final section of this chapter (3.5) the results of our studies will be discussed in an attempt to formulate a hypothetical framework of pupils' pre-instructional ideas about ionizing radiation and risk.

3.2 RADIATION EXPERTS' VIEWS ON THE INCIDENCE AND IMPORTANCE OF LAY-IDEAS

Introduction

Studying media-reports about radioactivity and ionizing radiation is only one way to gain insight into lay-ideas about radiation. One of the limitations of this method might be that news reports tend to deal with nuclear incidents, in which things go wrong in such a way that it is worthwhile for newspapers and magazines to pay attention to them. Another limitation is that certain contexts (particularly nuclear power stations and nuclear waste) get much more attention than others. In order to acquire additional information about lay-ideas, we decided to consult a variety of experts who are dealing regularly with lay-people in situations in which ionizing radiation is involved.

As we had already planned to consult radiation experts in a Delphi-study in order to legitimate the selection of contexts and concepts, it was relatively easy to approach this group on this matter by including questions dealing with lay-ideas. Our expectation was that it would be useful to draw together their experience of lay-ideas, particularly with regard to how such ideas might have practical consequences for people's decisionmaking about applications of ionizing radiation or radioactivity and for their perceptions of risk.

In the following sections we will first describe the research design and then the results of the Delphi-study on this topic. Then we will discuss some of the implications of this study, and the advantages and limitations of this research method.

Research design

In section 2.4 we described the reasons for selecting the Delphi-method to study the opinions of radiation experts on suitable contexts and concepts for physics education. The planned Delphi-study offered the opportunity to consult radiation experts on the issue of lay-ideas as well, although the method was not initially chosen for this purpose. An advantage was that the group of participants consisted of people from a variety of working-fields (mainly within health care, nuclear energy production, industry), who had regular contacts with lay-people and had at least four years of relevant working experience.

Hence we could expect to acquire information about lay-ideas in fields which do not get much attention in the media. So our first aim was to obtain a list of possible lay-ideas and to get an initial indication of which of these ideas are perceived by these radiation experts as occurring most commonly in the contexts with which they are familiar. In the course of the study two further aims were added.

Firstly we wanted to identify the views of the participants on possible consequences of lay-ideas for assessing the risks of ionizing radiation. The purpose was to select those lay-ideas which deserve special attention in this respect. We not only wanted to know which lay-ideas could be labelled as hindering adequate risk assessments, but we also hoped to extract descriptions of cases in which lay-ideas were clearly a hindrance to arriving at a thoughtful decision.

Secondly we hoped that radiation experts could comment on the view which we were developing about the coherence of a number of lay-ideas and about the differences in the ways of thinking of lay-people and experts. So we decided to devise questions to explore the importance of some general characteristics of the way lay-people think about ionizing radiation, for instance by comparing them with characteristics of the common scientific way of thinking about these matters.

We might summarize this by stating the research questions on which the 'lay-ideas'-part of the questionnaires were based:

A. Which specific lay-ideas about radioactivity and ionizing radiation are recognized at a more than incidental level by radiation experts?
B. To what extent are these ideas an obstacle to lay-people in assessing the risks of ionizing radiation?
C. What are the important characteristics of the differences between the ways of thinking about radiation of lay-people and experts?

In order to find answers to these research questions, we used the following procedure. In the first round of the Delphi-study we started off by stating that analysis of newspaper reports, TV-programmes and interviews with pupils has shown that many people have ideas which are partly or completely different from the scientific way of thinking. Then we presented fourteen specific lay-ideas which we extracted from existing studies (Riesch and Westphal, 1975; Eijkelhof and Wierstra, 1986) and from our first results of analyzing the news reports about Chernobyl. Participants were asked to indicate how often they noticed these lay-ideas. The opportunity was given to add lay-ideas which they had noticed themselves and which were not included in the list of fourteen. The results were analyzed and new questions were devised based on the results of this analysis and on the original research questions.

In the second round, we presented a further set of thirteen specific lay-ideas to the participants with the same request. This set was based on the lay-ideas which were added by the participants in the first round. In order to avoid too long a list we left out some which we considered to be too idiosyncratic, and we combined some which had - in our view- only small differences. The radiation experts were also asked to indicate how detrimental they considered all the various lay-ideas would be for personal risk assessment.

Analysis of the second round resulted in a preliminary general description (and some specific characteristics) of the differences in way of thinking on ionizing radiation between lay-people and experts. These were put forward in the third round, accompanied by the request to describe examples of situations in which lay-ideas had a negative influence on risk-assessment.

Perceived incidence of lay-ideas

We presented lay-ideas to the participants in the first and second rounds of the Delphi-study, asking them to indicate on a 4-point scale how often they met these ideas (4 = very often, 3 = regularly, 2 = sometimes, 1 = never). The combined results of both rounds are presented in Table 3.2.

Table 3.2 Frequency of occurrence of lay-ideas on ionizing radiation according to radiation experts

lay-ideas	rate of perceived occurrence average	s.d.
1. Radioactive substance and radiation are not distinguished	3.2	1.0
2. Activity and radiation dose are not distinguished	3.1	0.9
3. A radioactive substance is always dangerous	3.1	0.8
4. Irradiation of food results in radioactive food	3.0	0.8
5. A nuclear power station can explode like a nuclear bomb	3.0	0.8
6. A defective reactor spews out radiation	2.9	1.1
7. Radiation can be accumulated in the body	2.8	0.8
8. Radiation standards indicate a safety level: below safe, above dangerous	2.8	0.9
9. Irradiating a person results in radioactive contamination	2.6	0.7
10. Radioactive substances are always more dangerous than other substances	2.6	1.0
11. Radioactive and X-ray sources are not distinguished	2.4	1.0
12. After an accident in a nuclear power station the environment resembles Hiroshima after the bomb	2.4	0.9
13. Radiation attaches itself to objects	2.3	0.8
14. Artificial radiation is much more dangerous than natural radiation	2.3	0.9
15. An accident in a nuclear power station is always a nuclear accident	2.3	0.9
16. After taking away a radioactive source the radiation lingers for a while	2.2	0.9
17. Radioactive waste consists only of waste from nuclear power stations	2.0	0.8
18. Radiation floats in the air as a cloud	1.9	0.8
19. Radiation leads to impotence	1.8	0.7
20. After the half-life there is no danger left	1.8	0.9
21. Radiation is released only through nuclear fission	1.7	0.8
22. Radiation can be stopped or not be stopped (the absorption is 0 or 100 percent)	1.6	0.8
23. Radiation is reflected by a screen like light	1.5	0.5
24. Radioactive contamination can be undone by heating or a chemical treatment	1.3	0.6
25. Radiation flows around a screen like water around a tree	1.2	0.5
26. Ionizing radiation can be stopped by a vacuum	1.1	0.2
27. Radiation can be stopped by counter-radiation (like two colliding jets of water)	1.1	0.3

From Table 3.2 we can see which lay-ideas are rated by the participating radiation experts as most common. The ratings vary widely. We should not conclude however that this table accurately describes how lay-people think about ionizing radiation. It only presents the perception of the participating radiation experts about public thinking on this matter. For instance, further analysis of the answers of the individual experts shows that some experts seem to be much more sensitive to lay-ideas than others: some do not recognize half of the ideas while others state that they detect many of them regularly. That radiation experts are not necessarily also experts in lay-ideas is confirmed by the fact that some of the lower classified lay-ideas have often been detected in the newspaper reports about the Chernobyl accident, noticeably numbers 13, 18, 20 and 24.

During the analysis of the second round results we realized that we may have sometimes gone too far in combining various lay-ideas which were added by participants in the first round. A closer look at Table 3.2 shows that most items are formulated in a form that a lay-person could have expressed it: one might call them prototypical ideas. Others (for example items 1, 2 and 11) should be seen more as general characteristics of lay-ideas: they are not worded in daily-life language and could only be understood by people who have some insight into the topic. One might say that these items explain why some people hold certain ideas. For instance, item 1 (not distinguishing between radioactive substance and radiation) might be related to items 4, 6, 7, 9, 13, 18 and 25.

The importance of lay-ideas for risk assessment

In the second round lay-ideas 1 to 22 and 24 were presented to the participants in order to get initial indications of an answer to research question B. (We left out 23, 25, 26 and 27 as these were only detected by few of the participants in the first round and we included the set of thirteen new lay-ideas of which 24 was one). The radiation experts were asked to indicate which of these lay-ideas they considered to be a significant obstacle to lay-people in assessing risks associated with ionizing radiation. Table 3.3 shows the results. In this table we have classified the lay-ideas according to the number of participants who labelled these ideas as an important obstacle to risk assessment.

A closer look at this table shows that:

a. lay-ideas which relate to the irradiation of food and people are seen as an important obstacle to risk assessment in these situations (4, 9);
b. the same holds for ideas which show confusion between nuclear power stations and nuclear bombs (5, 12);
c. ideas concerning some physical aspects relating to the sources of radiation (6, 11) and absorption (22), about the sources of radioactive waste (17), about ways to combat radioactive contamination (24) and about some effects (19) were considered less important for risk assessment.

Table 3.3 Percentage of participants declaring particular lay-ideas an important obstacle to risk assessment

percentage of participants	lay-ideas
> 60%	4
50-60%	5, 9, 12
40-50%	1, 2, 8, 10, 14, 16, 20
30-40%	3, 7, 13
20-30%	15, 18, 21
10-20%	11, 17, 22, 24
< 10%	6, 19

These results might be influenced by the fact that some ideas were very context-specific, such as 4, 5, 9 and 12, whilst others were more general. Perhaps this context-specificity made it easier for participants to recognize the consequences of these lay-ideas for risk assessments in these situations.

It should be mentioned here that participants were asked to evaluate the importance of *separate* lay-ideas. Around a quarter of them, however, noted that some of these lay-ideas are related, for example 5 and 12, and 6, 7, 13, 16 and 18. We will come back to this point of clustering lay-ideas.

A framework of lay-ideas

Research question C was addressed in the final round of the Delphi-study. In this question it is assumed that lay-ideas are not just singular 'false' ideas which are held by lay-people and which could be replaced by singular scientific ideas but that they are products of a particular way of thinking of lay-people which is different from the way experts view the field (Schutz and Luckmann, 1974; Chi, Feltovich and Glaser, 1981; Redeker, 1985; Guidoni, 1985). Using the results of the first and second rounds (and some preliminary results of our media-analysis and student questionnaire on Chernobyl (see section 3.3)), we constructed a hypothetical framework which might characterize lay-people's way of thinking about ionizing radiation; we contrasted that with the way of thinking of radiation experts about the subject.

The question on this topic consisted of two parts. In the first part, a general description was given of the *difference* between the frameworks of lay-people and experts. This description reads as follows:

"The framework which experts have regarding radiation is based on a rational-theoretical, scientific way of thinking and is used to understand situations and to make a rational assessment of risks. Experts make, for instance, a distinction between a radioactive substance and the emitted radiation; therefore they find it important in assessing certain risks to check if internal contamination or external irradiation has taken place.
The framework which lay-people seem to have is based on their notion of danger and their ideas about safety-measures. What lay-people want to know about radiation is what to do in order to be least affected by it. This is illustrated by the kind of questions asked to experts during the Chernobyl affair, such as 'may we eat spinach?' and 'could we go on holiday in Eastern Europe?'. Hardly any questions like 'what does radiation mean and what are its effects?' were asked.
In short, lay-people seem to have a framework for radiation ideas which is based on a pragmatic and intuitive way of thinking about safety, and which guides them in perceiving certain risks and in interpreting safety measures."

Following this, the lay-framework was characterized in more detail in two ways. Firstly some prototypical lay-ideas were given concerning the safety of radioactivity and ionizing radiation, such as "radioactivity and X rays are always dangerous" and "a nuclear power station is just as dangerous as a nuclear bomb". They are formulated in the language of lay-people. These two examples of prototypical lay-ideas were based on some of the lay-ideas which are identified in Table 3.2: resp. items 3, 8, 10 and 5, 12. Secondly, some scientific ideas which seem to be missing from lay-people's thinking, such as the distinction between radioactive substance and the radiation emitted, were listed.

Analysis of the answers showed that 94% of the participants recognized the general description of the difference in frameworks. Some made comments in which they stated that not *all* lay-people think within the presented framework and mentioned one or two counterexamples. Perhaps we should have made it more clear that this was a model of the way we assume that *many* lay-people think rather than a universally applicable description. None of the respondents contradicted or added to the general description.

Regarding the more detailed characterization (prototypical lay-ideas and missing scientific ideas), we found no answers which contradicted the elements given. However 44% of the participants used the opportunity to add others. Analysis and weighing of these additions led to a rewriting of some of the elements (Table 3.4).

Table 3.4 Characteristic elements of the ionizing radiation framework of lay-people

A. 'SAFETY'-IDEAS ABOUT IONIZING RADIATION
1. Radioactivity and X rays are always dangerous: radiation or radioactive substances which one has received will remain permanently in the body; contact with radiation or radioactive substances results in cancer in due course.
2. Radiation for medical purposes is less dangerous than radiation used in other applications; for this reason X rays cannot be compared with radiation from radioactive sources.
3. Radiation standards indicate a safety-level: below this it is safe, above it is dangerous.
4. A nuclear power station is as dangerous as a nuclear bomb.

B. MISSING SCIENTIFIC IDEAS
1. The distinction between radioactive substances and the radiation emitted.
2. The distinction between the harmful effects of radiation and the radiation itself.
3. The distinction between activity and dose.
4. The distinction between high and low doses of radiation, and between acute and delayed effects.
5. The distinction between radiation of high and low energy.
6. For determining the radiation dose and assessing the risk, the time of exposure is an important factor.
7. Some radiation effects have a stochastic nature.
8. Ionizing radiation is a natural phenomenon.

Elements A3 and A4 are the same as in the original list; A1 has been extended. Elements A2 and B4 up to B8 were added.

We may assume that the new framework (Table 3.4) better represents the ideas which participants have about the way of thinking of lay-people about ionizing radiation.

Implications of the lay-framework for risk assessment

Research question B was partly covered in the second round when we asked which lay-ideas would be an important obstacle in assessing risks associated with ionizing radiation. The results only indicate which ideas are seen as a more important obstacle than others. They do not give an illustration of the kind of situation in which the lay-idea is problematic. We wanted to explore this point further in the third round by means of the following question:

"Finally we ask you to describe as clearly as possible one or more 'real life' situations from your own experience which illustrate that a lay-view on radiation leads to a wrong assessment of the risk of radiation and a false interpretation of safety measures".

This resulted in 38 case-descriptions from 28 (76%) participants.

About a quarter of these cases could be labelled as 'excessive fear': any amount of ionizing radiation, however small, is considered to be extremely life-threatening. These are illustrations of characteristic A1 in Table 3.4. Many of these cases dealt with the Chernobyl aftermath; for instance, people who were very worried after eating one plate of spinach, women who were afraid to get pregnant and families hiding themselves in cellars with food and a radio. Other examples of A1 were the following cases:

- fear of having an X-ray after reading about experimental nuclear arms explosions;
- a laboratory night porter got extremely worried after detecting any deflection on a radiation detector;
- a woman attributed menstrual problems to working with radioactive substances, because she had heard of the 'genetic effects'.

An example of A2 is the story of a Dutch kidney-patient who happened to be in Kiev just after the Chernobyl accident. He was more worried about the radiation dose received there (0.4 mSv) than about a kidney diagnostic test involving radioactive substances which he went through a few weeks later (from which he received 10-50 mSv).

Other participants gave illustrations of characteristic A3:

- a physicist was very worried after he got contaminated with radioactive material, but lost all his fear after he had heard that the dose was below the maximal dose for radiation workers;
- some people took the activity limits for food as absolute indicators of danger and safety, without taking into account the amount of food consumed.

Of a more general nature, not fitting into A1-3 but more in line with the general description of the lay-framework, are remarks from some participants who reported that safety measures themselves sometimes increase fear among the public. For example, if walls are made very thick, fences are impregnable and dose-meters have to be carried, then the radiation involved must be extremely dangerous. But the opposite also occurs: a university student considered a laboratory experiment involving radioactive materials to be safe, as otherwise it would have been forbidden.

About a quarter of the cases illustrated characteristics B1-3. In these cases people do not seem to be able to distinguish between irradiation and contamination. Examples include:

- reluctance to buy irradiated food for fear of radiation;
- the idea that walls of a medical X-ray department are full of radiation and therefore should be treated as radioactive waste;

- some workers who look after animals which are irradiated by X rays in experimental settings had a feeling of being neglected: they had not been issued dosemeters and did not get regular blood tests in contrast to personnel who irradiate the animals, although the latter personnel had less contact with the animals;
- a nurse who does not take place behind a wall when taking X-rays because "the radiation would reach me anyhow through the open door";
- the social isolation of an industrial worker who received an extra radiation dose by accident: he was considered by his colleagues and neighbours to be suffering from 'radioactive contamination'.

These examples show that people who embrace the lay-framework may have serious problems in assessing the risks of certain applications of ionizing radiation.

Discussion

In this part of the study we approached radiation experts in order to get a better insight (a) into lay-ideas which may exist about ionizing radiation, (b) into the importance of these ideas for risk assessment, and (c) into the relations between the various lay-ideas.

First some comments on the method used: the Delphi-study. We have already explained that this method was not chosen in the first place to investigate lay-ideas. It was chosen to study which contexts of use and which scientific contents should be included in a curriculum which emphasises pupils' learning about risk assessment and ionizing radiation. If our only aim had been to clarify lay-ideas, other methods might have been more appropriate. It has been important, however, in our experience that the method facilitated communication between participants, and between research staff and participants. A single questionnaire would not have been appropriate. A smaller number of experts could have been used but the chosen number was felt necessary for selecting contexts and contents, if we were to have a good representation of the many areas of application of ionizing radiation. With a smaller number of participants, more attention would have had to be paid to their sensitivity to lay-ideas. Perhaps it would also have been worthwhile preparing participants by sending them in advance some carefully selected articles about the differences between intuitive lay-ideas and scientific thinking. If the number involved had been smaller, some meetings might have replaced the questionnaires.

We would remind the reader that this study was set up principally with an educational end: to gain better insight into the problems of teaching and learning about ionizing radiation, to construct more successful teaching materials and to devise better teaching strategies. Its outcome should certainly not be regarded as a factual description of lay-people's thinking. We have asked for the views of radiation experts and have gained insight into their perception of the occurrence of lay-ideas among the public and the importance of these. The study shows that radiation experts are not automatically experts in lay-people's ideas: not all of them appeared to be sensitive to these ideas nor to the relations between the ideas. With these limitations in mind we will now comment briefly on the importance of the results of this Delphi-study.

Firstly, the results presented in the Tables 3.2 and 3.3 might serve as starting points for empirical studies on the ocurrence of lay-ideas among pupils. They give an indication of which ideas might be more worthwhile to study than others. For instance, some of the lay-ideas which Riesch and Westphal (1975) found in their study among German pupils (Table 3.2: 22, 23, 25, 26 and 27) are not recognized by our participants and/or do not seem to be an important obstacle in risk decision making. On the other hand, lay-people's problems with basic notions of radioactive contamination - also found in other studies among pupils (Eijkelhof and Wierstra, 1986; Eijkelhof, 1986) and in analyzing newspapers (section 3.1) - were often recognized and were seen as an obstacle for risk assessment.

Secondly, the framework describing lay-people's way of thinking about radiation (Table 3.4) is based upon a large number of separate lay-ideas which are recognized by radiation experts as being common. The framework was generally endorsed by the participants. A hypothetical framework of this kind might be useful for classifying newly discovered lay-ideas and for discussing which aspects of the framework should receive most attention in science education at various levels of schooling.

Thirdly, the cases have given us insight into the practical consequences of lay-ideas and in general lay-thinking. The number of cases should not be seen as complete; additions could be made by listening to public discussions, reading letters to the editors of newspapers or through discussions with radiation experts.

3.3 PUPILS' IDEAS ABOUT RADIOACTIVITY AND RADIATION IN THE CONTEXT OF CHERNOBYL

Introduction

In section 3.1 we summarized the results of our study of lay-ideas in news reports about the Chernobyl accident. These results show a lack of differentiation between the concepts 'radioactivity', 'radiation' and 'radioactive matter', alternative interpretations of the concepts 'dose' and 'half-life' and associations of 'radioactivity' with danger and risk. One might wonder which of these aspects of lay-thinking are to be found among pupils and with what frequency. To explore this we constructed a questionnaire in order to get more insight into pupils' ways of thinking about radiation and radioactivity in the context of the Chernobyl accident. In the following sections we describe the research procedure, report the results and discuss the findings.

Research procedure

The general aim of this study was to attain a general and representative picture of the ways in which pupils in forms 4 HAVO and VWO thought about radioactivity and radiation-related processes within the Chernobyl-context, before instruction about radioactivity at school. As in the Netherlands the topic of radioactivity is generally taught only in physics lessons for 16-18 year old pupils, we focussed our study on children just below this age.

At the time we constructed the questionnaire not much was known about pupils' ideas about ionizing radiation. So we decided to ask mainly open questions. The questionnaire asked pupils to describe (a) what they thought had happened at Chernobyl, (b) why the accident could have consequences in the Netherlands, (c) why certain safety measures were taken and (d) how they worked. They were also asked to explain the meaning of some scientific terms, such as 'radioactivity', 'radioactive contamination', 'radiation dose', 'becquerel', 'rem' and 'half-life'. The questionnaire was pre-tested, resulting in the rewording of some of the questions and leaving out of some others as the questionnaire would otherwise be too long.

The questionnaire was completed by 312 pupils of form 4 HAVO and VWO classes in October 1986, about six months after the accident took place. Pupils were selected from seven different schools and from fifteen classes. Although we did not choose the schools in such a way that the sample is representative of schools in the Netherlands, we would claim that the number of schools and classes is such that most school-specific influences have been eliminated. For instance, schools were drawn widely from different provinces, the denominations (public, Roman Catholic and protestant) were equally represented and the schools used a variety of methods in junior physics classes. So we may expect that the results give a quite representative picture of the ideas of these kind of pupils about the Chernobyl accident. At the time the pupils completed the questionnaire, they had not had any formal instruction about radioactivity, although it appeared that in some classes the Chernobyl accident had given rise to some discussion during physics lessons.

The answers were analyzed using a simplified network-method (Bliss, Monk and Ogborn, 1983). This method allowed us to categorize all answers of the pupils. Based on the categorization of the answers in this network a summary of pupils' answers was drawn up. Networks, categories and summaries were devised by one of the members of the research team and revised after consensus reached in discussions with the other members of the team.

Results of the questionnaire

The results will be presented in four categories: attention paid to news reports, ideas about transport, ideas about safety measures and their effects, and meanings attributed to terms.

A. Attention paid to news reports
A majority (70%) of the pupils indicated that they had followed the mass-media at least on a regular basis, whilst the remainder did so every now and then. Interestingly, 81% judged the information as "reasonably intelligible", 12% as "very intelligible", while only 3% found it "rather unintelligible". Taking into account that these pupils had had no formal schooling about ionizing radiation, the latter result is rather surprising. It may indicate that it is possible to experience a satisfactory feeling of understanding and meaningfulness from information that is often incorrect or confusing from a scientific point of view.

B. Ideas about transport
This category contains the results of the questions "What came out of the reactor into the atmosphere?" and "How do you explain that also in the Netherlands, over 1500 km from Chernobyl, consequences of the accident were experienced?". These questions were asked to collect answers from pupils about what came out of the reactor and what was transported to the Netherlands. Some of the answers could be classified as 'radioactive matter'. Examples of such answers are: "uranium", "plutonium", "caesium", "iodine", "strontium", "radioactive steam", "contaminated materials" and "fall-out". Other types of answers were labelled as 'radiation', as 'radioactivity', and as 'other answers' such as "nuclear energy", "smoke" or "poison". Table 3.5 presents the classification of the answers on these two questions.

Table 3.5 Classification of pupils' answers about:

1. What came out of the reactor?
2. What was transported to the Netherlands?

	Questions	
	1	2
radioactive matter	53%	37%
radiation	41%	28%
radioactivity	15%	16%
other answers	4%	29%

As the sum of the percentage shows, the answers of some pupils could be categorized in more than one category. More detailed analysis of pupils' use of terminology shows that in general this is not very consistent: 28% of the pupils used different terms in their answers to the two questions or used various terms in a single answer, for example "radioactivity (radioactive radiation)" or "radioactive substances (radiation)". To avoid repetition of the phrase "the non-differentiated radioactive matter/radiation/radioactivity concept" we will refer in the remainder of this section simply to 'it', except when it is necessary to do otherwise. However, some seemingly context-dependent differences in usage of terminology deserve attention, such as the fact that in both questions used to draw up Table 3.5 the term 'radioactivity' is used considerably less frequently than 'radiation' and 'radioactive matter', which points to at least some level of differentiation.

Summarizing the answers of most pupils to question 2, people in the Netherlands could experience 'it', because 'it' was transported to our country, mainly by wind and rain. After 'it' had been blown into the air 'it' reached us through air streams and came down with the rain. A few pupils said that 'it' reached us by way of rivers and the sea, partly because of the rain but also because of the cooling water of the Chernobyl power station.

Some others ascribed transport of 'it' not to the wind but to characteristics of the accident or to properties of 'it'. Some typical statements illustrating these ideas were:

"very large amounts have been set free"
"the reach of the radiation was enormous"
"it is very strong and goes through almost everything"
"it moves very easily".

According to other pupils, people in the Netherlands were affected by 'it' because its power was not yet exhausted. However, since 'it' was spread over a large area, pupils expected that its effect in the Netherlands should be less than in Eastern Europe.

C. Safety measures and their effects

Several questions dealt with pupils' perceptions of why some safety measures were taken and about what to expect from their effects. Two questions asked for the reasons and effects of large-scale government measures, such as the evacuation of villages in the neighbourhood of Chernobyl and the enforced keeping of cattle indoors. Another four dealt with advice about small-scale individual action, such as taking iodine tablets, staying indoors, taking a good shower and eating no fresh spinach.

Table 3.6 (pag.68) summarizes the answers to these six questions with regard to the use of the terms 'radioactive matter', 'radiation' and 'radioactivity'. Against a general background of undifferentiated use, some context-dependent use of the three terms is notable. In the case of the most drastic measures, which may be experienced as signs of an urgent threat to human life (questions 1 and 5), the term 'radiation' is dominant, while the term 'radioactivity' is more often used in less threatening situations, such as in questions 2 and 3. Only in the shower context is the term 'radioactive matter' dominant. In the iodine tablets context no term preference is evident.

Table 3.6 Classification of pupils' answers on six questions about safety measures (in %)

Questions	radioactive matter	radiation	radioactivity
1. Evacuation	11	55	18
2. Keeping in cattle	14	30	36
3. Avoiding fresh spinach	19	20	35
4. Taking a good shower	36	22	22
5. Staying indoors	20	46	19
6. Taking iodine tablets	15	20	23

A further analysis of the answers shows that, according to our pupils, the evacuation was necessary due to the detrimental effects on both people and the environment. These effects were seen as acute, such as immediate death, cancer and skin-diseases, or as longer term: affecting future generations. Damage to cells is mentioned frequently. The general view is that evacuation was needed because "too much" (some note "above the norm") or "too strong" radiation was "out there" for too long. The measure restricting cattle could be withdrawn after one week because there had been no new supply of 'it', the original amount had decreased or had partly or completely lost its effects. This was explained by the falling of rain, dissolution or mixing with air, or by the idea that 'it' demolishes itself.

Iodine tablets are seen as helpful because iodine works against 'it', protects the body and increases its resistance. Some pupils added as explanation references to neutralization, dissolution or conversion into something that is not radioactive. Others stated that iodine may protect you just like a lead wall, or by developing anti-bodies.

Eating fresh spinach was discouraged, according to many pupils, because 'it' had either got *into* the spinach (it was "stored", "gathered", "confined", "accumulated" or "absorbed in") or *onto* the spinach (it was "irradiated by", "exposed to" or "covered with"). Therefore the spinach was "radioactively contaminated" through contact with rain or air (of which spinach needs quite a lot, explaining the specific measure for spinach).

Two other measures seem to be perceived as obvious advice by nearly all pupils. When you stay indoors 'it' is stopped by the walls and the roof. Taking a shower means you are washing off dust, dirt and rain through which 'it' may have come into contact with your body.

We may conclude that pupils' reasoning concerning these safety measures is fairly plausible. From the actual stimulus given, i.e. the safety measure in question, they are able to find for themselves a satisfactory level of explanation. Whether this explanation is scientifically largely correct, as in the case of the cattle measure, or completely incorrect, as for the iodine tablets, seems to be unimportant to most of them, as they are not aware of this. The basic attitude behind their reasoning seems to be one of acceptance and of trust in the safety measures. For a smaller number of pupils, however, radioactivity seems to be such a mysterious and strong danger that this attitude dominates their reasoning, as is illustrated by answers such as:

"nonsense, radiation goes right through the walls of houses"
"probably to wash off radioactivity, but that is totally impossible".

D. The meaning of radiation terms

In the final section, dealing with the meaning of some radiation terms, a first question asked about the kinds of radiation that have to do with radioactivity. The spectrum of answers was broad and can be classified in four groups (in brackets the percentage of pupils giving one or more answers in this category):

a. radiation of a nuclear origin: α-, ß-, gamma- and neutron-radiation (34%);
b. electromagnetic radiation: X rays, ultraviolet, infrared, laser, radio (29%);
c. radiation from applications: in hospitals, from nuclear power stations, from nuclear arms explosions (9%);
d. "background" radiation: from television sets, the earth and the sun, "what you receive during air travel", "all objects in nature radiate" (6%).

The meaning of the term 'radioactivity' is mainly described as some kind of radiation (54%) and sometimes as radioactive matter (4%). Only about 11% described 'radioactivity' as a substance property or as a phenomenon and many of these answers are scientifically incomplete or incorrect. The rest of the pupils (31%) gave no answer, or general answers such as:

a "poisonous" or "chemical substance"
"dangerous stuff"
"very tiny particles"
"charge" or "force from particles"
"waste".

About 27% of the pupils used qualifying terms such as "hazardous" or "dangerous" in their answers.

A scientifically correct answer about the term 'radioactive contamination' was given by only 10% of the pupils. In most of the answers, pupils seem not to differentiate between contamination and irradiation. 'Radiation dose' was almost exclusively described as the amount, range or strength of a certain quantity of radiation. The notion of absorption was scarcely present in these answers. The units 'becquerel' and 'rem' were either unknown or simply described as units for an amount of 'it'. In the case of the becquerel hardly any association with the source was present, while for the rem the same applies to the notion of biological effects.

Finally, the term 'half-life' evoked quite a variety of meanings. A scientifically acceptable answer was given by 40% of the pupils. Pupils referred mainly to the halving of the radiation (23%) and of the (radio)activity (13%). Only 4% noted that half of the substance has disintegrated during one half-life or that half of the original substance is left. None of the pupils referred to the chance that one nucleus disintegrates.

A large group of pupils was unable to give an answer to this question (34%). The remaining answers were categorized into three groups of meanings for half-life:

a. time of disappearance: 'it' decreases to an acceptable/normal level or disappears during half-life (9%);
b. time in which a nucleus/atom/molecule is split into two halves (4%);
c. a variety of other meanings (12%), for example:
   "halving of the radiation of one atom/molecule"
   "halving of the radiation dose"
   "time in which a power station works at half rate"
   "time which leads to diseases doubles"
   "time you need between receiving radioactive irradiation".

Conclusions and discussion

If we compare the results of this study with those from the news reports analysis after the Chernobyl disaster, some similarities are striking. Many pupils seem not able to differentiate between the terms 'radioactivity', 'radiation' and 'radioactive matter'. They use the terms 'radioactivity' and 'radiation', similarly to many news reports, in a rather loose manner in answering questions about the event at Chernobyl and the subsequent safety measures taken, and describe the term 'radioactivity' often as "radiation". Most pupils are also unable to differentiate between 'radioactive contamination' and 'irradiation'. In the pupils' answers we further detected alternative interpretations of concepts such as 'half-life' ('time of disappearance') and 'radiation dose' ('amount of radiation'). Finally, we noted notions of hazard and risk which appeared in the descriptions of the meaning of 'radioactivity'. These similarities with the news reports are not surprising, as most pupils said they had followed the information about the Chernobyl event quite intensively.

In addition to these similarities with the conclusions of the analysis of the news reports, some new elements in pupils' ideas should be pointed out. Firstly, pupils do not appear to use the terms 'radioactive matter', 'radiation' and 'radioactivity' in a completely arbitrary way: in some contexts certain terms are used more often than others.

Secondly, pupils apparently constructed for themselves a functional interpretation of the Chernobyl-disaster, its consequences and the safety measures. We have the impression that most of them had the feeling that they could make sufficient sense of what was going on and of what to do about it, even though, from a scientific point of view, their actual knowledge was very defective. This might be explained by the fact that the questionnaires were filled in about six months after the event, by which time things had returned to normal. The emotional conflict ("what happens?"; "what is the risk for myself, my nearest and dearest?") was solved and few important questions remained.

In general terms, we may conclude that these pupils had very little scientifically correct knowledge about the topic radioactivity, which is not surprising considering that they had had little or no formal schooling on this topic. Most pupils did not have differentiated notions about activity, transport and absorption, nor about the processes that take place at a source or at a receiver of radiation. Knowledge about radioactive processes was mainly restricted to the vague idea that something dangerous ('it') is set free, which may reach us and may cause cancer and other problems. A measure of this danger is the amount of radiation, which can be expressed in certain units like rems or becquerels. The results show that the Dutch Minister for the Environment's statement "The average Dutch pupil knows after Chernobyl what a becquerel means" (NRC-H, 31-12-1986) is certainly overoptimistic.

3.4 PUPILS' IDEAS ABOUT RADIATION, RADIOACTIVITY AND RISK IN A VARIETY OF CONTEXTS

Introduction

The Chernobyl-questionnaire had two limitations. One is that it dealt only with the Chernobyl-issue which is a rather particular one because of its nature and scope. It was extensively reported in the papers as a major disaster with effects for people all over Europe, including those living in the Netherlands. The questionnaire did not deal with other applications in which radiation is used. However, there are good reasons for using a variety of contexts in education (see section 2.4) and it may be that pupils' ideas about radiation are quite context-bound. A second kind of limitation relates questionnaires in general: pupils tend to answer the questions with short statements which reflect only partly what they are thinking and which are often open to several interpretations, and it is not possible to ask follow-up questions about pupils' answers.

For these reasons we decided to explore pupils' ideas and ways of reasoning further using *interviews* about *various* radiation contexts. The aim of the interviews was to map out pupils' ways of thinking about radiation, radioactivity and risk in a variety of contexts, of which Chernobyl was only one of five, and to explore in more depth the meanings which pupils ascribe to various radiation terms. In the following sections we will describe the research procedure, report the results and discuss the main findings.

Research procedure

During the preparations for the interviews we formulated the following research questions:

1. How familiar are pupils with ionizing radiation in the selected contexts?
2. How do they perceive the risks of ionizing radiation in these contexts?
3. What ideas do pupils have about the origin, propagation, absorption and effects of ionizing radiation in these contexts?
4. What ideas do pupils have about the role of time in the various radiation contexts?
5. What meanings do pupils ascribe to the terms irradiation, radioactive contamination, radioactivity and radiation standards?

We will elucidate these questions. Question 1 aimed at finding out how familiar pupils were with the five contexts at the beginning of the interview: what did they know and what experiences did they have related to these contexts? The second question related to the risk assessment aspect of the research programme: how serious did they consider the risks to be in the various contexts? Question 3 focussed on processes related to the source and to the receiver, and on the transport process between source and receiver. Question 4 dealt with the factor of time and was aimed at exploring ideas about changes in radioactivity and ionizing radiation as a function of time. The last question was intended to explore the meanings which pupils explicitly ascribe to terms which are used quite frequently in the life-world. For this reason we did not include terms such as 'activity', 'half-life', 'radionuclide', or various units.

In the Delphi-study (section 2.4) a number of contexts were recommended by radiation experts as important for secondary education in physics (Table 2.8). From these we selected five:

- background radiation;
- medical applications (X-ray diagnosis, irradiation of tumours);
- nuclear energy (Chernobyl);
- storage of nuclear waste;
- industrial applications (food irradiation).

Some contexts from Table 2.8 are missing from this set of five, particularly 'nuclear weapons' and 'scientific research'. In trial interviews we included the topic nuclear weapons explosions, but this topic evoked too many political discussions in which scientific knowledge played a very minor role. The context of scientific research seemed to be too remote for pupils of this age group (around sixteen years) so we did not include it.

In the industrial context we focussed on food irradiation in order to take a context which seemed quite close to the pupils. The nuclear energy context we limited to Chernobyl, in order to be able to explore this topic in more depth than we had been able to do with the questionnaire.

In each interview three contexts were discussed with the pupils: one about irradiation (health or food), one about contamination (Chernobyl or waste) and one about background-radiation. More contexts would have taken too much time for the interview. In this way background radiation was dealt with in all interviews, whilst the four other contexts were discussed in 50% of the interviews. Each interview started with introductory questions about one of the contexts (research question 1), followed by questions based on research questions 2, 3 and 4. In the same manner another context was dealt with. In the next part of the interview questions were asked about background radiation in a similar way. Finally we asked direct and indirect questions about the meaning of various terms (research question 5).

The questions posed were of an open nature and could not be answered simply with "yes" or "no". At some points in the interview, photographs (e.g. of an X-ray department, irradiated food, a food irradiating room and radioactive waste vessels) and short newspaper cuttings (e.g. on irradiated food, Chernobyl and radon in homes) were shown as illustrations to certain questions. When the interviewer did not understand an answer, he added some questions in order to clarify pupils' ideas.

Interviews were held with groups of two pupils, partly to set pupils at ease, partly to stimulate additional comments on each others' answers and to promote discussion between them. Trial interviews with groups of three pupils were not successful as it took too much attention from the interviewers to keep the interview going in a proper way (i.e. following the interview scheme, watching the time and taking care that all pupils contributed). It was also difficult to decipher who said what on the tapes. Each interview took approximately one hour and was held after the last lesson of a school day.

Pupils were selected from five schools in and around Utrecht. A physics teacher from each school selected three groups of pupils from form 4 HAVO and VWO and took care that these pupils were not too quiet nor exceptional in ability. Pupils received a small reward for their participation.

In this way fifteen interviews took place in the period from April 7 to June 9, 1987. At each school three interviews were held at the same time in different rooms.

After the interviews the tapes were transcribed by an administrative assistant into protocols of about twenty pages each. The interviewers compared the protocols with the tapes and made corrections where necessary. The revised text of the interviews was cut into four parts. Each part was categorized according to the five contexts and 'meaning of terms'. For each category we noted the variety of specific answers until no new answers could be found. After this, for each context the answers were summarized according to the five research questions. Checks were made by colleagues to correct for incompleteness, incorrectness and dubious interpretations.

Results of the interviews on the radiation contexts

In this section we summarize the results of the interviews for the five contexts: Chernobyl, medical applications, radioactive waste, food irradiation and background radiation. In the five summaries we have categorized the results using the same classification, derived from research questions 1-4, in order to facilitate a cross-contextual comparison which we will make later. In the summaries we have included a large number of quotes from pupils to avoid imposing far-reaching interpretations which would be beyond the control of the readers. Of course, the quotes are originally in Dutch. We have tried to translate them in such a way that the quotes in English remain as closely as possible to the original wordings of the pupils.

The categories for each context differ in length due to the number and nature of the answers given on the various aspects.

A. CHERNOBYL

a. familiarity

The Chernobyl issue appeared to be still fresh in the minds of our pupils. They associated the issue with radiation, radioactivity, nuclear energy, nuclear disaster, nuclear arms and hazards to human beings. In their descriptions of the accident itself, pupils referred to overheating, meltdown, fire, loss of coolant, explosion, collapse of the roof, lack of a concrete dome and the release of a lot of "radiation".

b. risk perception

Chernobyl was seen as a serious accident, especially for those living in the countries of Eastern Europe. Some referred to personal experiences such as the cancelling of a holiday in Eastern Europe, the throwing away of vegetables from the garden and not buying any fresh vegetables for some time.

c. origin of ionizing radiation

Pupils claimed that the radiation originated from "the core", "from fission products" or "from a tube". Some assumed that the radiation was produced by a reaction during the explosion.

d. nature of the radiation

According to the pupils, the following was released during the accident: "(radioactive) radiation", "radioactive substances", "radioactive particles", "active particles", "dust particles", "radioactivity", "nuclear waste" or "cooling water".

e. propagation of radiation

Not surprisingly some pupils answered that the radiation emitted by the nuclear reactor in Chernobyl was taken away by the wind.

Others also referred to the influence of the wind but used terms such as '(dust) particles' or 'radioactivity' instead of 'radiation'.

Asked for analogies pupils compared the spreading of 'it' with "flower-seed", "brown rain from the Sahara", "air pollution" and "gas that spreads in a classroom".

f. absorption of radiation

On the question where 'it' would eventually be, the pupils answered that it would be spread across a large area, in higher parts of the atmosphere and in human beings.

We showed them also a newspaper cutting about milk powder which was contaminated as a result of the Chernobyl accident and asked them how they would explain the contamination. Typical answers were:

"radiation is inside" or "is built in"

"radiation is right inside the little grains"

"radiation creeps into the molecules".

g. effects of radiation

As consequences of Chernobyl, pupils referred mainly to cancer and sometimes to deformed children and brain-effects. According to most pupils, medical doctors could not determine if a particular case of cancer was due to Chernobyl, sometimes with the argument "at present you get cancer from everything".

Various views were found about ways to limit the consequences of Chernobyl:

"when you have the radiation inside you can do nothing"

"when people are contaminated they cannot get rid of it; I think they will die"

"greengrocers should be obliged to indicate how many becquerels it contains".

h. radiation and time

Radioactive milkpowder is expected to remain dangerous for a long time, from "a couple of years" to "some hundreds of years". One pupil thought the problem not so great, as "most radiation will remain in the cow".

B. MEDICAL APPLICATIONS

a. familiarity

A majority had some experience of X-rays: they referred to bone injuries or dental diagnoses. Many knew that radiation is used to treat cancer. Some mention the use of radioactive substances as tracers in the body, doing scans, dispersing kidney or gallstones, chemotherapy, treatment of epilepsy and assistance with surgery.

b. risk perception

X rays were in general not perceived as very dangerous. Pupils made remarks like:

"they only use X rays when it is necessary"

"one X-ray picture is not dangerous, only many are".

A minority see some hazards in X rays:

"X rays must be dangerous as my mother and the nurse had to stand behind a special window"

"pregnant women should be careful with X rays".

Pupils expected more risks for members of staff in hospitals, with some comments like:

"not such that they will get cancer"
"they opt for the risk".

Reference is also made to safety measures such as the use of lead screens. These measures are also the reason that most pupils would not fear working with radiation in a hospital. Some expect that if you work with it for years you will contract something, as some of the radiation will always get past the protective clothing and as there is a chance of making mistakes.

c. *origin of radiation*

In the medical context, pupils often mentioned a piece of apparatus as the source of radiation. The X-ray source is sometimes compared with a camera "but with a much bigger flash". The idea of a flash is inferred from the experience that they had to remain for only a short period near the apparatus. Others said they did not notice where the radiation came from as it was dark in the room or because they paid more attention to their own body at the time.

d. *nature of radiation*

A majority of the pupils assumed that cancer is treated with a kind of radiation which differs from X rays. In support of this, they argued:

"you are not cured by X rays, unlike the radiation they use to treat cancer"
"X rays make something visible, you can make a picture, and with the other radiation you don't see anything"
"it has a different function so the radiation should be different".

A minority have the idea that both kinds of radiation only differ in the dose, the power or the focussing on one point. One said:

"radiation is radiation, so something in it must be similar".

Some compare X rays with a beam of light or with a weak kind of laser-rays.

e. *propagation of radiation*

In the medical context most pupils compared the propagation of X rays with that of light:

"it is like taking a picture"
"just as light but with a different wavelength"
"a beam which gradually scatters and fades away".

A few assumed that the radiation moves by way of air particles, comparable with sound.

Ventilation of an X-ray room has a radiation effect according to nearly all pupils. Most of them expected an accumulation of radiation in the room, especially if the room is small; they feared that people working in the room will receive too much radiation and therefore ventilation is useful and necessary. Some noted that ventilation would only result in a shift of the problem: "everything will get into the open air".

f. absorption of radiation

Half the pupils who were interviewed about the question of where the radiation would end up when taking an X-ray, answered that it would remain in the body. The term 'absorption' was used by only a few of them. One pupil remarked that the radiation accumulates in the body and is then filtered in the blood which results in "a high concentration in these filters". Others had the idea that the radiation is reflected and "is printed in a picture" after reflection.

All pupils did agree about the usefulness of a screen or wall for the protection of the radiation workers. However the explanations for it were different:

"the things that are dangerous stay behind the screen"
"apparently it is more dangerous beside the beam than in the beam"
"some radiation will pass through the wall as they wear lead coats".

One pupil expected that the screen would finally get full of radiation.

g. effects of radiation

We asked the pupils what the X rays do when a picture is taken. The ideas about this varied:

"in special places it remains and in other places it passes; those places you can see on the picture"
"it passes through your body"
"it takes care that your skin is not visible on the picture, it conjures some of your skin away"
"it makes your bones better visible by giving off some light"
"it is stored in your body, for example in the subcutaneous fat, just like poison"
"something must happen otherwise it would not be dangerous"
"it causes some injury, it damages DNA and that could result in cancer".

As other effects of X rays were mentioned: cell damage, hereditary consequences ("as you carry the radiation") and various side-effects. Some commented that the risks would depend on age and other individual characteristics.

h. radiation and time

In general pupils did not expect X rays to act for a long period. They mentioned periods which varied from a few seconds to a couple of hours. This conclusion was based on their experience that the taking of the picture takes only a short time.

Radiation used to treat cancer acts for longer according to the pupils and they deduced that from the fact that there is an interval between treatments, and from the function of the radiation: "all cells have to be killed". Periods between a day and a month were mentioned:

"not very long as people have to be irradiated several times".

C. RADIOACTIVE WASTE

a. familiarity

A majority had heard about radioactive waste. This waste originated according to most pupils from nuclear power stations as a by-product of nuclear fission. Other places of origin mentioned were hospitals (X-rays), food irradiation facilities, nuclear arms, nuclear submarines, uranium enrichment factories, small laboratories and technology.

The pupils stated that radioactive waste is stored in depots, dumped in the sea or laid up underground in salt domes. It is packed in water and airtight or lead containers, or in concrete.

b. risk perception

Radioactive waste is considered to be dangerous by all pupils:

"after many years it has spread in such a way that it doesn't give any more trouble, but it is still not healthy"

"normal waste could decay, but radioactive waste remains for ever, or at least for a very long time"

"the waste has been irradiated, so the radiation could be released".

Most pupils were opposed to storage of this kind of waste in their neighbourhood because of the possibility of accidents or because "something will always pass". One pupil had no objection as "it will be well packed". Burning of the waste was not favoured by any of the pupils as "you will blow it into the air", "the radiation does not disappear during burning", "otherwise they would have done it already" or "it is too expensive".

c. origin of radiation

This topic was not dealt with in the interviews.

d. nature of radiation

Pupils appeared to have a large variety of representations of radioactive waste: "a kind of muddy substance", "a kind of powder", "a very thin layer of dust", "gases", "a kind of metal", "fission-bars", "only radiation, a bottle with radiation" or "peels of potatoes that have been irradiated".

The only elements mentioned were uranium and plutonium.

e. propagation of radiation

In the waste context we asked the pupils what would get into sea water if a container bursts. Both 'radiation' and 'radioactive materials' were mentioned. According to many pupils this would result in irradiation of water and fish, and "life in the sea will spread it". One pupil illustrated this with a remark about fish which could get tumours and therefore move slower with the result that predators will more easily catch the fish:

"but as they emit radiation the predator will also get the radiation inside it".

Others referred to the rain-cycle:

"the water is affected, it evaporates and then you will get rain with radiation in it"

or made a distinction between a closed and an open container:

"in a closed container the radiation will gradually be absorbed by the water; when the container bursts open you will get all the radiation at once".

f. absorption of radiation

In the waste context we presented the pupils with a photograph of a storage room with full containers and asked them if anything got through the walls of the containers. Most pupils answered that something would pass:

"radiation", "radioactivity", "radioactive particles"
"nothing is fully closed and the particles are very small"
"most radiation will be stopped, but some will always be released".

Some expected that this would only happen in the long run:

"with concrete it escapes after 50 or 100 years"
"the walls will slowly break down".

One pupil expected nothing to get out as "otherwise the containers would be useless". Others expected that some would remain in the walls: "radioactive waste" or "(a little bit of) radiation".

g. effects of radiation

All pupils agreed that a container dumped at sea containing radioactive waste will cause trouble for human beings if it bursts open. They referred to contamination of people by eating fish, swimming in the sea or drinking water. Another idea about detrimental effects was:

"plants cannot grow any more, animals cannot be kept outside, agriculture becomes impossible, life becomes impossible".

Another pupil had greater discrimination in his/her view:

"when you receive a certain kind of radiation on your body it is not dangerous, but if it was inside the food it would be dangerous as then you will get the radiation inside".

Some specific radiation effects were named: breaking down of the body, effects on tissues and cells, inducing of cancers, skin irritation and eye trouble.

h. radiation and time

Radioactive waste becomes less dangerous in the long run, according to most pupils. In support of this they gave the following reasons:

"the same applied to the Hiroshima bomb; it is now less radioactive than at the time, so the radiation decreases"
"when a sweet has a particular smell that smell will decrease at a certain moment; with radiation it will be the same"
"the substance will be used up"
"through half-life:... then it decreases at once by half"
"the radiation remains in the wall".

Some expected it to remain dangerous at the same level or assumed that its danger would only decrease when the waste is released, but not while it remains in the container.

According to all pupils the radioactive waste has to be stored for a long period: answers were given between 50 and a few million years. Some stated that it would depend on the kind of substance, the radioactivity of the substance and the way the substance has been used. In three of the interviews the pupils argued that the waste will always remain radioactive:

"when you keep dividing something into halves you will never reach zero, so always some radiation will remain".

D. FOOD IRRADIATION

a. *familiarity*

Food irradiation was rather new to many pupils: they had never heard about it or had erroneous ideas about its function ("to promote growth", "to defrost food") or about the way irradiation takes place ("caused by Chernobyl", "happens after a nuclear bomb has exploded"). A minority knew that food irradiation was used to preserve food:

"to eliminate insects and bacteria"
"just like pasteurization or sterilization".

After the introductory questions the interviewer explained that food irradiation served to make food less perishable, for instance to prevent sprouting of potatoes. Asked for their ideas about how irradiation was done pupils compared it to X-rays and to spraying stuff on a field ("with a piece of cloth to cover your mouth") or in a closed space. Some pupils said that the food was first packed and then irradiated with a radiation source.

b. *risk perception*

Many would never buy irradiated food, would prefer less good looking food that has not been irradiated, or find food irradiation unnecessary as "there is enough fresh food available". They fear that by consuming this kind of food you receive a little bit of 'it' and "many small ones add up" or that not all bacteria would have been killed. A minority however, would not mind eating irradiated food. They think that it is not dangerous "otherwise they wouldn't do it", rely on research done, are not afraid of contamination, assume that only small amounts of 'it' are used and that these quantities are quickly broken down. One pupil adds that it would be a bit harmful but the same applies to smoking so you should not bother too much.

c. *origin of ionizing radiation*

The radiation with which food is treated is also seen as coming from "special substances", "elements" and "isotopes"; some pupils mention enriched uranium, plutonium, iridium and strontium. Others expect the radiation to originate from the "fission of certain molecules" or from "a blue spiral in a tub of water".

d. *nature of ionizing radiation*

A large variety of answers was given on the question what kind of radiation is used to irradiate food. Pupils compared this radiation to the radiation from an atomic bomb ("but less dangerous"), with alpha-rays ("they are least dangerous for the human body"), with electron-, laser-, infrared-, X- and gamma-rays, with invisible and concentrated light, with the waves from a stone thrown into water, and with magnetic field lines "which run from one point to another". Some pupils stressed that certain kinds of radiation are not suitable for this purpose, such as heat radiation and X rays ("these make things visible").

e. propagation of radiation

In the food context pupils compared the propagation of radiation to heat:

"nearby the stove you feel the radiation, at a distance you only feel the hot air which is heated up by the heat radiation"

or with sound waves:

"if you turn up the volume of the radio you will hear it through the walls".

Gamma-rays are expected to pass through everything. One pupil had the idea that radiation is necessary "to get radioactivity into a potato; so the radiation spreads the radioactivity".

Almost all pupils expected ventilation of the room to be useful, mainly using arguments similar to those in the previous context:

- accumulation of radiation;
- the molecules or dust particles get irradiated.

Opinions differed about the acceptability of ventilation. According to some the radiation would then spread more easily outside the room. Others held the view that the radiation should be kept inside the building. Only one pupil did not see any use for ventilation:

"with ventilation you only displace molecules; if you direct a fan towards a light ray the ray will also not move".

f. absorption of radiation

After irradiation of food a bit of radiation will remain in the food, according to some pupils:

"that is why it is not safe to eat"

"otherwise food irradiation would make no sense"

"as there are a lot of protests against it".

One pupil called irradiated food "contaminated" and expected that the food would start to emit radiation until the radiation disappeared again. Another pupil concluded from the fact that personnel wear special clothing that not all the radiation remains in the food. Others assumed that the radiation would pass through the food and affect the food on the way or that "the radiation disappears but the radioactivity, which demolishes the body, remains".

According to nearly all pupils, very little radiation or no radiation will pass through the walls of the irradiation room. Some expected that the wall would be affected by the radiation:

"it crumbles so that more and more radiation can pass through in the long run"

or that the radiation which could not get through would accumulate:

"the activity of the radiation will decrease but if it has a long half-life than you have a chance that when the factory is pulled down it will be released, especially beta and gamma".

g. *effects of radiation*

In food radiation will, according to the pupils, kill insects, bacteria, organisms and growing cells, but also things which are part of the food, such as milk. According to some pupils the food itself is neither destroyed nor burned but the radiation "contains substances which are harmful for insects and human beings". It is evident for many pupils that if you eat irradiated food you will get the radiation into your body and that could have detrimental consequences such as headache, cancer, hereditary changes and diseases. According to some the consequences are not very substantial for the following reasons:

"the quantities are small as you wash the food"

"if you don't eat a lot of irradiated food or food that has been a little bit irradiated, the remaining amount of radioactivity is broken down by the body"

"your body could have a certain dose of radiation, which is thrown out by the defence-system of the body"

"the radiation only acts on plants and not on man otherwise they would not use it".

Other pupils were not so sure of the safety of irradiated food, influenced by the picture of an irradiation plant:

"if it is done in a room like that they couldn't say it is not dangerous"

"rather tricky, if you see what is required to keep it from the open air"

"something could go wrong, just like in nuclear power stations".

Another pupil did not see any safety problems:

"it is safe; in a nuclear power station it remains also inside".

h. *radiation and time*

In food the pupils expected the radiation to remain for a long time:

"just like other radioactivity"

"it will decrease slightly, but of course it remains".

Several times comparisons were made here with the atomic bomb. Some mentioned factors such as:

"which particles are inside that emit radioactivity"

"the half-life: in that period the activity of the radiation decreases by half".

E. BACKGROUND RADIATION

a. *familiarity*

Most of the pupils appeared to have notions about background radiation being present in the environment. Many of them associated this kind of radiation with the sun:

"solar radiation contains harmful substances"

"UV-radiation from the sun (non-radioactive)",

or with heat, "earth rays", radiation from people, sound waves and radiation from a computer screen.

b. *risk perception*

Background radiation was not perceived to be dangerous by a majority of the pupils:

"background radiation has a low concentration"
"artificial radiation is more dangerous than natural radiation as the latter has always been with us and I never had any trouble with it"
"natural radiation remains in equilibrium, some is added, some goes away"
"background radiation is only dangerous when it comes from Chernobyl".

A minority did see some hazards in this kind of radiation:

"background radiation makes people old"
"background radiation breaks things down".

c. *origin of ionizing radiation*

Questions about the origin of background radiation started with some measurements of the background radiation with a Geiger counter. Then pupils were asked where they expected this radiation to come from. Pupils referred mainly to the sun and Chernobyl but also to the walls and ceiling of the building, central heating, lamps, wooden furniture, plasterboard, and atmospheric nuclear test explosions. In addition to these concrete examples, pupils gave answers about processes:

"the result of a natural process, fusion, reaction between some substances which occurs at some places, for example in building materials, which results in radiation"
"radiation/radioactivity is in the air, reaches the surface of the earth and comes out in the morning with the dew".

d. *nature of the radiation*

For a number of pupils background radiation was seen as very different from X rays:

"X rays are more concentrated"
"X rays have a very different effect"
"X rays are more dangerous"
"radioactive rays remain inside and X rays pass the body for a large part"
"otherwise you could use a gypsum plate as an X-ray source"
"X rays have a definite purpose and background radiation doesn't".

Other representations which pupils used to describe background radiation were:

"radioactive radiation"
"a kind of light"
"just like poisonous substances in a pvc-tube which are released in burning"
"I see it as a wave-sign from the wall with an arrow".

Finally we present some pupils' ideas which came up during discussions about radon released by some building materials. One pupil did not believe that radon was released by building materials:

"radon reaches us through the air and does not come from plasterboard; radon is everywhere, it is too expensive to process in building materials and, furthermore, the boards have been out in the open air on the building site for some time".

About the nature of radiation and radioactivity we noted during these discussions the following remarks:

"radioactive radiation is released very slowly, just like the smell from a bottle of shampoo"

"radiation is the same as radioactive particles; they are very small and fly low"

"radiation and radioactivity are the same, at least they are used indifferently; only chemists can keep them apart"

"an atom of radioactivity"

"radon is an inert gas that can be made radioactive".

e. propagation of radiation

As regards the propagation of background radiation, we noted the following ideas:

"from radiation from space we could conclude that radioactive radiation passes through a vacuum"

"radiation which is always present is reflected by building materials and this results in a higher concentration inside the house".

Some pupils expected that ventilation of the house would help against background radiation:

"radiation would remain inside"

"it accumulates in a well insulated house"

"the radon/radiation will leave the house with the air"

"the radiation will not pass easily through insulating materials"

"in a well ventilated house the radiation passes through the building materials more easily, just like a sieve".

Others had some doubts about the usefulness of ventilation in this respect:

"it does not help in general, only for the occupants"

"you should not open the door otherwise it will get back into the house"

"radiation will pass through everything, even through windows"

"I don't think ventilation has anything to do with radiation as I have never heard of that".

f/g/h. No questions were asked about these topics.

Conclusions and discussion on the five contexts

As nearly all the eight aspects (a-h) of radiation were summarized for each of the five contexts it is possible to compare the contexts with each other. Table 3.7 presents a matrix of contexts versus aspects.

One difficulty in filling in this matrix is that pupils' answers have to be classified within categories which are derived from a scientific point of view. Origin, nature and propagation are not clearly distinguished by the pupils, and the same applies to absorption and effects. A second

Table 3.7 A comparison of pupils' views on five radiation contexts

aspects	contexts				
	Chernobyl	Medical	Waste	Food	Background
familiarity	all pupils	all pupils	all pupils	some pupils	most pupils
riskiness	very (esp. in E.Europe)	X-rays not (if few pict. are taken)	very	quite	not
origin	reactor	apparatus	--	apparatus	sun Chernobyl
nature	'it'	rays	'it'	rays	'it'
propagation	wind	as light	water and food cycle	as heat or sound	as a gas
absorption	conservation	conservation transmission reflection	conservation transmission	conservation	--
effects	acute cancer genetic	acute cancer genetic	acute cancer genetic	acute cancer genetic	--
time-scale	long	short	long	quite long	--

problem is that it is not always clear how speculative the answers of the pupils are: did they invent an answer on the spot to the questions asked or did they express ideas they already had before the interview? One may assume that the more variety which is found in the answers, the more likely it is that pupils were giving spontaneously invented answers. This last effect seems to have occurred mainly in the context of 'background radiation'. A final problem, due to our small sample and to the fact that not all pupils gave answers to all questions, is that any comparison between the contexts is necessarily tentative and cannot be read as a final and firm conclusion about pupils' ideas on these contexts.

Despite these limitations, we consider it useful to give a general description and interpretation of what we see as a common view held by pupils on each of these contexts.

Pupils' views on the *Chernobyl* and *waste* contexts appear to be quite similar. The existence of both contexts is familiar to the pupils, probably because both have got a great deal of attention in the media. Central to their view is that these contexts imply large, real and long-lasting hazards but the sources of the hazards are rather distant. As the sources are distant and the hazards are seen as real, it is obvious to the pupils that some transport occurs. The wind in the Chernobyl context is a likely means of transport, taking into account the media coverage of the incident (see section 3.1). Transportation in the other context is ascribed to the movement of water and fish, perhaps because of associations with the Gulf Stream and with popular ideas about the food chain. The question of what exactly is transported seems not to concern the pupils: they perceive no need to make a distinction between 'radiation', 'radioactivity' and 'radioactive matter'.

Food irradiation is known only by some of the pupils. Most pupils do not consider this a safe practice. One might argue that the ban on certain vegetables and milk in the days following the Chernobyl accident has influenced this view, but we think that reports of past research (Ulmann, 1972; NIPO, 1973; Defesche, 1983) show that consumers were very reluctant about buying irradiated food, long before 1986. In our opinion it is more likely that this fear is due to conservation ideas about radiation: when radiation falls on an object (i.e. food) it must go somewhere. Such a view would obstruct any evaluation of the relative importance of the disadvantages to the process of irradiating food on a large scale, as summarized by Piccioni (1988). None of these is that the food itself becomes radioactive. Although food irradiation is not well known, pupils have no difficulties in formulating opinions about it, perhaps because food is something which is very familiar to them and they have the idea that diseases are often caused by eating the wrong food.

Propagation in this context is not seen as relevant as the source is near to the food when irradiation takes place. The nature of the source is seen as "radioactive" or "fissionable" matter, the distinction not being seen as an important one.

Pupils' views on the use of radiation for *health* purposes seems to be influenced by personal experience. Many of the pupils have had X-rays. X rays are not seen as very dangerous, perhaps because it seems unlikely to them that this radiation would be used so often if any serious risks are present. Also the usefulness of X-rays may have played a part in forming their opinion.

Associations with light are common as photographs are the product of using X rays. The nature and persistence of X rays and of radiation from radioactive sources are not compared from their scientific properties but from their functions.

Medical radiations are not seen as completely safe, based perhaps on factors such as:

- safety regulations and practice: warnings for pregnant women, restrictions on the number of X-rays in a given period, the position of the nurse when using the radiation and the use of lead aprons;

- ideas about the conservation of radiation; these seem to be less important in this context as most pupils assume that all or most of the radiation passes the body.

Radiation in the *environment* is quite familiar to many pupils. However they appear to mean many different things by background radiation. This conclusion may be drawn from associations with the sun, Chernobyl, earth rays, heat radiation, nuclear test explosions and food irradiation. It is not clear how many associate background radiation with radioactivity.

Background radiation is seen as relatively safe, not because of its nature or effects but apparently because of its 'natural' character. So the pupils do not see background radiation as a potential hazard, which is the case with all the other four contexts, albeit with different degrees of riskiness.

No clear ideas are found about the nature and propagation of background radiation. Pupils seem to compare its propagation with that of gas but this kind of answer may have been induced by our questions about radon gas and about the usefulness of ventilation.

The general descriptions of pupils' views within these contexts show that common-sense and incoherent bits of information from the media dominate many of their views. Scientific notions play a small or non-existent part. Reasoning appears to be centred around the perceived risk of radiation for people. The nature of the effects of radiation is quite well known and does not differ for the contexts, contrary to the perceived seriousness of the radiation hazard in the five contexts.

Pupils seem to be less concerned with the nature and origin of the radiation. They often make analogies. These analogies are based on the characteristics of the contexts, especially the function of radiation and the saliency of safety measures in each particular context. Propagation only evokes specific ideas if the source is at a large distance and is seen as dangerous (Chernobyl and radioactive waste). When sources are nearby and inside buildings (food irradiation, health applications and radon from building materials), ventilation is considered to be useful, even if they have mainly used the term 'radiation' in their answers (food and health contexts). The ideas on both ventilation and contamination seem to be based on a common idea of conservation of radiation. The scientific notion of absorption is seldom found.

Pupils' ideas about the meaning of terms

This section deals with the meanings which pupils ascribe to various terms: 'radiation', 'contamination' of food and people, 'radiation standards' and 'radioactivity' (research question 5). To avoid repetition we will not present a wide collection of quotations to illustrate the answers which pupils gave to the questions about the meaning of terms asked towards the end of the interview. Instead we will summarize meanings found in the answers about contexts and add only those quotes which illustrate new aspects.

A. Radiation

(Ionizing) radiation is a term whose meaning is hard for most pupils to describe. One of the more indirect ways to discover which meanings are attributed to this concept seems to be to ask for comparisons, properties, effects and relations to other concepts. As regards the meaning of radiation, we found in the five contexts many associations with other kinds of radiation, especially with ultraviolet light, but also with heat, radio waves and sound waves. Invisibility is a property which is acknowledged by almost all pupils. A large proportion of pupils make distinctions between natural radiation, X rays and "radioactive radiation". They draw this conclusion partly from the differences they perceive in effects, and partly from the differences in function of these kinds of radiation.

We questioned them further on the relation between radon and radiation. Pupils gave the following kind of answers:

"the radon keeps radiating until the molecule has decayed"
"radiation consists of radon"
"the gas is the radiation"
"the radon gas activates the radiation or the other way round"
"radiation and radon gas are very different, aren't they?".

We conclude that several ideas appear to be present:

a. the idea that one molecule has a particular amount of radiation which it keeps emitting until the molecule has decayed;
b. radon is a particular kind of radiation: similar to not making a distinction between radiation and radioactive matter;
c. radon and radiation are different entities which act upon each other.

B. Contamination of food

Contamination of food came up in the interviews in the contexts of Chernobyl (radioactive milkpowder and vegetables), waste (fish), food irradiation and background radiation from food. Radioactive contamination of food was seen by pupils as a serious hazard. The idea that irradiation is the cause of contamination was rather general. We suggest that this idea may be based on a notion of conservation.

We explored pupils ideas about contamination further by asking questions about the meaning of the term, about the cause of it, about the relation between 'contamination' and 'irradiation', and about the effects of time.

Pupils' answers on the nature and cause of radioactive contamination can be classified into three groups:

a. due to received radiation;
b. due to received radioactivity;
c. due to radioactive particles.

The first group of answers represents the dominant view and is the one which is most different from the scientific view. Within this group we found a variety of ideas about the relation between radiation and contamination. A majority seem to have the idea that contamination is a matter of having received too large a quantity of radiation:

"it has received so much radiation that at a certain moment it starts giving off radiation itself"

"if something is exposed to radiation for a long time, it accumulates and at a certain moment it is that high that it wants to get out and to go to a lower concentration by means of diffusion".

This supports our suggestion about the conservation idea. A minority had ideas about activation of the food by radiation:

"as a result of a radioactive source on the outside, the atoms get unstable and so the food starts to emit radiation".

This idea is not very different from the scientific idea: in principle it is possible to activate nuclides. However, in food irradiation the energy of the radiation is too low for this effect to arise and in the other contexts contamination takes place as a result of the intake of radioactive matter.

Most pupils expected radioactive contamination to decrease in the course of time:

"it breaks down, just like a decaying process"

"a natural process: it meets another substance which could compensate for it"

"it hands over radioactivity to the air" or "mixes itself with air"

"now we are able to consume spinach, endive and milk again".

The ideas behind these statements seem to be based upon analogies with decay and reaction processes, upon the evidence that radiation/radioactivity must be emitted and upon the experience of the resumption of sale of some foodstuffs.

C. Contamination of people

Contamination of people was scarcely mentioned in the context parts of the interviews. So we tried to get more insight into pupils' ideas about this concept by asking questions about the origin, nature and effects of contamination.

As regards the origin and nature of contamination, a similar classification to that used with contaminated food is applicable: it is either described as due to exposure to radiation, to receiving radioactivity or to storage of radioactive particles. Some pupils referred to the amount of radiation as a factor: "being exposed to a surplus of radiation" or "more radiation than normal".

Most pupils claimed that X rays could not result in radioactive contamination using the arguments that this kind of radiation is not radioactive, too weak or "fades away quickly".

One pupil mentioned that he expected the elements in the body to become unstable due to the radiation.

A number of pupils expected it to be possible to treat contamination, by using "anti-radiation", "anti-catalysts to slow down the formation of tumours", "anti-bodies", "a source which would extract radiation from the body" or "a good wash". Others were less hopeful: they referred to the permanence of meat contamination ("and we too are made up of meat"), to the strength of the radiation and to the places where the radiation is stored in the body.

A contagious character of contamination was affirmed by some people. According to them contamination could be passed to others by emission of radiation, by breathing radioactive particles, by mouth-to-mouth resuscitation, by blood transfusion or from mother to child in pregnancy. Others denied this, using arguments such as that radiation/radioactivity would remain inside the body, or the loss of activity of the radiation.

D. Radiation standards

Radiation standards did not come up in the earlier parts of the interviews about contexts. When asked about the meaning of radiation standards, most pupils appeared to have heard about them. However, they attributed different meanings to the idea. Their answers fall into four groups:

a. the maximum amount which is allowed in air or food, or which one is allowed to receive: a 'regulation' view;
b. the maximum amount one might receive without getting ill or which the body could cope with (e.g. because of "antibodies"): a 'threshold' view;
c. the amount at which the chance of getting something is small: a 'probabilistic' view.

In a fourth group of answers (d) we sensed some suspicion about radiation standards:

"they don't know how much the effect is of that standard on someone"
"to me these standards are a lot of rubbish as radiation below the standard also contributes to getting cancer"
"it is a sop for the crowd so that they don't panic"
"if it suits them they just increase the standards"
"the problem with radioactivity is that it manifests itself only after twenty years in the form of cancer, so they could easily claim that you are allowed to receive that much".

In these answers we read doubts about the level of available scientific knowledge, distrust of authorities, the idea that all radiation is dangerous and the belief that long-term effects are not being taken into account. We call this the 'distrust' view.

Some questions were asked about the risks associated with radiation doses below the standard levels. Three kinds of ideas appeared to exist:

a. there will be no risk at all:
   "if you receive the same as usual"
   "your body is able to break down these particles".
   Answers are based on the idea that the body receives an amount to which it is used and with which it could cope. We recognize the 'threshold view';

b. it is quite safe:
   "a very small chance of effects"
   "no direct hazard".
   Here we recognize probabilistic views and the idea that the effects are not immediate;
c. it is not really safe:
   "increased radiation remains harmful"
   "maybe a hazard in the long run"
   "danger of accumulation"
   "anyhow, you will contain radiation and that is not funny".
   From these statements we extract ideas such as 'all radiation is dangerous', 'the long-term effects have to be taken into account' and 'radiation accumulates'.

Some pupils referred to risks to special groups (babies, females, people with a small natural resistance) or to the need to weigh the effects against the advantages.

E. Radioactivity

In all interviews the term 'radioactivity' came up in the answers to the questions about radiation contexts. Although the meanings seem to be rather varied and indistinct, from a scientific perspective the following two meanings can be distinguished in these answers:
a. the same as radiation: it is emitted or given off, passes through walls, is absorbed by food through irradiation;
b. substances: food and radon gas contain it, or a proportion of it.

At the end of the interviews we asked pupils to specify the meaning of the term 'radioactivity' explicitly. The same classification is applicable:
a. radiation, with the following characteristics:
   - origin:
     "radiation which is emitted by heavy metals/ heavy atoms/ radioactive isotopes"
     "radiation which is released if you try to generate energy from atoms"
   - nature:
     "a dangerous form of light"
     "radio wave with a wavelength which is dangerous for man"
     "in pure physics it is radiation"
   - propagation:
     "radiation which moves easily"
     "particles which go through anything by means of radiation"
   - effects:
     "radiation which ionizes"
     "accumulation of radioactive radiation"
     "particles you cannot see and which have a negative influence on cell division".

   In some answers the term 'particles' was used but most likely in the sense of 'radiation particles'.

b. substances, with the following characteristics:
"noxious substances which are everywhere"
"substances which emit rather dangerous radiation".

'Radiation' appeared to be the dominant meaning ascribed to the term 'radioactivity'. In the light of the results of the Chernobyl questionnaire (section 3.3), it is not surprising that in many of the statements above reference is made to danger. Additional remarks of this sort were:

"something dangerous will be in it, when I hear something about radioactivity I always think: be careful"
"it could help to cure people and it is useful for energy, but it may also destroy man: so it is a kind of love-hate relationship".

Common-sense reasoning

In the interviews we noticed many examples of pupils' reasoning which is not based on scientific knowledge but on a common-sense form of argument. Examples on the *nature* of radiation are:

"you are not cured by X rays, unlike the radiation they use to treat cancer"
"X rays make something visible, you can make a picture, and with the other radiation you don't see anything"
"X rays are different as otherwise you may as well use plasterboard as an X-ray source"
"X rays have a definite purpose and background radiation doesn't"
"it has a different function so the radiation must be different".

The last quote is a good summary of the others; it seems that salient aspects of the use of radiation (curing, making pictures) are important for pupils as they draw conclusions about the nature of different kinds of radiation.

Other examples relate to the *absorption* of radiation. Some pupils assume that radiation will remain in food "that is why it is not safe to eat" or "as there are a lot of protests against it". Another one assumes that some radiation will pass through a screen "as they wear lead clothing". In another interview a pupil reached the opposite conclusion: according to him/her nothing would pass through the wall of a container filled with radioactive waste as "otherwise the containers would be useless". These pupils draw conclusions based on protests or on trust in safety measures.

A further set of examples deals with ideas about the *duration* of radiation or radioactivity. Many pupils conclude that X rays work only for a short time as an X-ray picture is quickly taken. So their reasoning is based on personal experience of this diagnostic procedure. Radiation to treat cancer, however, works longer "as all the cells have to be killed" but not *very* long "as people have to be irradiated several times". Here the function of the radiation and knowledge about the therapeutic procedure play a role in drawing conclusions.

The final examples all deal with the *risks* of radiation. Reasons which pupils give for considering a certain application of radiation dangerous include:

"X rays must be dangerous as my mother and the nurse had to stand behind a special window"

"apparently it is more dangerous besides the beam [of X rays] than in the beam" [as nurse has to stand behind screen and patient not]

"if it [irradiation of food] happens in a room like that they couldn't say it is not dangerous"

"rather tricky, if you see what is required to keep it from the open air"

"if you look at how the workers have to be protected with special clothing, it could not be right for an apple to receive a dose of radiation".

These pupils conclude from the existence and nature of safety measures that there must be something dangerous about that kind of radiation.

Others take the opposite view about the risks of applications of radiation using the following arguments:

"you don't notice anything so it [X rays] cannot be bad"

"natural radiation has always been with us and I never had any trouble with it"

"otherwise they wouldn't do it [irradiation of food]"

"otherwise they wouldn't use it [building materials]".

These pupils use two kinds of arguments to defend the safety of an application of radiation. One is that they have no personal experience of it, perhaps meaning that they never heard of any hazards associated with it. The second argument is that if anything is done there must be a good reason for it. These pupils rely on the wisdom of experts who work with the radiation or on official safety measures.

All these quotes about hazards and safety indicate that pupils do not really weigh aspects of risk and safety. For them current practice is unproblematic: there is no reason to apply any scientific knowledge.

In summary, in many pupils' answers we detected forms of reasoning which we could label as 'common-sense reasoning'. Pupils draw conclusions which seem logical to them as they are based on the uses of radiation, on personal experience or on the existence of safety measures or protests about safety. One could argue that this kind of reasoning is a function of the context of the interviews, in which an expert (the interviewer) asks questions about a field with which the respondents are not very familiar. So we cannot be sure whether the pupils had these opinions already or invented them on the spot in order to satisfy the interviewer or not to look too ignorant (McClelland, 1984). Although we do not deny that this is a problem, the number of occasions on which we found this kind of common-sense reasoning is quite large. So we feel justified in defending the hypothesis that this kind of reasoning is relatively common among pupils. It may be derived from common culture (Arca, Guidoni and

Mazzoli, 1983; 1984) and reflect a kind of natural thinking which drives behaviour within a context according to a purpose and which allows people to disregard selectively information (Guidoni, 1985) and to suspend doubts about the reality of the world (Schutz and Luckmann, 1974). This way of thinking may serve goals that are more important and fundamental than holding correct views about particular issues (Nisbett and Ross, 1980); such goals may be 'feeling safe', 'showing not to be afraid' or 'expressing one's distrust in experts in general'. If so, it is likely that this common-sense reasoning may seriously interfere with learning and especially with educational efforts to relate scientific knowledge to everyday life. More research is required to reveal the nature and importance of this way of thinking if we want "acquired knowledge to become flexible, comprehensible, organizable, applicable, sharable, i.e. useful, to the individual, to the group and to society" (Arca et al., 1983).

A reflection on the interviews

In this study we interviewed pupils of forms 4 HAVO and VWO in order to explore further their ideas and ways of reasoning about radiation and radioactivity. We have provided summaries of the results above and will reflect on the (educational) implications of the results in the final section of this chapter (3.5). We will now look back on the interviews and focus on the method and the validity of the results.

As regards the method, the following points were noted. Firstly, interviewing is very time consuming. The actual interviews and the draft transcription took relatively little time. Most time consuming was the word for word editing and checking of the draft interview transcripts (before the analysis it is not clear which quotes are important and must be recorded literally), and the analysis itself: a large number of interesting quotes were noted, and these had to be classified and interpreted. Secondly, teachers and pupils were very cooperative in this study. At some schools teachers even had to draw lots among pupils to decide who was to be allowed to participate in the interviews. It may be that the reward was attractive to pupils. Thirdly, the 300 pages of interview transcripts contain a much greater amount of interesting information than could be outlined in this chapter. For instance the interviews include dialogues between pupils which show a development of concepts. It would also be possible to analyze which verbs were used with which of the concepts, although it might be difficult to express these results in English and we may expect a number of such findings to be language-specific. The transcripts should remain available for analysis later on both these points.

The sample of respondents was too small to allow us to draw any reliable conclusions about the proportion of Dutch pupils holding certain ideas. There is, however, no reason to expect important differences if larger numbers of pupils were interviewed, as the main results of our interviews appear to be convergent, internally and with the results of our media analysis and of our Chernobyl questionnaire. From a larger number of interviews, we would expect only more idiosyncratic statements by pupils, mainly invented on the spot under the pressure of the questions posed. Those are not likely to be very persistent and therefore less important in relation to our educational aims.

3.5 EVALUATION OF OUR STUDIES ON LAY- AND PUPILS' IDEAS ABOUT RADIOACTIVITY, RADIATION AND RISK

Summary of results

In this chapter we have presented the results of four studies which were carried out in order to gain more insight into lay-ideas (especially pupils' ideas) about radioactivity and ionizing radiation.

In the news-reports about Chernobyl we detected a number of lay-ideas, especially about radiation, radioactivity, half-life, activity, dose, risks of radiation, radiation levels and safety measures. Many of these ideas seem to be related to the undifferentiated meanings ascribed to the terms 'radiation' and 'radioactivity'. In addition to this, evidence was found for the existence of negative associations with 'radioactivity' and 'radiation' in our culture. Both terms were often linked with notions of poison, death and disaster. This suggests that many of the lay-ideas fit into a mental model of radioactivity and radiation which has both cognitive and affective elements. A check on reports about other nuclear incidents showed that these lay-ideas in news-reports are not peculiar to the Chernobyl case.

In the second study we communicated with radiation experts about the occurrence and importance of lay-ideas, and about general characteristics of lay-ideas of radioactivity and radiation. Confirmation of the existence of lay-ideas was found, particularly as regards the terms 'radiation' and 'irradiation', and the risks of radiation and safety measures. New features were lay-ideas about the relation between nuclear reactors and nuclear arms, about the difference between radiation from natural and artificial sources, and about radiation in other contexts (medical and industrial).

Based on these lay-ideas a lay-framework was formulated consisting of three parts:

1. a general description of the differences between the frameworks of lay-people and experts;
2. prototypical lay-ideas about the risks of radioactivity and ionizing radiation, formulated in ordinary language;
3. characteristics of lay-ideas, described in the form of missing scientific ideas.

New insights from the Delphi-study are the cases which illustrate the influence of lay-ideas on risk assessment in specific circumstances. Most of these cases deal with excessive or ill-founded fear of radiation.

The third and fourth studies reported in this chapter dealt with pupils' ideas about radioactivity, ionizing radiation and risk in the contexts of

Chernobyl, medical use of radiation, radioactive waste disposal, food irradiation and background radiation, and with the meanings of terms. Differences and similarities between pupils' ideas in the various contexts were identified. Furthermore, pupils appear to attribute meanings to the terms 'radiation', 'contamination', 'radiation standards' and 'radioactivity' which differ from the accepted scientific ones.

As regards the meaning of 'radiation', we found many associations with other kinds of radiation, especially with light, but also with heat, radio waves and sound waves. Invisibility is a property which is acknowledged by almost all pupils. Some pupils seem to reify radiation by calling it a kind of gas ("radon"). A large proportion of pupils make distinctions between natural radiation, X rays and "radioactive radiation". They draw these distinctions partly from their ideas about differences in effects, partly from differences in function, of these kinds of radiation.

According to many pupils the propagation of 'radiation' is influenced by ventilation: this is seen as a means of preventing further accumulation of radiation in rooms where X rays are used, in factories where food is irradiated and in houses which are well insulated. Related to this view is the idea that radiation could be carried away by the wind (in the Chernobyl context). From a scientific point of view one might conclude that 'radiation' is then being used for 'radioactive substances'.

Many pupils lack the scientific idea of absorption of radiation. They seem to have 'conservation' ideas about radiation, which could be summarized as:

> when an object (such as food or a wall) receives radiation, the radiation will accumulate in the object; when the amount of radiation is large enough, the object will itself start emitting radiation.

So 'absorption' is confused with 'accumulation of radiation'. The same idea applies to people who receive radiation, a difference being that people are seen as living beings with some resistance: the body has some defence system which breaks down radiation as long as there is not too much.

In the light of this, it is to be expected that indiscriminate use of the terms 'contamination' and 'irradiation' will be very common. Many pupils speak of 'contamination' when someone or something has received a certain amount of 'radiation', sometimes specified as "a surplus" of it or "more than normal". A few pupils have the idea that irradiation makes something radioactive by making the atoms or molecules of the irradiated matter unstable, something which in fact could only occur if radiation with very high energies is used.

Analysis of the answers also showed that pupils seem to have different views on the meaning of 'radiation standards'. We recognized four distinct views:

a. a 'regulation' view, expressing the idea that standards are what the regulatory bodies consider to be acceptable; this would apply to contamination of food and air, and to irradiation of people;

b. a 'threshold' view encompassing the idea that there will be zero-risk below a certain standard level; the body is expected to be able to cope with small amounts of radiation;
c. a 'probabilistic' view in which the risks are seen as more or less directly proportional to the received dose; below the standards the risk is generally seen as small;
d. a 'distrust' view: standards are seen as meaningless as 'all radiation is dangerous'.

The term 'radioactivity' is often used in implicit and explicit ways to mean 'radiation'. So pupils spoke about "radiating", "releasing" or "emitting radioactivity" and defined 'radioactivity' as "radiation" or "an accumulation of radiation". We also found meanings which could be labelled as 'the source of radiation'. Here we refer to pupils' descriptions of "radiation emitting substances"; "particles"; "an atom of radioactivity", "having", "handing over" or "containing radioactivity". Very often effects of radiation were included in the definition of the term 'radioactivity': the pupils spoke of "dangerous" and "noxious".

Finally, in the interviews we identified forms of reasoning which we labelled as 'common-sense reasoning'.

A revised model to characterize pupils' frameworks

In section 3.2 (Table 3.4) we presented a list of characteristics of the framework of ideas which lay-people hold concerning radioactivity and ionizing radiation, based on the results of the Delphi-study among radiation experts. The list consisted of two parts: (A) dealing with lay-people's 'safety' ideas, (B) with missing scientific ideas. We will first focus on the former and compare this list with the results of the interviews with pupils.

In the interviews we found that not all pupils adhere the view expressed in characteristic A1 ('radioactivity and X rays are always dangerous'). It seems more realistic to distinguish two polar points of view about the safety of (applications of) radiation:

a. it is *safe*, as:
   - otherwise they would not use the radiation for this purpose;
   - the safety measures are sufficient;
   - I never suffered any consequences;
   - I have never heard of any safety problems.
b. it is *not safe*, as:
   - there are reasons for the protests;
   - if it was safe they would not need those kinds of safety measures;
   - not much is known about the effects in the long run.

Pupils who are towards the 'safe' end of this continuum seem to have a predisposition about safety which determines the way they deal with any information about the topic. In the interviews they use all kinds of arguments which are partly based on knowledge and partly attributions in line with their view, such as:

- the body can cope with small amounts of radiation: it has an appropriate defence system;
- radiation decreases as a result of natural causes;
- radiation can be stopped by lead sheets or concrete walls.

The other group of pupils is better described by characteristic A1. They tend to use their knowledge and interpret new information in such a way that it confirms their attitude towards radiation, using typical arguments like:

- the effects of radiation are very damaging: cancer, deformed children etc.;
- radioactive contamination is permanent: it never decreases to zero;
- radiation is very strong and can pass through anything.

Based on these observations from the interviews we would propose revising part A of Table 3.4 in such a way that we differentiate between these two groups of pupils (Table 3.8).

Table 3.8 Characteristics of two views about the safety of radiation

I Radiation is dangerous

1. radiation/radioactivity/radioactive matter is permanent: it never falls to zero and can accumulate in the body; in the event of contamination nothing can be done;
2. the effects of radiation/radioactivity/radioactive matter are always dangerous, leading to cancer and other serious consequences;
3. all radiation is dangerous, including X rays;
4. safety measures indicate how dangerous the applications are;
5. radiation standards have a very limited value as any quantity of radiation has a hazardous effect;
6. radiation is dangerous as it passes through anything;
7. radiation/radioactivity is dangerous as it cannot be observed by the human senses;
8. the detrimental consequences in the long run are uncertain.

II The dangers of radiation are limited

1. radiation/radioactivity/radioactive matter decreases in the long run; in the event of contamination, some measures can be taken;
2. a small dose of radiation will be broken down by the defence system of the human body;
3. X rays are very different from (radioactive) radiation and are less dangerous;
4. safety measures are effective in reducing the risks of radiation;
5. radiation standards indicate a safety level: below them it is safe;
6. radiation can be stopped by lead sheets and concrete walls;
7. radiation/radioactivity/radioactive matter can be measured;
8. a lot is known about the effects of radiation.

We have quite deliberately not formulated view II as 'radiation is safe'. We have not found any pupils who think that radiation is completely safe. The difference between the two views has more to do with the extent of their feelings about the control of radiation: on the first view hardly any control exists; the second puts more trust in experts and the safety measures taken.

Another difference between Tables 3.4 (A) and 3.8 is that in the latter elements of knowledge play a larger part. This seems a plausible interpretation as even pupils who have not received any substantial amount of formal education on this topic have some knowledge at their disposal which is used to defend their view.

A final difference is that the comparison between nuclear power stations and nuclear bombs has been left out. One reason is that this kind of confusion was not prominent in the pupil interviews. Secondly, one could argue that the consequences of an accident with a nuclear power station (which was one of the contexts used in the interviews) are in the long run comparable with those of an explosion of a nuclear bomb. Finally, these contexts are, perhaps, too specific to be taken into account in a characterization of pupils' ideas of radioactivity and ionizing radiation.

A final remark which seems appropriate here is that we do not wish to imply that all pupils could be easily classified into two groups along the lines of Table 3.8. We do expect, however, that a correlation exists between the various elements of both categories.

The second part (B) of Table 3.4 consists of a list of scientific ideas missing from the framework of lay-people.

The results of the studies presented in this chapter lead to some amendments of this list. Element B1 is confirmed but should also include 'radioactivity'. The second element might be better described as a lack of discrimination between 'absorption' and 'accumulation' of radiation. On element B3 we can conclude that the units are confused so it might be expected that the entities are also not distinguished by many pupils. The first part of element B4 is confirmed, the second discrimination was not found to be missing with pupils. Element B5 is not found but that may be because this element was not further investigated. We suggest deleting it as it is rather advanced and can be seen as incorporated in element B4. Element B6 was not found among pupils. It is likely that this is not an important lacking element: in view and in extension of Andersson's idea of an 'experiential gestalt of causation' (1986), one might assume that it sounds logical to pupils that the longer one receives radiation the more serious the effects will be. Element B7 was not found and can be seen as included in element B4. Finally, element B8 was disconfirmed: many pupils are well aware of the existence of radiation in the environment, though they are not very familiar with the nature and effects of this radiation (but that is part of other elements).

Not included in Table 3.4 (B) are some elements which were found repeatedly in the interviews, namely the lack of distinction between 'irradiation' and 'contamination', and between 'absorption' and 'stopping' of radiation.

We have therefore constructed a revised list of missing scientific ideas (Table 3.9).

Table 3.9 Missing scientific distinctions in pupils' ionizing radiation frameworks

1.	Between 'radiation', 'radioactivity' and 'radioactive substances'.
2.	Between 'irradiation' and 'contamination'.
3.	Between 'absorption', 'accumulation' and 'stopping' of radiation.
4.	Between 'activity' and 'dose', and their units.
5.	Between the effects of 'high' and 'low' doses of radiation.

Some final points of evaluation

If we look back on the general results of this chapter and compare them with the literature, the following points are striking:

a. pupils appear to have a large number of ideas about terms, processes and risks related to radioactivity and ionizing radiation; these ideas seem to serve purposes (Guidoni, 1985), especially to confirm notions of risk and safety, are at least partly context-specific (Schutz and Luckmann, 1974), encompass meanings which have imperceptibly shifted from scientific to common culture (Arca, Guidoni and Mazzoli, 1983) and seem to be socially influenced (Solomon, 1987), for instance by the media coverage of nuclear incidents (Eijkelhof and Lijnse, 1987; Eijkelhof and Millar, 1988; Millar and Wynne, 1988);
b. many pupils use undifferentiated concepts (e.g. of radiation, radioactivity, contamination) and slip from one meaning to another without necessarily being aware of it; they do not see the need to make distinctions; similar undifferentiated concepts have been reported from studies on children's ideas on other topics, such as force, energy, heat, temperature and light (Wiser and Carey, 1983; Champagne, Gunstone and Klopfer, 1985; Driver, Guesne and Tiberghien, 1985);
c. pupils show ways of thinking which seem to be rather general and not specific to the field of radioactivity and ionizing radiation; in these ways of reasoning, conclusions are drawn from the functions of appliances, the existence of safety measures and hear-say about protests (comparable to 'availability heuristics', Tversky and Kahnemann, 1974) or based on the degree of confidence in experts involved in current practices; this way of reasoning seems to serve preferences (Zajonc and Markus, 1982) and may discourage access to the realm of scientific thinking (Solomon, 1987).

The results suggest that an approach in which pupils' ideas are studied from the specific perspective of physics, as in the study by Riesch and

Westphal (1975) on the radiation transportation process, will face difficulties as pupils attribute alternative (different or undifferentiated) meanings to scientific terms and use context-dependent ideas. The pupils are unlikely to use a coherent theory about the world (Guidoni, 1985) and appear unaware of any need for consistency across situations (Champagne, Gunstone and Klopfer, 1985). One might therefore expect serious problems in interpreting pupils' answers.

The studies reported in this chapter were carried out with a view to the improvement of physics education. We postpone a discussion on the implications of these results for teaching as we first have to report the results of our studies which focussed on education itself (chapter 4). The educational implications will be discussed in chapter 6. Here we only answer the question: What might a teacher expect from his/her pupils at the start of a series of lessons about radioactivity and ionizing radiation in senior HAVO/VWO classes. Generally, the teacher might anticipate the following:

a. pupils are likely to be familiar with the existence of a number of terms such as 'radioactivity', 'radiation', 'dose', 'contamination' and 'irradiation'; however, these terms are unlikely to have scientific meanings for the pupils; instead they are likely to use alternative meanings which will be imprecise and will overlap each other;
b. pupils are not likely to be familiar with concepts such as 'half-life' and 'activity' or with units such as the 'gray', 'sievert' and 'becquerel';
c. pupils' ideas about the nature, propagation and riskiness of ionizing radiation are likely to be dependent on the context; it is likely that many of these ideas have a social origin;
d. pupils are likely to use forms of reasoning which tend to confirm pre-existing beliefs; some of these forms of reasoning may obstruct the application of scientific knowledge in assessing the risk of radiation in a particular context.

4. TEACHING AND LEARNING ABOUT RADIOACTIVITY, RADIATION AND RISK

4.1 INTRODUCTION

In the preceding two chapters we presented the results of our investigations outside the classroom. In chapter 2 we surveyed developments in the teaching of this topic at the curriculum level and we presented the views of radiation experts on the curriculum. In chapter 3 we identified a number of lay-ideas which pupils might meet in daily life and we presented our findings on pupils' ideas and ways of reasoning before they had received any substantial formal education on the topic of ionizing radiation, radioactivity and risk. The assumption was that these prior ideas which pupils held might interfere with the teaching and learning of this topic. In this chapter we will report and discuss the results of several studies in which we tried to obtain greater insight into the role of these lay-ideas in education and into factors which may influence this role.

Firstly, we examined current physics textbooks, as these are an important tool in the classroom. In this study we sought increased insight into the concepts covered and into the ways these concepts are introduced, with particular attention to meanings attributed to concepts, to the way lay-ideas occur and/or are dealt with, and to the extent of a risk approach in these textbooks.

Secondly, we interviewed teachers about their experiences with teaching about ionizing radiation and risk. We wanted to find out about their teaching experiences, particularly in dealing with lay-ideas and with the risk approach. In this way we expected to gain insight into the perceptions of teachers of this kind of teaching and into factors which should be taken into account when writing teaching materials and in teacher training.

Thirdly, we observed a series of lessons in which use was made of the PLON-unit *Ionizing Radiation* and recorded the interactions between pupils, and between teacher and pupils. This allowed us to observe education-in-progress and to draw conclusions about factors which may influence effective learning of this subject matter.

In our fourth investigation we studied the ideas of pupils in the final year of pre-university education (6VWO), after they had studied this topic, either through the PLON-unit or using another textbook. This should give us information on the persistence of particular lay-ideas, on apparent difficulties in learning scientific notions and on the influence of particular textbooks.

In the following four sections we will report our findings. In the final section of the chapter we will discuss these findings and draw some conclusions.

4.2 RADIATION, RADIOACTIVITY AND RISK IN DUTCH SCHOOL TEXTBOOKS

Introduction

In a constructivist approach to teaching and learning the teacher is expected to take into account the ideas pupils already have about a certain topic and the notions they have about specific phenomena, concepts and processes. Similarly, if one aims at innovation in education on a specific topic one should take into account those ideas which teachers have and current practices in teaching the topic. One factor which is likely to be important for current teaching practice is the content of school textbooks. For this reason we have decided to analyze school physics textbooks using the following research question:

> How do Dutch physics textbooks deal with the topic of ionizing radiation?

In the light of the general aim of our study we have analyzed the textbooks on the following points:

a. the coverage of context domains and concepts;
b. the meanings which are attributed to basic concepts;
c. the inclusion of, and emphasis on, lay-ideas;
d. the way they deal with risk aspects.

It was not our purpose to describe the treatment of this topic in all Dutch textbooks. A selection was made in order to include the most popular books and those which take a different approach to the topic. The following books were studied:

- *Natuurkunde op corpusculaire grondslag*, deel 4H (Schweers & Van Vianen, 1981): a revised version of the most popular book of the sixties and seventies, academic approach;
- *Systematische Natuurkunde*, deel D, voor bovenbouw VWO/HAVO (Middelink, 1980): the most popular book of the eighties, academic approach;
- *Scoop*, Natuurkunde voor de bovenbouw 5 HAVO (Biezeveld & Mathot, 1985), increasing popularity, academic approach but with more attention to applications;
- *Natuurkunde voor de vierde klas HAVO* (DBK-na, 1986), quite popular, academic approach, activity oriented, based on a differentiation model;
- *Ioniserende Straling*, bovenbouw HAVO/VWO (PLON, 1984), use restricted, thematic approach: based on a central question (section 2.3).

Coverage of context domains and concepts

Use was made of the results of the Delphi-study as described in section 2.4 of this thesis (Tables 2.8 and 2.9). Analysis of the textbooks on the use of context domains shows the following:

- background radiation is dealt with only in PLON and *Scoop*;
- medical applications are mentioned in a few sentences in most of the books; only PLON and *Scoop* pay attention to this context domain in other than a casual way;
- nuclear energy is treated in a quite detailed way in most of the books; however, most of the treatment concentrates on the working of the reactor and not on the emission of radioactive substances;
- most books omit the topic of radioactive waste or devote only one or two sentences to it; exceptions are DBK-na and PLON;
- fall-out of nuclear explosions is covered only in *Scoop* and PLON;
- tracers in scientific and technological research are mentioned in most of the books in only a few sentences; the same applies to other industrial applications of radioactive substances and ionizing radiation;
- immediate consequences of nuclear explosions are well covered by PLON and *Scoop*; others either ignore nuclear arms or mention only the fission and fusion processes in the bombs;
- radioactive substances in the emissions from coal fired power plants are not mentioned in any of the books.

On the other hand, most books give more than casual coverage of dating methods using traces of carbon-14 in archeological finds.

Our general conclusion is that most books are, like the current examination syllabus, not focussed on applications other than nuclear reactors. Exceptions are PLON and, to a lesser extent, *Scoop* which pay much more attention to applications: they are ahead of other methods in relation to the WEN-proposals for a new examination syllabus, not only in the texts but also in the exercises, which often have a realistic setting.

The subject-matter items from Table 2.9 can now be compared with the contents of the above mentioned books. The following conclusions can be drawn from this comparison:

- most items in part A of Table 2.9 (basic knowledge about atomic and nuclear physics) are found in all the books; an exception is the concept of activity, which is introduced only in PLON; some of the atomic and nuclear physics items are only touched upon in the PLON-unit *Ionizing Radiation* as these items are dealt with in other units of the PLON-curriculum (*Matter* and *Light Sources*);
- most items in part B of Table 2.9 (basic knowledge about radiation protection) are missing in nearly all books; exceptions are again PLON and *Scoop*; the PLON-unit covers all these items, except the dispersal of radioactive substances in the environment and the human body; *Scoop* deals, albeit much more concisely than PLON, with the items dose, interaction with living matter, the effects of radiation and the film badge.

So in most of the current physics textbooks, hardly any emphasis is given to radiation protection aspects. Therefore one might not expect that pupils are well prepared to assess risks of ionizing radiation after studying these books. Pupils working with *Scoop* are likely to be better informed about the effects of radiation but would not have become familiar with the nature and extent of radioactive contamination or with the potential effectiveness of a variety of safety measures. Pupils working with the PLON-unit are informed about a large number of radiation protection aspects in considerable depth. In the optional chapters 5, 6 and 7 especially, many items are introduced which are beyond the recommendations of the Delphi-study. However, in the light of these recommendations, more emphasis should be given to the dispersal of radioactive substances in the environment and in the human body.

These conclusions about context domains and subject-matter are not very surprising taking into account the history of teaching about the topic of radioactivity and ionizing radiation in the Netherlands (section 2.2), the contents of the current national examination programme (Table 2.4) and the aims of the Dutch physics textbooks we analyzed. Most of these textbooks were not written with the same aim as that of the PLON-unit: learning to assess risks of ionizing radiation. Rather they were written in order to prepare pupils for the national examinations, which might explain why contexts and items outside the current syllabus are scarcely included.

Meanings of concepts

In Table 3.9 we listed scientific distinctions which seem to be missing in pupils' ionizing radiation framework. Important concepts in this respect were radioactivity, activity, (ionizing) radiation, absorption and dose. We have added the concept of half-life as this is often related to several of the other concepts. Elaborating on this we analyzed the textbooks discussed above to identify which meanings of these key terms are to be found in them. We will present the results of our analysis for each of the main concepts in turn.

A. Radioactivity

In the textbooks we identified five different views on the concept of radioactivity. The first one (*phenomenon*) was found in several textbooks:

> "radioactivity is a process of disintegration of unstable nuclei" (Middelink, p.122, 129)
>
> "The Curies ... called this spontaneous radiating radioactivity" (Scoop, p. 218)
>
> "Radioactivity may be a natural phenomenon" (Scoop, p. 233).

A second meaning (*property*) was also found, but only once:

> "Radioactivity is a property of some nuclei which are unstable" (Scoop, p. 219).

As a third meaning we identified *strength* of a source. It is used synonymously with the concept of activity:

> "When at a certain moment 10^4 nuclei in a sample decay per second, we say that the radioactivity is 10^4 becquerel (Bq). A measure for radioactivity which is often still used is the curie..." (Scoop, p. 221)

"The radioactivity of the bars has decreased..." (DBK-na, p. 9.17).

The fourth meaning could be described as *radiation*:

"Natural radioactivity consists of α-, ß- and gamma-radiation" (Scoop, p. 244)

"radioactivity (the intensity of the radiation)" (DBK-na, p. 9.26).

Finally, also a fifth meaning (*radioactive substance*) was traced:

"When a large amount of radioactivity escapes from a nuclear power station..." (DBK-na, p. 9.19).

In only one of the books did we find a description of radioactivity which might lead to confusion between radioactivity and fission:

"The radiation discovered by Becquerel and the Curies, appeared to be very energetic. Molecules and atoms hit by this radiation fall to pieces. The fragments are charged: ions" (Scoop, p. 218).

It should also be mentioned that some books use the term 'radioactivity' but do not give a definition for this concept (e.g. PLON, DBK-na, Schweers & Van Vianen). It is left to the pupils to ascertain its meaning from the context.

Some other books do give descriptions or definitions but then use the term in different senses. An example is *Scoop* which uses the term 'radioactivity' with four different meanings.

B. Activity

In many of the textbooks (Middelink, Schweers & Van Vianen, DBK-na) the term 'activity' is avoided. It is used only once by *Scoop* ("the activity decreases", p. 221) but no clarification of the meaning is given. This book instead speaks of "the strength of a radioactive sample" (p. 244) or uses the term 'radioactivity' to denote activity (see above). It is not clear in this book what is exactly meant by 'strength' whether it is 'activity' or 'intensity of radiation'.

The only book which defines the term uses the following words:

"To indicate the strength of a radioactive source we use the term activity. It is defined as the number of nuclei which decay in one second (or the number of disintegrations per second)" (PLON, p. 14).

The unit curie is defined only in PLON; the unit becquerel was found in *Scoop* and PLON.

C. Half-life

We have identified four different interpretations of the term 'half-life'. The first one refers to *the number of atoms which decay or survive* in a given time interval and is found in all the textbooks:

"the period in which half of the number of nuclei has decayed" (Middelink, p. 132)

"the period in which half of a large number of radioactive particles has decayed" (Schweers & Van Vianen, p. 149)

"after 16 seconds half of the xenon nuclei have been transformed into

caesium-140 nuclei. The period of 16 seconds is called the half-life" (DBK-na, p. 9.18)
"after 14 days half of the radioactive nuclei have decayed. We call this periode the half-life... After n half-lives the number of active nuclei is still $(1/2)^n$ of the original number" (Scoop, p. 220)
"The number of non-decayed nuclei is halved every 8 days. We call this period of time a half-life" (PLON, p. 14).
Most books introduce this meaning in a general way. *Scoop* and PLON start with an example of a specific nuclide and define half-life using this example.

The second interpretation refers to the *decrease of activity*. The following sentences were found:
"The half-life of a radioactive isotope is the time in which the strength decreases to half of its original value" (Scoop, p. 244)
"In 16 seconds the number of nuclear reactions of the xenon isotope is halved" (DBK-na, p. 9.18)
"The activity depends on the number of undecayed nuclei. So it is halved after a period 1τ" (PLON, p. 14).

In a third interpretation it is the *decrease of radiation* which is emphasized. Examples in the textbooks are:
"the period in which the number of particles emitted by a radioactive substance per second is halved" (Schweers & Van Vianen, p. 149)
"the period after which the intensity of the radiation is halved" (Middelink, p. 132)
"In 16 seconds the quantity of radiation which appears with these disintegrations is halved" (DBK-na, p. 9.18).

A fourth interpretation (*degree of stability of a particular nuclide*) was also found in the set of textbooks we studied:
"the degree of instability is determined by the half-life" (Schweers & Van Vianen, p. 149)
"a measure of the stability of its nuclei: the larger the half-life the more stable the nuclei" (Middelink, p. 133)
"a measure of the rate at which the nuclei of that isotope decay" (DBK-na, p. 9.26)
"a measure of the speed of the process of radioactive decay" (PLON, p. 14).
We noticed that most of the books give two or three interpretations of the term 'half-life'. Often, however, the relationship between the different interpretations is not clarified and is sometimes even obscured by using undifferentiated terms such as 'strength of a source' and 'intensity of radiation'.

D. Radiation
Most of the textbooks analysed use the term 'radioactive radiation': DBK-

na, Middelink and Schweers & Van Vianen. Radiation experts have expressed their strong objections to this term in Dutch textbooks for linguistic, scientific and educational reasons (Eijkelhof, Klaassen, Lijnse and Scholte, 1987). In *Scoop* and PLON this term is avoided and terms such as 'ionizing radiation' and 'nuclear radiation' are used instead. Neither of these books, however, explain why the term 'radioactive radiation' might be misleading.

A specific interpretation of the term 'radiation' was found in *Scoop*. The book states, after its introduction of α-, ß- and gamma-radiation:

"The radiation of radioactive elements cannot be influenced" (p. 219), probably meaning here the process of emission of radiation, and not the radiation itself, as the radiation itself can certainly be influenced by absorbing materials and (in the case of α- and ß-radiation) by electric and/or magnetic fields.

A similar quote was found in Middelink:

"the intensity of the radiation can definitely not be influenced by external conditions" (p. 133).

E. Absorption

The term 'absorption' is avoided by most of the textbooks. *Scoop* instead uses expressions such as "is stopped by" or "is slowed down by" when dealing with the properties of nuclear radiation. In some books (*Scoop*, Schweers & Van Vianen) the term 'absorption' appears only in the exercises.

PLON often makes use of the term 'absorption' and states that:

"the rate of absorption is dependent upon the number of collisions with the nuclei of the medium, and the energy transfer per collision" (p. 15).

None of the books pays any attention to what happens to the α- and ß-particles themselves. This may leave lay-ideas about conservation of radiation undisturbed.

F. Dose, dose equivalent and its units

Many of the books avoid the term 'dose'. *Scoop* defines the concept of dose as:

"the number of joule per kg tissue" (p. 242).

No units are given. DBK-na states:

"the amount of radiation absorbed by human tissue is expressed in millirem" (p. 9.17),

ignoring the mass of the absorber and choosing not to differentiate between dose and dose equivalent. Only PLON (p. 15, 19) makes a distinction between these two concepts.

Inclusion of and emphasis on lay-ideas

In this section we will present the results of our attempt to identify examples of lay-ideas in the textbooks. These are ideas which are exactly like or strongly resembling the non-scientific ideas found in the newspapers and among pupils.

Not surprisingly, the number of clear lay-ideas in the textbooks is quite small. Many of the lay-ideas discussed in chapter 3 of this thesis were not found in the books. Writers were able to avoid them, probably because the non-scientific character would have been obvious to them. These lay-ideas would be seen as 'mistakes'.

However, a number of quotes will be presented which illustrate that some lay-ideas even exist among authors of school textbooks.

1. Contamination and irradiation

Middelink describes very briefly some applications of "types of radioactive atoms". One of the applications is the conservation of food:

> "A nutrient could be sterilized by adding to it a very small amount of radioactive substance: the radiation from it kills germs. In this way the sprouting of potatoes could also be prevented" (p. 138).

In this quote it is suggested that the food is treated by adding radioactive matter and not by irradiation from an external source. Such statement might be expected to confirm the idea held by many pupils, namely that the food itself becomes radioactive as "some radiation remains".

The same author (Middelink) uses the term 'radioactive contamination' only rarely. Where he does so no definition of it is given:

> "Obviously one has to handle radioactive substances very carefully and one must try to prevent 'radioactive contamination'. Therefore a radioactive substance is kept in a lead box of which the walls are so thick that even gamma-radiation is fully absorbed" (p. 123).

By stating that gamma-radiation is fully absorbed it is suggested that contamination would occur when this radiation is not absorbed.

A similar confusion between contamination and irradiation is promoted in DBK-na:

> "human beings who are 'contaminated' by the radioactive radiation" (p. 9.7).

2. Safety-level of X rays and nuclear radiation

In one of the books (*Scoop*) some quotes suggest that X rays bear no risk if one remains below a certain level:

> "X rays are dangerous if you receive too much of it" (p. 56)
>
> "TV-screens are bombarded by electrons which results in the emission of X rays. At about 15 cm distance you hardly notice anything" (p. 56).

We recognize here a 'threshold' idea of the radiation risk. The same idea is found in this book in the description of the effects of radiation in the context of 'nuclear bombs':

> "The damage to the body depends on the received dose (number of joules per kilogram tissue). A small dose results only in a temporary decrease in the number of white blood cells. The next steps are: reduced resistance towards infections ..." (p. 242).

At the same page the authors state:

"Especially with small doses it may take years before the hazardous consequences emerge".

It is not made clear what these consequences might be and how this latter statement and the former one relate to one another.

3. Distinction between radiation and radioactive substance

In DBK-na the authors describe the working of a GM counter by using the term "radioactive particle":

"When a radioactive particle enters the tube by passing through the thin window, it ionizes a number of gas molecules along its path"

"After this, a new radioactive particle could be counted"

"So a GM counter counts individual radioactive particles" (p. 9.9).

We may assume that the authors have in mind α-particles, ß-particles and gamma-photons. The use of the term "radioactive particle" suggests that a radioactive substance is entering the tube, thus promoting the lack of distinction between 'radiation' and 'radioactive substance'.

So far we have reported some lay-ideas which have been included unintentionally. Another way of including lay-ideas is to use them deliberately for educational reasons, for instance to discuss the differences between these lay-ideas and scientific ideas. In none of the books we studied did we find examples of this use of lay-ideas.

Risk aspects

Even though the radioactivity and X rays chapters of the physics textbooks are not based on a risk approach (except the PLON-unit *Ionizing Radiation*) they often include aspects of risk and safety. In this section we will analyze the same Dutch physics textbooks, now on the way they deal with risk aspects. The PLON-unit is not given special attention here as the risk approach of this unit has been outlined already, in section 2.3.

Middelink (1980) pays scarcely any attention to risk aspects. The risks of nuclear radiation are completely ignored. Pupils are assured that all radiation from a nuclear reactor is absorbed by concrete and steel walls. Only in the topic 'X rays' do we find one sentence about the biological effects of this kind of radiation and about the possibility of treating cancer with X rays. It is stated that preventive measures are required and that safety regulations are therefore strict.

Schweers & Van Vianen (1981) refer to radiation risk in relation to several context domains. On X rays the effects of lengthy irradiation are mentioned, especially on the pioneers in this field. According to the book people became more careful with this kind of radiation after the explosion of the atomic bombs above Japan in 1945. Now strict safety rules are obeyed and the use of X rays for examining living beings is restricted to those situations where it is necessary.

On nuclear reactors the book refers to the hazards of releasing radioactive substances through cracks; the accident at Harrisburg is mentioned. However, as regards this kind of accident, "chances are very small and will certainly diminish further". On the other hand it is acknowledged that radioactive waste with long half-life from nuclear reactors forms an unsolved problem.

This book also gives some attention to nuclear weapons and raises some moral questions: "In fusion bombs such gigantic amounts of radioactive radiation arise that these weapons could destroy humanity. Conclusion?!".

DBK-na (1986) deals quite extensively with the risks of nuclear reactors. Of the nineteen performance objectives formulated at the start of the chapter on nuclear energy, two refer to risks:

"18. You should be able to mention the risks associated with a nuclear power station.

19. You should be able to indicate which problems are involved in the reprocessing and storage of nuclear waste."

Points are made about:
- violent clashes between police and demonstrators near a nuclear power plant;
- the controversial public discussion on the future of nuclear energy in the Netherlands, related to potential accidents and their effects for man and the environment, to the storage of nuclear waste (long lasting isotopes) and to increases in price because of expensive safety measures;
- reasons for safety measures: prevention of attacks by terrorists, of theft of Pu-239, of escape of radioactivity (e.g. at Sellafield) and of terrorists' attacks on transport of nuclear materials.

The explosion of the nuclear bombs in Japan (1945) is mentioned: "people are still dying as a result of the radioactive radiation which arose from the explosion of the bombs".

Scoop (1985) could be labelled as the most risk oriented of this set of four books. On X rays it is said that they are hazardous if you receive too much, and that at 15 cm from TV-tubes you can hardly detect anything of the X rays which are released.

On the risks of radioactivity we find the following general points:
- "radioactivity has a bad name and is often seen as an unwanted product of modern physics. This is partly justified";
- need for preventive measures associated with the use of radioactivity;
- ionizing radiation cannot be felt or smelled and consequences are only detectable later (after hours or many years);
- effects on pioneers (Becquerel, Mme Curie);
- stringent demands regarding certain organs;
- children and pregnant women extra vulnerable;
- problems of contamination by ã-emitters (radium painting);
- use of film badges.

As regards the risks of nuclear energy, the idea that there is not yet a satisfactory solution for radioactive waste is briefly mentioned.

Much more attention is paid to the consequences of nuclear arms explosions:
- number of immediate victims of the bombs on Hiroshima and Nagasaki in 1945;
- the effects of fall-out, with effects at longer distances and longer lasting: "even today people in Japan are still dying as a result of the bombs in 1945";
- specific effects of the neutron bomb.

Although many risk aspects are touched upon in the book this is only done in a narrative way. In the exercises hardly any questions about risks of radiation are included. So it is not clear what the pupils are supposed to know about risk aspects after the relevant chapters in the book have been studied.

Conclusions and discussion

The analysis of the textbooks indicates that a number of changes in the content of textbooks are required if one's aim is to promote pupils' ability to analyze and assess the risks of ionizing radiation. The WEN-proposals are likely to provide a reason for changing chapters in the physics textbooks dealing with the topic of ionizing radiation. However, one could imagine a number of approaches in which the required context domains are simply mentioned, keeping the risk aspects to a minimum.

A second conclusion we might draw from the results is that radiation concepts are defined and used with a large variety of meanings. For instance we identified five different meanings of radioactivity and four of half-life. Some of these meanings blur the distinctions between scientific concepts, for example, between:
- 'radioactivity' and 'activity'
- 'radioactivity' and 'radiation'
- 'radioactivity' and 'radioactive substance'
- 'activity' and 'radiation intensity'
- 'dose' and 'dose equivalent'.

This is, however, not specific to school textbooks, as a similar variety in the usage of some of these concepts has been detected in comparing scientific dictionaries, such as McGraw-Hill (1971, 1974), Van Nostrand (1976), Winkler Prins (1977), CRC (1985) and Barnhart (1988) (Eijkelhof, 1989). Some of this variety can be attributed to careless formulations. It should also be recognized, however, that scientific concepts are too complex and rich to be comprehended by a single definition (Ravetz, 1971) and that a definition is always incomplete (Polanyi, 1958), partly because a concept is involved in an immense network of relations with other concepts (Johnson-Laird, 1983; Pines, 1985), and partly because a definition can be understood only by those who are familiar with the situation in which the concept has a function (Polanyi, 1958).

Some school textbooks use several meanings of a concept, often without clarifying the relation between them or the conditions under which each interpretation is valid.

A third conclusion is that the number of explicit lay-ideas found in the textbooks is limited. The ones we traced regard the irradiation of food, the nature of contamination, a threshold idea of radiation risk, and confusion between radioactive particles and radiation. We suggested that this might be explained by the expertise of the authors and their editors in detecting 'mistakes'. Another reason might be that many of the books are very limited in their treatment of applications and the risks of radiation, focussing on the pure physics aspects.

A fourth conclusion is that the amount of attention given to risk aspects in the four non-thematic books we investigated varies a great deal. The problem of radioactive waste from nuclear power stations is mentioned in most books. DBK-na presents most information about the risks of nuclear power stations whilst *Scoop* focusses mainly on the general hazards of radioactivity and on the effects of nuclear bomb explosions. Only DBK-na contains a number of exercises about risk and safety aspects, which may be expected as the book contains some performance objectives related to this. In the books which pay least attention to risk aspects, we find the most reassuring statements, for instance about the effectiveness of reactor shielding, the ever diminishing chance of accidents in nuclear power stations, the existence of strict safety measures and the use of X rays only when essential.

Most books suggest that X rays are less dangerous than nuclear radiation. None of the books deals with principles of radiation protection, the concept of risk, risk comparisons or risk evaluation.

What are the implications for educational innovation which can be drawn from this analysis of physics textbooks? Firstly, one might expect that in most schools which do not use the PLON-unit *Ionizing Radiation* the attention paid to questions of risk and safety is minimal. This suggests that some specific in-service training of teachers will be required, now that the new physics syllabus for HAVO and VWO (WEN, 1988) has been adopted, containing a number of concepts related to risk.

Secondly, as none of the textbooks deals explicitly with lay-ideas and as several basic concepts are dealt with in a confusing way, one might conclude that the books do not deal adequately with these lay-ideas, despite the fact that only a few erroneous lay-ideas are introduced unintentionally. Recommendations for improvement will be made in chapter 6 of this thesis.

4.3 EXPERIENCES OF TEACHERS WITH THE PLON-UNIT IONIZING RADIATION

Introduction

In section 2.3 the contents of the PLON-unit *Ionizing Radiation* were described as being the only Dutch senior physics textbook which deals with this topic in a risk context. Experience with the second version of this unit dates back to 1984. Pupils' opinions and learning related to the unit were also reported in section 2.3. But what do teachers think about the unit? What teaching problems do they face? How do they feel about the risk approach? Do they take pupils' ideas into account? Answers to these questions could expected to be useful as they might elucidate some teaching problems related to the general aim of our study, give indications for teacher training, lead to suggestions for writing new teaching materials and result in the detection of new problems which need further exploration.

In the following section we report our findings of a series of interviews with seven teachers who had two or more years of experience with teaching the unit *Ionizing Radiation.*

Research procedure

This study was based on the following research question:

> What is teachers' experience of teaching the topic of ionizing radiation in a risk context?

The aim of this study was to get more insight into the teaching problems which arise when ionizing radiation is taught within a risk context. The main focus of the interviews was teachers' experience of the risk approach adopted by the unit and with the ways these teachers dealt with pupils' lay-ideas.

Since the writing of the second version of the unit, in 1984, the unit has been used in at least twelve schools. In February 1988 we sent a letter to a representative sample of seven teachers at different schools, asking them to participate in this investigation. We included a list of the main questions to be asked. All the teachers we approached agreed to an interview. The seven interviews were held in the period 21-31 March 1988 by one of the researchers, mainly by telephone, partly face-to-face. Table 4.1 (p. 116) contains some information about the participating teachers.

The interviews started with collecting some factual information as shown in Table 4.1. In the subsequent questions the following points were raised:

- general opinion of the unit;
- general problems with teaching the unit;
- emphasis on risk aspects during teaching;
- learning problems of pupils and teaching difficulties;
- attention given to preconceptions of pupils.

Table 4.1 Some information about the teachers interviewed

school	town	number of years of experience with the unit at HAVO	VWO
Eemland College Noord	Amersfoort	3	3
S.G. Oost-Betuwe	Bemmel	1	1
C.S.G. Revius	Deventer	3	-
C.S.G. Jan van Arkel	Hardenberg	3	1
C.S.G. G. Farel	Ridderkerk	3	2
Niels Stensen College	Utrecht	4	3
Christelijk Lyceum	Veenendaal	4	-

During the interviews the interviewer made notes which were written up in full immediately after each interview. Further analysis was based on these elaborated notes.

Results

A. Points of appreciation

The unit is generally highly regarded by the teachers. Some reckon the unit among the best of the PLON-units. The following points were raised regarding this matter:

- the unit deals with an actual theme: the relation of the unit to reports in the newspapers about developments in real life are obvious;
- the unit takes advantage of the questions which pupils have about radiation. Some teachers reported that pupils still had questions about the Chernobyl accident. Several teachers attributed the involvement of pupils to this anticipation of pupils' questions. This involvement was particularly clear when dealing with the effects of radiation on the human body and with health applications of radioactivity and ionizing radiation. Pupils' involvement was reported to be less with nuclear energy (less topical in 1988 and to some extent familiar to pupils due to lessons in junior physics education) and with nuclear arms (not all pupils liked this topic);
- the unit makes pupils more aware of the nature and size of the risks of radiation: they learn to distinguish between situations in which fear of radiation is justified and those where it is not, and to deal with various sources of radiation. Teachers considered this to be useful everyday coping knowledge;
- the unit offers an orientation on further education and future occupations, especially in the medical sector. Some teachers mentioned examples of pupils who chose a radiological training after studying the chapter on medical applications.

B. General teaching problems

All points mentioned under the previous heading were common to many of the teachers and therefore the various points of appreciation could be labelled as the common view. Far more variety of opinion was found about the problems which teachers experienced with teaching the unit. We have categorized these according to the sets of chapters in the unit (Appendix B).

- *Core chapters* (2-4): some teachers found that chapters 2 and 3 deal with a large number of concepts, units and effects. According to them, the information density is high and for pupils it is difficult to recognize which of the information is essential to know and which is added as illustration. These teachers had no suggestions for cutting the content but would appreciate the inclusion of tables with concepts, units and effects to assist pupils to acquire an overview of the field.

  Various teachers reported that the contents of chapter 3 (about radiation effects) was mainly new to them which meant that considerable time for preparation was required when they first taught the unit.
- *Optional chapters* (5-7): several teachers made remarks about this group of chapters. One teacher regretted that health applications are mainly dealt with in the optional chapters. He found this topic so important that he would like the whole class to study it. A limitation would be that hospitals are not able to cope with a visit by a whole class of pupils at once.

  Another teacher was not happy with the topic nuclear arms in the optional period. He argued that, due to the large scale effects of nuclear explosions and the strategic aspects involved, risk assessments in this field are quite different from those in the fields of nuclear energy and health. Both the latter risks are also more part of the life-world of pupils. According to him, nuclear explosions are detested by all pupils and in the discussions on nuclear arms non-physics arguments are mainly used.
- *Chapter 8*: only one teacher spontaneously mentioned teaching problems with this final chapter. He tried to teach the chapter several times but never to his satisfaction. The main problem was that he could not get pupils involved in a discussion: questions posed were just answered with a plain "yes" or "no" and no further arguments were given. His pupils seemed to think that some situations on which they are asked to make assessments would never happen to them or that a doctor's advice should not be questioned.

C. Aspects of risk

From the answers of the teachers it is difficult to assess how much attention in their lessons is really given to aspects of risk. However, it is clear that they use different approaches. Some teachers do not bring in the risk aspects themselves but wait until the pupils come up with questions on this. Of those some reported that pupils did not have many questions, but others stated they always do or that it depends on the class. Other participating teachers, however, declared that they are personally interested in the risk aspects and find this a very important point in education. These teachers do not wait and see, but put forward questions of risk deliberately, for instance by selecting some relevant exercises from the unit.

In the unit itself, most attention is given to risk in the chapters 1, 3 and 8. One teacher starts teaching chapter 1 by discussing personal experiences of the pupils with X rays and radioactivity, then finding differences between practices of dentists regarding the use of X rays. In chapter 3 the topics of the ALARA-principle and radiation levels often give cause to discussions about risk.

One teacher reported getting many questions from pupils about the pros and cons of radiation sources (chapter 4), particularly in relation to nuclear energy. On this topic he usually finds more differences of opinion between the pupils than on nuclear arms and health applications.

Chapter 8 is passed over by most teachers, either sometimes or always. Arguments given are:
- shortage of time;
- risk aspects are well enough covered in other chapters of the unit: the chapter is a kind of summary and contains nothing new;
- difficult to get pupils to undertake serious risk assessments;
- teacher doesn't know enough about risk assessment himself;
- risks to be discussed are of a very different and not easily comparable nature and size.

Only one teacher reported very positive experiences with the chapter. In his view it is a very important chapter and he tries to spend two lessons on it if time permits. One of his methods is to ask pupils to formulate statements of opinion related to their experiences with the optional investigations, for instance after a visit to the radiological department of a hospital.

One teacher discusses the risks of radiation when he prepares the pupils for the practicals of the mobile centres (Heij and Hooymayers, 1980). Some pupils are a bit scared of the practicals: they would like to avoid them. He sometimes spends half a lesson on this discussion, often ending with some safety measures such as not eating and drinking during the practicals and washing hands afterwards. After these discussions so far nobody has refused to do the practicals.

Finally, one teacher acknowledged that his pupils are very much geared towards the final examination and consider anything which might not be examined (e.g. risk aspects) as less important.

D. Specific teaching and learning problems

Four of the teachers established problems with pupils in dealing with the large number of concepts and units they find in the unit. The units are especially mentioned: becquerel, curie, sievert, gray, rem and rad. One of these teachers draws a scheme on the blackboard, distinguishing between concept, unit and detecting instrument.

Other concepts and processes which are difficult for pupils according to one or two teachers:
- the distinction between α-, ß- and gamma-radiation;
- the concept of radiation dose: energy absorbed per kilogramme;
- differences between properties of the source and of the receiving object;
- the medical terms somatic, genetic, mutation, leukaemia and tumour;
- local damage by α-radiation in case of internal radiation;
- damage by gamma-radiation, as most of this radiation leaves the body;
- dose limits for various parts of the body;
- radioactive 'cow';
- calculations about fission reaction equations.

Two teachers mentioned no specific learning problem.

E. Preconceptions of pupils

Two teachers were not familiar at all with pupils' preconceptions on radiation. One of them claimed that his pupils know only a little about radiation beforehand and have afterwards hardly any problems with the concept of radiation. The other one acknowledged having no idea about pupils' representations beforehand and therefore not knowing what changes the unit accomplishes in this respect.

The other five had some ideas about pupils' notions, e.g. not being able to make a distinction between radioactive matter and radiation. Two of them mentioned explicitly that they only realised the existence of this problem after their sixth form pupils completed a questionnaire for one of our studies (reported in section 4.5).

Two teachers bring up pupils' notions in the orientation of the unit (chapter 1), for instance:
- by asking what they mean by 'radiation'; the experience was that pupils started disagreeing immediately and it posed some problems dealing with the discussion without anticipating ideas in the rest of the unit;
- by asking if they would buy a packet of irradiated fruit juice; a typical answer is "no, because it contains radiation"; the teacher then made a comparison with light which does not remain after irradiation.

Other teachers only deal with pupils' preconceptions when they notice them, for instance if pupils claim that X rays remain in the body or that radiation is taken away by the wind. Others deliberately initiate discussions on preconceptions, assuming that pupils will not lose these ideas at once and that recurrent attention is required. Two of them do this for instance by discussing the afore mentioned sixth form questionnaire or by trying to detect contradictions in pupils' reasoning during discussions. One teacher claimed to be satisfied with activities of this kind this year as the class was cooperative and interested in the topic. He feared that with other, noisy classes or with other, less interesting topics it might be more difficult to give attention to pupils' notions.

Another teacher noticed after teaching the unit that pupils still feared irradiated food: according to him they apparently were still unable to make a distinction between being irradiated and containing radioactive substances. And finally, one teacher had only recently noticed that one of the most popular Dutch physics textbooks states that radioactive substances are added to food (see section 4.2); previously he had overlooked this point.

Conclusions and discussion

The teachers who took part in the interviews had taught the unit *Ionizing Radiation* at least twice (on average more than four times). So we might expect that at the time of the interviews most of their initial problems with the unit had been solved. So the difficulties they report might be seen as structural to the contents and the teaching approach of the unit.

The teachers appeared to be relatively satisfied with pupils' motivation to learn about this topic. This confirms earlier findings on the unit (Wierstra, 1984; Eijkelhof and Wierstra, 1986; Jörg and Wubbels, 1987). The main problems with teaching the topic ionizing radiaion in a risk context could be summarized as follows:

A. Number of concepts and units

This regards concepts such as activity, half-life, radiation dose, dose equivalent, types of radiation, effects of radiation and units such as becquerel, curie, gray, sievert, rad and rem. Cutting the number of concepts and units is not recommended by any teacher, as they are all recognized as being important. One teacher suggested including a table with concepts and units. We do not deny that such a table might be useful but in our view it is not likely that a table in itself would solve the problems of confusion regarding the meaning of the various terms. We would recommend paying more attention to the relation between the various terms. In chapter 6 we will elaborate this point.

B. Risk

Teachers are generally satisfied with the way the unit deals with risk aspects and have no suggestions for improvement. An exception is chapter 8 (on evaluation of personal and social risks), which is often discarded. Teachers attributed this to time constraints, but also to perceived redundancy of the chapter. However, the chapter does contain risk aspects which are not covered in other parts of the unit, namely the distinction between personal and social risks, the concept 'acceptable risk' and risk assessment procedures. Apparently, the present approach of these risk aspects does not appeal to most of the teachers.

From the interviews it is difficult to draw definite conclusions about the reasons behind this. Possible explanations might be: feelings of insecurity on the part of the teachers, too high demands made on the pupils or too strong a socio-political flavour (not recognized by pupils and teachers as being part of science). The first point should be tackled by in-service teacher training, the second by improvement of the instructions for the pupils' tasks and the third by making more connections between the exercises of this chapter and the scientific contents of earlier chapters.

C. Preconceptions of pupils

A majority of the teachers had taken notice of earlier results of this research programme. This should not be seen as indicative of the familiarity of all teachers with this kind of research as the teachers working with PLON-units generally keep better track of research carried out as a follow-up of the work in the PLON-project.

As may be expected it appeared that teachers who have been informed about this kind of research do recognize more of these ideas with their pupils. Such a recognition is a prerequisite for taking into account the preconceptions of pupils in the physics lessons. Some teachers already attempt to give attention to these preconceptions in class discussions, but not systematically. This is not surprising as in the unit itself pupils' notions of this kind are ignored.

We conclude this chapter with some remarks about the scope of this investigation. The method of interviewing teachers mainly by telephone appeared to be useful. Experiences with PLON-teachers in the past were that questionnaires are often not returned and those which were completed contained often concise answers. By sending teachers the main questions in advance, the respondents were able to prepare themselves for the interview. Although the number of respondents was small, we assume to have received a representative picture of the opinions of teachers about using the unit *Ionizing Radiation* in the classroom.

It should be recognized, however, that the interviews did no go very deep on the following two levels:

- learning problems
  We attribute this to the fact that the teachers are not in the position of researchers and judge the effects of the unit at face-value, missing out the extent and nature of some of the learning problems.
- risk aspects
  The teachers comment little upon the way risk aspects are dealt with in the unit. The way it is worked out in the book either suits them or not, but alternatives are not given. This is again not very surprising as they are no experts in this field and have not been able to assess various ways of dealing with these aspects in their lessons.

This lack of reflection by teachers about learning problems and risk aspects needs further attention in the light of the aim we have chosen for teaching the topic of ionizing radiation. In chapter 6 we will present some recommendations for dealing with this in the preparation of teachers.

4.4 OBSERVATION OF LESSONS

Introduction

In the previous section we reported the results of interviews with teachers. The interviews gave us better insight into the problems teachers face with teaching the unit *Ionizing Radiation*. An advantage of this interview method is that the experiences of a number of teachers can be taken into account. A disadvantage, however, is that teachers' reports have some limitations: they observe the lessons from their own viewpoint which is not exclusively directed towards the learning progress of pupils, as teachers are occupied with many things during teaching. Many teachers are also not skilled as observers of pupils' learning and are not familiar with the results of research on science teaching. And of course it is particularly difficult for teachers to reflect on their own role in teaching as they are fully involved in the lesson. So it is likely that teachers may miss problems in teaching and learning.

One way to detect problems which teachers may miss is to undertake classroom research where the emphasis is on what takes place in the educational setting. Observation of lessons is a method which has often been used in educational research, but in most cases the observations focus on points which are not content-specific.

Our focus in classroom observations was content-specific. With many colleagues in the science education research community (Osborne and Wittrock, 1983; Novak, 1988; Driver, 1988) we assumed that pupils in science lessons are engaged in constructing meaning, which implies often that they must *re*construct the ideas which have previously formed their views of the world. Examples of pupils' prior ideas on ionizing radiation have been reported in the previous chapter. In that chapter we also attempted to describe more general differences between the cognitive frameworks of lay-people and of experts. As regards the classroom setting we assumed that the teacher had a framework close to that of experts and that pupils had some ideas from the lay-framework. We were interested in the process of generation of meanings by pupils in the classroom, in the influence of preconceptions and in the role of the teacher in facilitating learning.

We therefore observed a series of lessons and analyzed some dialogue between the pupils and between pupils and teacher. In the following sections we describe the procedure followed in this study and report the results.

Research procedure

This study was based on the following research question:

> Which teaching and learning problems can be traced in classroom dialogue during lessons using the unit *Ionizing Radiation*?

As the unit was not written with a particular learning theory in mind and as pupils' preconceptions were not taken into account in designing the unit, it was decided to give this study an exploratory character. So no attempt was made to find out which teaching and learning problems occur in most classes and which in only some. We were more interested in the nature of the problems which could occur and in additions to the information which teachers reported in the interviews. With these considerations in mind we decided to follow a series of lessons in one class.

For practical reasons we followed the lessons in a school in the city of Utrecht. At this school we were allowed to carry out the investigation in a form 5 class with fourteen pupils in the HAVO-stream. An advantage of such a small class is that class discussions would be easier to record. A HAVO-class was chosen as we expected to find more learning problems in such a class than in a VWO-class. We asked a teacher who had several years of experience with the unit so that problems we observed would not be put down to inexperience with the unit. The teacher was not familiar with lay-ideas on the topic of ionizing radiation.

In January 1988 a series of ten sequential lessons were attended. This number is smaller than usual for a full series of lessons as, by mistake, the first two lessons had already been taught before the observations started and as the teacher realised during the lesson series that he was running out of time in view of the final examinations in May. So he shortened the series of lessons by reducing the period for studying the optional sections and by deleting the final chapter on risk assessment. The latter deletion is quite common as we have outlined in section 4.3. Apart from this, the teacher followed the book closely. His teaching style was quite didactic. Generally, he explained some of the theory in the book, answered pupils' questions and the pupils were then asked to work in small groups to solve the exercises in the book. Sometimes he summarized the theory in a chapter.

The lessons were recorded on videotape in order to facilitate the interpretation of the dialogue as non-verbal aspects would be recorded as well. Whenever the pupils worked in groups the camera was pointed at one particular group of pupils. This group consisted mainly of three pupils: Erik, Karin and Pauline; in some lessons they were joined by some others (Christiaan, Vincent and Tom).

After viewing all tapes it was concluded, as might be expected, that not all dialogue was equally interesting. Because of this and also due to time constraints only six excerpts of dialogue were transcribed as protocols. Those were the passages of dialogue which most clearly illustrated pupils' and teacher's struggling to bridge the gap between the lay- and the expert framework. Table 4.2 (p. 124) lists and characterizes the protocols.

Table 4.2 Characterization of the selected protocols

number	date	nature of activity	topic	length (lines)
1.	7-1	class discussion	theory Ch. 2	455
2.	11-1	class discussion	exercises Ch. 2	199
3.	12-1	group discussion	exercises Ch. 3	625
4.	13-1	class discussion	theory Ch. 4	170
5.	13-1	group discussion	exercises Ch. 4	119
6.	14-1	class discussion	exercises Ch. 4	370

For the analysis of the protocols we made use of the list of missing scientific distinctions as given in Table 3.9, as these distinctions are assumed to characterize the difference between both frameworks mentioned above.

Results

In this part we will present the results of our analysis of the six protocols. We have classified them according to the categories used in Table 3.9. At the end, some additional points are made which seem worth mentioning.

1. Distinction between 'radiation', 'radioactivity' and 'radioactive substances'.

In the protocols we find several statements by teacher and pupils which seem to illustrate the confusion between 'radiation' and 'radioactive substance'.

In the following remark the teacher gives the impression that radiation suspends somewhere:

> "So in this room and everywhere there is a certain quantity of radiation".

Some pupils' remarks point in the same direction:

> "if you work there [at a radiation department of a hospital] it is normal that the radiation will come to you from everywhere"
> "then all the radiations would have disappeared".

Similar remarks about 'radiation' concern the ideas of pupils about the propagation of radiation. A discussion on this topic arises when the pupils are trying to answer a question in the following exercise:

> "This poster can be found in the X-ray department of many hospitals. Explain why unborn children are very sensitive to ionizing radiation."

Karin assumes that it is possible to inhale radiation: she claims this three times in protocol 3. Erik claims that it is not possible to breathe in radiation as:

> "radiation propagates in straight lines, nearly straight, only with a little wave".

In the analysis of this part of the discussion it was useful to make use of a videotape of the discussion. The video-tape shows that Erik supports his statement by making a wave-like movement with his hands. Karin argues then that it might be possible to have your mouth open accidentally, suggesting that it would be possible to swallow the radiation. Subsequently Erik performs a mime to illustrate that one has to wriggle enormously in order to get the radiation into the stomach. From the rest of the protocol it is not clear that Karin was convinced by this performance.

At a number of places in the protocols we find the term 'particle' being used by pupils in a variety of ways, for example:

"α-radiation: positively charged particles"
"uranium particles"
"beta-particles"
"radiation particle"
"particles in the atmosphere of the earth and the particles which come from the sun and other stars".

So the term 'particle' is used in the scientific meanings of both 'radiation' and 'radioactive substance'. This might be an illustration of undifferentiated use of the term 'radiation' or, if not, in any case a possible source of confusion. Elsewhere in the dialogues we also find the use of 'particle' in the meaning of nucleon: proton or neutron.

2. Distinction between 'irradiation' and 'contamination'

The term 'contamination' is hardly used in the unit, which may explain that in the discussions this term did not appear. The unit does make, however, the distinction between 'external' and 'internal' exposure to radiation in its chapter 3. Some pupils appear to interpret this distinction in an alternative way. This is what Erik says in a group discussion:

"α-radiation, that one hardly comes internal, as it doesn't pass your skin. But if you have it internal, than you really have it, as it goes inside like this [making boxing movements], that will never come out again. But external radiation, that is only beta- and gamma-radiation on the inside".

It seems that he means by the term 'internal radiation' 'radiation which has come inside', focussing on the place which is reached by the radiation and not on the location of the radionuclides (internal or external source).

3. Distinction between 'absorption', 'accumulation' and 'stopping' of radiation

From a scientific viewpoint it could be noted that pupils and teacher were speaking in various parts of the discussions about 'absorption of radiation'. Pupils however rarely use the term 'absorption'; they use terms such as "stopping", "getting lost" and "resistance". The teacher, on the other hand, does use the term 'absorption' frequently. In protocol 1 he explains that this term is understood to mean that the energy of the radiation is absorbed. A few lessons later, however, Karin says:

"that absorption taking place in air, I don't understand that".

The teacher then explains that a beta-particle loses part of its energy in collisions with air atoms, resulting in ionizations. That energy is then taken by the air molecules and in this way the electron is gradually losing its energy. The teacher does not go into the problem of what would happen finally to the electron after it has lost all of its energy. This might be necessary as the pupils seem to have a materialistic view of absorption, as we might conclude from the use of terms like "stopping", "getting lost" and "resistance".

4. Distinction between 'activity' and 'dose', and their units

We did not come across examples of this lack of distinction but noted a problem with the interpretation of the term 'dose' itself. Somewhere the teacher defines the concept of radiation dose as:

"the absorbed amount of radiation energy per kilogramme",

and introduces the unit gray (1 Gy = 1 J/kg). He appears to be uncertain about the seriousness of a dose of one gray. From a physicist's perspective this is understandable, as the additional energy of 1 joule per kilogramme is in most circumstances very small, resulting in a temperature rise of the body of less than 1 mK. The radiation effects of this dose, however, are considerable: most people receiving a dose of 1 gray of X- or gamma-radiation will show signs of radiation sickness. It corresponds with 200 times the annual permitted dose for the Dutch citizen.

5. Distinction between the effects of 'high' and 'low' doses of radiation

No example of this was found.

Besides confirmation of a lack of distinction in these cases we also found some new problems with particular concepts or ways of reasoning:

A. Distinction between 'natural radiation' and 'background radiation'

Chapter 4 of the unit *Ionizing Radiation* deals with radiation sources. The first section of this chapter is about 'natural radiation'. In the class discussion Karin appears to have difficulties in viewing radiation from building materials as natural. Twice she asked a question about it. One might conclude from these questions that in Karin's view the building materials are made by people and therefore are not natural. The obvious criterion for her is the production of the building materials and not the production of the substances which emit radiation. In the scientific view the radon from building materials originates from substances which came into being at the formation of the earth crust and were not produced by human activities.

In his explanation the teacher makes no distinction between 'background radiation' and 'natural radiation'. He confines himself to giving some examples of artificial sources, such as used in the hospital. Herewith he is following the text of the unit which also makes no distinction between natural and background radiation. From a scientific point of view, the two are not identical, as background radiation includes radiation from the fall-out which is formed after the explosion of nuclear weapons or which is released by nuclear power stations.

B. The concept of half-life and its various meanings

In the transcripts which we selected some parts deal with the concept of half-life. In protocol 1 we find some statements of pupils about the meaning of this term:

"In that time it halves"

"then half of the radiation is emit.., eh halved".

The teacher explains that there are two ways to define half-life:

"the time in which the radiation intensity, activity halves"

"the time in which half of the original substance has disappeared".

Actually, the teacher refers here to three interpretations of half-life: halving of the intensity of the radiation, halving of the activity and halving of the original quantity of substance.

After stating these meanings he switches to calculations of the amount of substance left after 1, 2 or more half-life periods. So he does not clarify the correspondence between the various ways of describing the meaning of half-life. He also does not refer to half-life being a property of a particular nuclide.

The different interpretations of half-life also play a part in a discussion about an exercise, which asks:

"Why do the nuclides found in rocks have such long half-lives?"

In the discussion, the observer is involved by the pupils. One of the pupils, Tom, keeps talking about the

"disappearance of the radiations",

while the observer is speaking about the disappearance of the substances. It looks as if those two interpretations obstruct the discussion and make it difficult for the pupils to understand the explanation given by the observer.

C. Distinction between 'radioactivity' and 'nuclear fission'

At several places in the protocols we find remarks by pupils and teacher which might indicate or cause confusion between the terms 'radioactivity' and 'nuclear fission'. For instance Karin uses the expression

"nuclei falling to pieces",

when describing the emission of electrons (beta-rays) by a particular nucleus. And elsewhere the teacher says in an explanation of the term 'activity':

"so I am speaking about the total number of fissions that occurs in one second".

This kind of confusion is perhaps promoted by relating the emission of nuclear radiation exclusively to elements with a large atomic number, as the teacher does in summarizing chapter 2 of the unit:

"we also discovered that if you look for this kind of [radioactive] substances in the periodic table of elements that you will find them at the high side, yes among the heavy elements".

Fission is found only with heavy elements. It is also true that some heavy elements only have radioactive isotopes and no stable ones. Radioactivity is also found, however, with a number of isotopes of elements with lower atomic numbers (even the lowest one, hydrogen, has a radioactive isotope, tritium).

D. The relation between source, radiation and receiver

One of the exercises reads as follows:

"A cancer tumour is irradiated with a radioactive source. List the five factors which determine the size of the radiation dose received by the tumour. Hint: think of factors related to the source, the medium and the receiver."

In protocol 2 we find a record of the class discussion on this exercise. The teacher starts with asking for factors related to the source. Karin mentions "being nearer to the source". The teacher reacts with:

"First about the source itself. Which properties of the source determine the amount of received radiation dose, Vincent?".

The teacher does not notice that Karin assumes that the distance from the source is more or less a property of the source. One might argue that the imprecise wording of the exercise promotes this kind of confusion. In our view it is more likely that the term 'property' would have for some pupils a different meaning from the one which is kept in mind by the teacher and the book. This would have the consequence of making it difficult for these pupils to make a distinction between factors or properties related to the source, the medium and the receiver.

Vincent also appears to have difficulties with this, as is illustrated by the next dialogue between him and the teacher:

Teacher: "Which properties of the source determine the amount of received radiation?"

Vincent: "When it is not too dangerous for man"

Teacher looks very surprised.

Vincent: "or is that not what you mean?"

Teacher: "Yes, the strength, and that is what we call the activity".

This is a clear example of teacher and pupil misunderstanding each other. The pupil seems to be thinking outside the teacher's framework, and the teacher seems not to notice that this framework is not evident to the pupil and even 'hears' a pupil's remark which was not made.

E. Drawing conclusions from the size of the dose

Another case of misunderstanding between teacher and pupils is found in the class discussion about another exercise, which reads as follows:

"A radiation worker receives, from a radioactive source 10 m distant, a radiation dose of 1 mGy per hour.

a. Which type of radiation is certainly emitted by the source?".

The following discussion arises:
Iwan: "α-radiation"
Teacher: "α-radiation, why?"
Iwan: "Simply because it is so slight"
Teacher: "Because it is so slight. How do you see that it is slight?"
Iwan: "Yes, one milligray"
Teacher: "One milligray, yes, but..."
Iwan: "A radiation worker could never have got beta-radiation or gamma-radiation..."
Teacher: "Eh...gamma-radiation is more likely as...".
Some pupils are murmuring.
Teacher: "Why could you conclude that it would for instance not be α-radiation?
Karin: "Because of the ten meters of air..."
Teacher: "That one would never reach ten meters distance"
A pupil: "But that is what Iwan said"
Teacher: "Sorry, I just missed that".
Our interpretation is that both teacher and Iwan have the idea that α-radiation does not reach as far as both other kinds of nuclear radiation. But they come to different conclusions as their reasoning is different. Iwan seems to reason from the perception that 1 milligray is not very much so it must have been α-radiation which would give at a distance of ten meter a smaller dose than both other kinds of radiation. The teacher reasons from the property of radiation: α-radiation does not reach ten meter in air.

Conclusions and discussion

In drawing any conclusions about the results it should be considered that this investigation could in no way lead to a complete picture of all possible teaching and learning problems with the unit *Ionizing Radiation.* The investigation was limited to one class (and within that class mainly to one group of pupils), one teacher and one school, and we might have reported some idiosyncrasies which only occur in this particular setting. So we cannot make any firm statements about the most important and most common didactic problems in teaching ionizing radiation in a risk context. The results should be seen as an illustration of the kind of problems which might arise when teaching this topic in this context.

Some of the points which are reported above might have been expected as they are similar to the results of some of the other studies in this research programme. The protocols not only show these problems, but they also elucidate the nature of the problems or the factors which might influence the stubbornness of lay-ideas about the terms involved. In summary, points of elucidation are:

- the imprecise use of the term 'particle' for many purposes (dust, atom, molecule, α- and ß-radiation, nucleon) might obstruct the distinction between the concepts of radiation and radioactive matter;

- the viewpoint of the pupils about 'absorption' might be characterized as 'materialistic'. The 'energetic' viewpoint of the teacher may be better grasped by the pupils if he includes in his explanation a description of the consequences of absorption for the α- and ß-particles themselves;
- the difficulties in distinguishing between internal and external exposure to radiation might not only be due to a lay-idea of the concept of radiation but also to the lay-viewpoint that this distinction refers to the places which are reached by the radiation, contrary to the scientific view that this distinction is based on the location of the radionuclides, i.e. the source of the radiation;
- it should be realized that the relation between the different scientifically correct meanings of the concept of half-life is not evident to pupils;
- if radioactivity is exclusively attributed to elements with high atomic number, the confusion with 'nuclear fission' might be stimulated as indeed nuclear fission only occurs with some of those elements (such as plutonium, uranium and thorium).

Besides the five problems mentioned above which were already quite familiar to us, we also noted some problems which had not been encountered before:
- the meaning of the term 'natural radiation';
- the linear propagation of radiation;
- differences of approach in interpreting the concept of radiation dose;
- problems in interpreting the scheme source-medium-receiver.

We will discuss these points one by one.
- The distinction between natural and background radiation, which is not made in the unit, seems on first thoughts not very important. However, a disadvantage of the use of the term 'natural radiation' is that artificial sources in the environment - like fall-out - are not included, that pupils tend not to recognize building materials as a natural source and that the term 'natural' suggests to the pupils that this kind of radiation does not bear any risk. It might be better to use the term 'background radiation' instead and to state that this background radiation is mainly caused by natural sources in our environment.
- The linear propagation of radiation does not seem to be a very difficult idea to pupils. This kind of propagation is analogous to that of light. For at least one of the pupils this linearity is no longer self-evident when the radiation has reached the body: it seems that she has the idea that the radiation could follow the path of the digestive system. Another pupil does not share this idea but he takes the wave representation too literally.
- Even for teachers it appears to be difficult to relate a particular radiation dose to its effects, especially if they take the quantity of absorbed energy per unit mass into account. The radiation damage is not the result of the amount of energy which is absorbed but of the

number of ionizations caused by the interaction of the radiation with the atoms of the absorbing matter. A dose of 1 Gy (1 J/kg) is small, from an energy point of view, but could cause considerable radiation damage. In dealing with ionizing radiation in a risk context it seems suitable to focus on the radiation damage of a radiation dose and not on the energy content. However reference to the absorbed energy is useful in order to explain why ionizing radiation cannot be immediately detected by the human body: the temperature rise is negligible.

- In the unit a distinction is made between the source of the radiation, the medium through which the radiation propagates and the receiver of radiation. It is assumed that this scheme is understandable for pupils because of the analogy with, for instance, light, sound and radio waves. It is expected that this scheme is helpful for them in analyzing various radiation contexts by focussing on the properties of the source, the medium and the receiver. However, some of the pupils seem to have a different idea of 'properties' from the authors of the unit. The latter used this term in the meaning "a quality or trait belonging and esp. peculiar to an individual or thing" or "an attribute common to all members of a class " (Webster, 1979), while the former (the pupils) seem to attribute the meaning "having anything to do with" to this term. This last kind of meaning undermines the scheme significantly as all parts of the scheme are related to each other: the distinctions lose their value. Similar problems may arise with the scheme source-radiation-receiver.

Finally we should discuss briefly the experiences with this method of investigation. The method used is very time-consuming. It involves attending a series of lessons, recording the lessons on video-tape, examining the tapes to select the most relevant parts, transcribing these parts as protocols and analyzing the protocols. In our view this effort has been worthwhile as the research findings thus obtained show that observation of education in progress renders an outcome which supplements the findings of studies of other kinds. It might have been difficult to identify the same learning problems through other methods. However, we are aware that more process-oriented observations are required in order to study the development of ideas with specific pupils and the effectiveness of the selected learning strategy. In our view such research is not useful with the present PLON-unit or any other Dutch physics textbook as no strategies have been used which take pupils' lay-ideas into account.

We suggest that it would be valuable to carry out this kind of observations when teaching materials have been written which incorporate the results of the studies reported in this thesis. In these teaching materials more use should be made of the social interaction between fellow-pupils on tasks which draw attention to the differences between lay- and scientific meanings of concepts.

4.5 THE PERSISTENCE OF LAY-IDEAS AMONG PUPILS

Introduction
In several studies we have investigated the existence of lay-ideas. For this purpose we consulted radiation experts, analyzed newspapers and questioned pupils by means of questionnaires and interviews. One could argue that lay-people and pupils involved were not educated on the topic of ionizing radiation, at least not to the level of senior secondary education in physics. Would the same kind of ideas also be present among 'educated' pupils?

The study reported in the previous section reveals that at least some of these lay-ideas appear during dialogue between pupils but because of the qualitative nature of that study no conclusions can be drawn about the strength of these lay-ideas. Studies on preconceptions in other topic areas have shown clearly that many preconceptions are quite resistant to change, at least by exposure to traditional instructional methods (Champagne, Gunstone and Klopfer, 1983). Considering the resistance to change several questions arise. Would the same kind of resistance to change also occur in the case of topics such as 'ionizing radiation and radioactivity' where hear-say may be a more important source than personal observation? If so, which lay-ideas would be more 'persistent' than others? Would it make any difference what kind of instructional methods were used, for instance the traditional/academic textbook of Middelink (1980) or the PLON-unit *Ionizing Radiation* (1984)? Answers to these questions would be useful in order to decide if any new instructional strategy is required and if so on which preconceptions and concepts this strategy should focus.

In the following sections we present the results of a questionnaire given to pupils in their final year of pre-university education (form 6).

Research procedure
This study tried to get a first indication of answers to the following research questions:

1. Which lay-ideas about radiation and related concepts are recurrent amongst form 6 pupils who have studied the topic of ionizing radiation in physics lessons?
2. What differences are apparent in the persistence of lay-ideas between pupils who used the PLON-unit *Ionizing Radiation* and those who have used a more traditional textbook?

The first question aims at collecting information about the persistence of lay-ideas found in our studies reported above. It is assumed that some lay-ideas would be more resistant to change than others, for instance because some were found abundantly in the media.

The purpose of the second question is to investigate what difference it would make studying the PLON-unit *Ionizing Radiation* or a more traditional textbook, i.e. Middelink (1980). Both books have in common that pupils' ideas have not been taken into account.

As research method we opted for a multiple choice questionnaire, based on the findings of our previous studies. The multiple choice format was chosen in order to be able to deal with a large number of lay-ideas in a limited amount of time and to facilitate the processing of the answers. A previous, shorter version of this questionnaire was used by Keren and Eijkelhof (1987) in a study about the difference in the occurrence of lay-ideas among form 4 and form 6 pupils. Their experiences were used to revise the questionnaire. Some questions were added and comments of colleagues (a radiation expert and some physics education experts) and pupils were taken into account.

The questions could be divided into two groups:

a. those which asked for lay-ideas on three kinds of radiation:
   - X rays in a medical context;
   - nuclear radiation from man-made sources, contexts being nuclear reactors, hospitals, nuclear waste and food irradiation;
   - radiation from natural sources.

   These questions dealt with ideas about the nature, propagation, absorption, effects and use of these types of radiation.
b. those which aimed at exploring lay-interpretations of pupils regarding the following concepts:
   - radioactive contamination;
   - radioactivity;
   - half-life;
   - radiation dose;
   - radiation standards.

The preliminary results of the interviews among form 4 pupils (section 3.4) played an important part in the selection of the questions, although at that time the analysis of the interviews had not yet been completed.

Questions to pupils were asked in two formats (Appendix C). In the first format (sixteen questions) pupils had to read a few sentences about a particular risk context and choose from three to five alternative answers. An advantage of this format is that it offers the opportunity for pupils to choose from a number of alternatives.
Examples of such questions are:

1. During a school experiment pupils examine an apple in front of an X-ray tube and observe an image of the apple on a screen. Eating the apple afterwards is:
   [] dangerous because the apple contains radiation
   [] dangerous for some time, as long as the radiation in the apple is active
   [] not dangerous.

11. Which patients it is better not to approach:
    - [] people who have been administered with a radioactive substance
    - [] people who have been irradiated by an external radioactive source
    - [] both kinds of people
    - [] nonsense, both kinds of people can be approached.

In the second format (26 questions) a statement was given and pupils had to indicate if they considered this statement to be correct or not. This second format was mainly, but not exclusively, used for questions of group b. It allowed for presenting a number of interpretations of a concept in order to find out which of these interpretations were acceptable to pupils. Examples of these questions are:

Half-life is the time in which:	correct	incorrect
a. a nucleus loses half of its radiation	[]	[]
b. a radioactive substance is dangerous	[]	[]
c. a radioactive substance has been reduced to half its amount	[]	[]
d. the nuclei of a radioactive substance have been split in half	[]	[]
e. after which a radioactive substance emits radiation at half its original level	[]	[]

The questionnaires were completed by 138 sixth-formers from five schools (one class in each school) in the period December 1987 - February 1988. The numbers were not large enough to be representative of 6VWO pupils. But the group was sufficiently large to provide indications of the answers to the research questions.

In two of the schools (N=63) the unit *Ionizing Radiation* was used, in the other three schools (N=75) use was made of the textbook *Systematische Natuurkunde* (Middelink). Physics teachers were asked to participate with their examination classes in exchange for a quick evaluation of the results for the class to facilitate the use of these in the preparation for the written examinations. None of the teachers had given before any substantial attention to lay-ideas on ionizing radiation and radioactivity in their lessons.

Results regarding ideas about radiation

In this section we report the results of the nineteen questions which dealt with the nature, propagation, absorption, effects and use of three kinds of radiation: X rays, nuclear radiation and radiation from natural sources. Nearly all questions were based on one particular lay-idea. It appeared to be useful to reduce the number of data per question in order to be able to determine how many pupils held these lay-ideas. For questions of the second format this was obviously not necessary. For questions of the first format we added the numbers of respondents who gave answers which expressed the same kind of ideas. For instance, in question 1 (above) we added items 1 and 2 as both show that pupils have the idea that X rays remain in food, at least for some time. Four questions contained too many different lay-ideas for an analysis of this kind so their results are not reported here.

In the tables which present the results, three columns of figures are given. These give the percentage of 6VWO pupils who hold the specific lay-ideas: PLON pupils (P), non-PLON pupils (nP) and all 6VWO pupils (T). Crosses (*) between figures in two columns indicate that the differences between the PLON - non-PLON pupils are significant at the 5% level, calculated applying the Chi-square method (Siegel, 1956).

A. X rays

Table 4.3 gives the percentages of pupils who hold particular lay-ideas about X rays.

Table 4.3 Lay-ideas about X rays amongst pre-university pupils (in %)

	P	nP	T
1. X rays remain for hours in the air in an X-ray department	41	*24	32
2. X rays should be extracted from air in order to reduce radiation risks	41	*59	51
3. X rays remain in food which is irradiated, so it is for some time dangerous to eat that food	60	44	51
4. After having an X-ray taken some of the rays remain in the body for months	27	31	29
5. One reason that X rays are harmful during pregnancy is that the rays are transported to the unborn via the blood system	18	21	20
6. X rays have effects on the human body which are very different from those of nuclear radiation	56	52	54
7. X rays are not used to treat cancer patients	29	33	31

Most striking in these results is that after education many 6VWO pupils still hold ideas about 'conservation of radiation', especially in food and air (items 1-4). Most pupils do not expect X rays to remain for long in the human body. The usefulness of ventilating the X-ray department is expected by about half of the 6VWO pupils.

A second interesting point is that pupils expect effects of X rays which are different from those of nuclear radiation. This might be due to the kind of reasoning which we found in the interviews (3.4), namely that properties of radiation could be deduced from the function of the radiation.

B. Nuclear radiation

Table 4.4 contains the results for nuclear radiation.

Table 4.4 Lay-ideas about nuclear radiation amongst pre-university pupils (in %)

	P	nP	T
1. After an accident in a nuclear power station the radiation might be spread by the wind	54	*72	64
2. Radiation might be spread by ocean currents	11	*31	22
3. Radiation might accumulate in the human body	59	72	66
4. Radiation might be stored in food	52	60	57
5. The period for which nuclear radiation from an external source remains active in a cancer patient depends on half-life or length of irradiation	62	77	70
6. Patients who are irradiated are hazardous to others	19	20	20
7. Patients who have been given radioactive substances are not hazardous to others	41	44	43
8. A shower helps to wash off radiation	2	*11	7
9. Nuclear radiation is not used to treat cancer patients	27	41	35

Two points are most striking in these results. One is that a majority of the 6VWO pupils hold the idea of 'conservation of radiation': in food and in the human body (items 3, 4 and 5). This suggests an inability to make a distinction between 'radiation' and 'radioactive substance', and between 'irradiation' and 'contamination'. If we compare these results with those on X rays it looks as if 'radiation storage' is expected more from nuclear radiation than from X rays, maybe because contamination of food has been related in the news media more to radioactivity than to X rays. The period for which the radiation remains active is erroneously thought to be dependent on half-life or length of irradiation. The idea of wind spreading the radiation, so often found in the Chernobyl reports, is still dominant among these pupils. Ocean currents are seen by far fewer pupils as means of transport of radiation.

Secondly, a considerable number (around 40%) erroneously expect no hazards from someone who has been given radioactive substances. This might be because they never heard about the ways these patients are treated in hospitals. Irradiated patients are rightly not seen by most of the pupils as hazardous to their environment.

C. Natural radiation

Table 4.5 presents the results for the three questions about natural radiation.

Table 4.5 Lay-ideas about natural radiation amongst pre-university pupils (in %)

	P	nP	T
1. The human body is immune to natural radiation	6	7	7
2. Natural radioactive substances are not found in the environment	3	5	4
3. Most of the radiation which man receives in normal circumstances is not from natural radiation sources	13	23	18

Nearly all pupils appear to be familiar with the existence of natural radioactive substances in the environment and with the possibility of effects of natural radiation to the human body. About 20% do not know that in normal circumstances citizens receive most of their radiation from natural sources of radiation.

Results regarding the meaning of scientific concepts

Twenty of the questions concerned lay-meanings about five concepts which are basic to the field of radiation protection: radioactivity, half-life, radioactive contamination, radiation dose and radiation standards.

A. Radioactivity

Table 4.6 presents the results for the concept of radioactivity.

Table 4.6 Lay-ideas about the concept of radioactivity amongst pre-university pupils (in %)

	P	nP	T
1. The term radioactivity might be well described as 'radioactive radiation'	64	68	66
2. The term radioactivity might be well described as 'radioactive substance'	22	24	23
3. The term radioactivity should not be described as 'phenomenon of radioactive decay'	36	49	43
4. The term radioactivity should not be described as 'property of a radioactive substance'	10	13	12

A large majority of the pupils appear to have the idea that the term 'radioactivity' is synonymous with 'radioactive radiation', a term which is very common in Dutch - also in Dutch physics textbooks (4.2) - to a much greater extent than in English. The 'radiation' meaning of the term 'radioactivity' was also found to be common among form 4 pupils (3.3;

3.4). Education does not seem to have much influence on this idea. The meaning 'radioactive substance', often found in the newspapers (3.1), is held by only a small minority of the pupils.

Rather surprising is the number of pupils who deny that the term 'radioactivity' denotes a phenomenon of radioactive decay. This might indicate that pupils have difficulties with the meaning of the term 'phenomenon'.

B. Half-life

The results on this concept are given in Table 4.7.

Table 4.7 Lay-ideas about the concept of half-life amongst pre-university pupils (in %)

	P	nP	T
1. The term half-life might be well described as 'the time in which an atomic nucleus loses half of its radiation'	51	*23	36
2. The term half-life might be well described as 'the time in which a radioactive substance is dangerous'	6	8	7
3. The term half-life might be well described as 'the time in which the atomic nuclei in a radioactive substance are halved'	11	16	14
4. The term half-life should not be described as 'the time in which the quantity of a radioactive substance is halved'	67	*50	58
5. The term half-life should not be described as 'the time after which a radioactive substance emits half as much radiation'	30	25	28

Pre-university pupils appear not to have the ideas that half-life is similar to the danger period (found in the newspapers) or that it is the time in which nuclei are halved (confusion between 'radioactivity' and 'fission'). However, a majority do not have the notion that the quantity of a radioactive substance is halved after one half-life period. This might be due to the fact that teachers pay more attention to the relation between 'half-life' and 'activity', or 'half-life' and the radiation emitted.

It is also striking that a considerable number of pupils seems to have the idea that each nucleus has a particular amount of radiation of which half is emitted during one half-life period, indicating some learning problems in the micro-level understanding of the concept of radioactivity.

C. Radioactive contamination

Table 4.8 presents the results of the questions on the concept of radioactive contamination.

Table 4.8 Lay-ideas about the concept of radioactive contamination amongst pre-university pupils (in %)

	P	nP	T
1. A person who is contaminated does not contain radioactive substances	33	45	40
2. A person who is contaminated is contaminated with radiation	73	77	75
3. A person who is contaminated contains too much radiation	33	47	41
4. A person who is contaminated does not have a radioactive body	78	80	79
5. A person who is contaminated has too much radiation in his blood	11	24	18

Lay-ideas about this concept appear to be very common and scarcely influenced by education. Contamination also is strongly associated by 6VWO pupils with radiation, as we often found among form 4 pupils (3.3; 3.4).

D. Radiation dose

Pupils' and students' ideas on the concept of radiation dose are given in Table 4.9.

Table 4.9 Lay-ideas about the concept of radiation dose amongst pre-university pupils (in %)

	P	nP	T
1. The term radiation dose means 'the quantity of radiation which is released'	15	23	19
2. The term radiation dose means 'the quantity of radiation which is really dangerous'	15	9	12
3. The term radiation dose does not mean 'the quantity of radiation which is received'	7	9	8

We might conclude from this table that a large majority of the pupils has the scientific notion that radiation dose is a concept related to the receiver and not to the source. Only a small number believes that the term 'radiation dose' refers to a dangerous quantity only. It should be noted here that the questions have not explored pupils' ideas about absorption, e.g. the difference between receiving, transmitting and absorbing the radiation.

E. Radiation standards
The last concept dealt with in the questionnaire is radiation standards. The results are presented in Table 4.10.

Table 4.10 Lay-ideas about the concept of radiation standards amongst pre-university pupils (in %)

	P	nP	T
1. A radiation dose of .5 Sv is likely to cause death within months	26	28	27
2. Only a radiation dose of more than 50 Sv is likely to cause death within a few months	33	32	33
3. As long as somebody receives less than the annual permitted dose s/he does not run any risk	40	36	38

The first two statements in the table refer to the dose (equivalent) at which 50% of the population is expected to die as a result of acute effects of the received radiation. This dose is generally taken to be around 5 Sv. About 40% of the pupils selected this level, the others took the level either higher or lower.

About 40% of the pupils may have a threshold idea about the annual permitted dose of radiation: they expect no risk below that level. However it might be that these pupils assume the term 'risk' to mean: 'being very dangerous' and not 'the chance of harm'. In chapter 5 we will give more attention to various interpretations of the concept of risk.

Conclusions and discussion
In this study answers were sought to two research questions. Question 1 dealt with lay-ideas about radiation which are recurrent among form 6 pupils after studying the topic of ionizing radiation in physics lessons. We found ten lay-ideas held by a majority of our 6VWO pupils, tabulated in Table 4.11.

The lay-ideas listed in Table 4.11 were found among 51 (J) to 79 % (A) of the 6VWO pupils. Two of these lay-ideas (A and G) have not been found very often before, neither in the newspapers nor among form 4 pupils. Maybe one should not call these 'lay-ideas' but 'undeveloped scientific ideas' as they deal with scientific notions which are missing with pupils, perhaps showing that it is difficult for pupils to grasp these scientific notions.

Table 4.11 Common lay-ideas about ionizing radiation amongst pre-university pupils

A. 'Radioactive contamination' does not mean that a person has a radioactive body.
B. 'Radioactive contamination' means that someone is contaminated with radiation.
C. The period in which nuclear radiation from an external source remains active in a cancer patient depends on half-life or length of irradiation.
D. Radiation might accumulate in the human body.
E. The term 'radioactivity' might be well described as 'radioactive radiation'.
F. After an accident in a nuclear power station the radiation might be spread by the wind.
G. The term 'half-life' should not be described as 'the time in which the quantity of a radioactive substance is halved'.
H. Radiation might be stored in food which is irradiated, so it is for some time dangerous to eat that food.
I. X rays have effects on the human body which are very different from those of nuclear radiation.
J. X rays should be extracted from air in order to reduce radiation risks.

Many of the other lay-ideas of Table 4.11 seem related. They are about ionizing radiation being in the air and transported by air currents (F and J), about radiation stored in food and in the human body (C, D and H) and about contamination by radiation (B). This strongly suggests that 6VWO pupils still have considerable problems with three kind of related distinctions (see Table 3.9):
1. Between 'radiation', 'radioactivity' and 'radioactive substance'.
2. Between 'irradiation' and 'contamination'.
3. Between 'absorption', 'accumulation' and 'stopping' of radiation.
Item E confirms what was found among form 4 pupils: the term 'radioactivity' is mainly associated with 'radiation' and not with 'radioactive substance', as seems to be assumed by science writers. The remaining item (I) suggests that also 6VWO pupils view properties of radiation more from the context than from their scientific characteristics.

Research question 2 dealt with the differences between PLON and non-PLON pupils. In general the PLON-pupils tend to have slightly fewer lay-ideas than the other pupils, but the differences are not significant at the 5% level, exceptions being some lay-ideas about X rays (Table 4.3, items 1 and 2), nuclear radiation (Table 4.4, items 1 and 2) and half-life (Table 4.7, items 1 and 4). The differences regarding X rays and nuclear radiation (item 1) are due to deviant answers from only one school. The differences on the concept of half-life might be explained by the fact that less attention is given in PLON-lessons to more abstract aspects of this concept. However, larger differences between PLON and non-PLON pupils are to be expected as the PLON-unit deals more with topics such as the use of X rays and radioactive substances in hospitals, the risks of radiation, and radiation protection. Perhaps the small differences between the groups might be explained by the fact that the PLON-unit, like the other books, gives no attention to lay-ideas and to the dissimilarities between scientific and lay-ideas. Apparently, dealing with ionizing radiation in a risk perspective is no guarantee of proper learning of scientific concepts.

One might argue that these results are not representative as only five schools were involved, making the results rather dependent on specific circumstances, such as the ability and learning attitude of the classes, the amount of time spent on the topic and the quality of teaching. Indeed, class differences were found such as the average percentage of lay-ideas among pupils varying between 29 and 45%. But, although the results could not be claimed to be representative of all Dutch 6VWO pupils, the number of pupils and classes should be large enough to get indications about the persistence of some lay-ideas found in newspapers and among form 4 pupils.

The investigation did not aim at finding a correlation between particular lay-ideas. Such a study should be useful for developing a diagnostic instrument for measuring the rate at which particular lay-ideas occur and persist with groups of pupils.

4.6 EVALUATION OF OUR STUDIES OF TEACHING AND LEARNING ABOUT RADIOACTIVITY, RADIATION AND RISK

In this chapter we have reported four studies which deal with teaching and learning:
- a content analysis of physics textbooks;
- interviews with teachers;
- observation of lessons;
- evaluating the ideas of form 6 pupils, using a questionnaire.

In the final section of this chapter we will compare the results of these studies and draw some general conclusions about ways to improve physics education on this topic.

All four studies sought to provide more insight into problems of teaching and learning of the topic of radioactivity and ionizing radiation in a risk context. In each study the approach was very different:
- in the book analysis we tried to increase our insight into the way current school textbooks deal with the topic of ionizing radiation;
- in the interviews we tried to extract from teachers the main problems in their view with teaching this topic in a risk context;
- in the lesson observations we tried to detect learning problems in the use of the unit *Ionizing Radiation*;

- in the questionnaire of sixth formers we tried to identify those lay-ideas which seem to be most resistant to change by present education.

In such a kaleidoscopic research approach the question arises quite naturally about the extent to which the results relate to each other. The following points might be worth mentioning.

The book analysis shows that only a few lay-ideas could be found. It became also evident that the books use a number of meanings of terms without clearly indicating the relation between concepts. Maybe more relevant is the conclusion that books pay no attention to the deliberate use of lay-ideas in promoting learning, perhaps assuming that lay-ideas do not exist or are easy to change (Gilbert, Osborne and Fensham, 1982).

The problems which teachers noted are mainly not with the persistence of lay-ideas but with the large number of concepts and the information density of the PLON-unit and with risk assessment procedures. A large number of smaller problems were noted by only one or two teachers. Only some of the teachers dealt explicitly with lay-ideas by discussing some of the questions used in our fourth study with their pupils. The success of this approach was only evaluated at the opinion level. It may be that the general satisfaction with the unit diminishes the sensitivity for learning problems or that teachers tend not to look very sharply at learning problems in general.

The third study showed clearly that learning problems exist. Some were expected in view of the studies among form 4 pupils, but a number of new problems were noted.

Results of the fourth study indicate that a majority of form 6VWO pupils (both PLON and non-PLON pupils) have difficulties in making the distinction between several important concepts. Some problems were also identified with the scientific meaning of concepts.

What general recommendations could be based on the studies reported in this chapter?

Firstly, lay-ideas on ionizing radiation deserve attention in physics education, as ignoring them appears not to be a successful way of teaching.

Secondly, the meaning of terms should get more attention, especially the relation between terms. Perhaps not all the possible meanings of a concept should be introduced at once.

Thirdly, teachers should familiarize themselves with the main lay-ideas in order to be able to recognize them and deal with them at the appropriate time.

Fourthly, textbooks should be more careful in their introduction of concepts, should relate concepts more clearly to each other, should avoid lay-meanings where scientific meanings are required and should deliberately use lay-meanings in order to clarify the correspondence and difference with scientific meanings.

Fifthly, more research is required to get insight into the learning process from lay- to scientific ideas. The most useful longer-term strategy may be to devise teaching materials based on the general recommendations mentioned above and to evaluate pupils' learning.

These recommendations will be elaborated in chapter 6.

5. FOCUS ON RISK ASSESSMENT

5.1 INTRODUCTION

In this chapter we will focus on the risk side of our investigations and try to see what lessons can be drawn as regards the general aim of our study.

We will introduce the topic by presenting and discussing some of the findings of researchers working in the field of risk analysis, risk perception and risk communication. Then we will present the results of one part of the Delphi-study, which dealt with radiation anxiety in physics education. Finally we will draw and discuss some conclusions about the aim of teaching about risk assessment in physics education.

5.2 RISK ASSESSMENT IN THE LITERATURE

Introduction

During the last two decades the topic of risk has been the focus of many experimental and theoretical studies. The large number of publications reflects the increased attention to risk by psychologists, philosophers, ethicists, gamblers, technologists, economists, environmentalists and decision makers. These publications can be found in a variety of professional journals such as *Risk Analysis, Science, Environment, Journal of Experimental Psychology, Health Physics* and *Policy Sciences*, in proceedings of conferences (for example, Goodman and Rowe, 1979; Schwing and Albers, 1980; Slaa, Turkenburg and Williams, 1983; Ricci, Sagan and Whipple, 1984) and in a number of books (for example, Lowrance, 1976; Fischhoff, Lichtenstein, Slovic, Derby and Keeney, 1981; Douglas and Wildavsky, 1983; Royal Society, 1983; Shrader-Frechette, 1985; Rowe, 1988). In this section we will outline some of the results of these studies which may be of relevance to our educational aim.

First, attention is given to the meaning of terms used in the literature. Then we will present some findings about risk perception, especially those concerned with the risks of ionizing radiation. We then describe differences between lay and experts' ideas about risks. Finally we sketch some different opinions about the role of education as regards public perception of the risks of ionizing radiation.

Risk terminology

So far we have used the terms 'risk' and 'risk assessment' without defining them precisely. Greater precision seems to be required in order to formulate more sharply what the aims of physics education on the topic of ionizing radiation should be. On the other hand, a full chapter could be devoted to such definitions and the different views behind them

(Fischhoff, Watson and Hope, 1984). As that would be beyond the scope of this study, we have limited ourselves to some generally agreed opinions on the use of these terms. Table 5.1 shows some definitions of the term 'risk'.

Table 5.1 Some definitions of the term 'risk'

"the chance of harm" (Rowe, 1982)
"the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge" (Royal Society, 1983, p. 22)
"Risk is the potential for realization of unwanted, negative consequences of an event" (Rowe, 1988, p. 24, 463)
"combined outcome of the probability of a hazard resulting in an adverse consequence" (O'Riordan, 1983)
"a measure of the probability and severity of adverse effects" (Lowrance, 1976, p. 94)
"the potential for harm and/or safety" (Wildavsky, 1988, p. 3).

In all these characterizations of the term 'risk' we find two components. One is probability, chance or potential. The second one is harm, consequences of an adverse event or safety. Less unanimity exists in the views on the importance of and the relation between both components. We will return to this point later.

A second term which we have often used is 'risk assessment'. Rowe (1988, p. 464) describes 'risk assessment' as

"the total process of quantifying a risk and finding an acceptable level of that risk for an individual, group, or society".

He agrees with Kates (1976) that risk assessment has three components:

a. risk identification: this includes identification of causative events, the observation and recognition of new risk parameters, the recognition of new relationships among existing risk parameters, or perception of a change in the magnitude of existing risk parameters;
b. risk estimation: this encompasses the determination of the magnitude of consequences and of the probabilities of outcomes;
c. risk evaluation: the developing of acceptable levels of risk to individuals or society; this is a complex process as it encompasses risk perception, weighing risks and benefits, determination of acceptability of levels of risk, and aversive action, i.e. the reduction of risks to acceptable levels or acceptance of the risks.

Rowe also uses the term 'risk determination' which is aimed at defining a given level of risk, to permit risk evaluation to take place. It includes risk identification and risk estimation.

We may conclude that 'risk assessment' could be used as a general term as it covers a wide area of risk related activities. The disadvantage, however, is that such a general term makes it difficult to specify which kind of activities should be included in physics education.

Three types of risk studies

Using the classification introduced above we can make a distinction between three types of risk studies. A large number of studies is devoted to determining the risks of personal life such as habits (e.g. smoking, drinking), diseases (e.g. cardiovascular, cancer, diabetes, influenza), travelling (such as by car, by airplane or as pedestrian) or sports (e.g. mountaineering, skiing, hunting). In other studies the risks of new technologies are identified and estimated, for instance of X-ray examinations, food preservatives, DNA-experiments, nuclear power stations and manned space-flights. These studies are mainly carried out to inform policy decisions aimed at avoiding or reducing these risks. They generally result in tables of loss of life expectancies of a range of human activities ("catalogue of risks") (Cohen and Lee, 1979) or conclusions for a particular technology or natural disaster about the chance of an accident with a certain number of fatalities (La Fors, Badoux and Defize, 1979; Struyker Boudier, Heilmann and Urquhart, 1985).

Another type of risk studies is concerned not with the nature and scale of risks as assessed by experts but with the way the public in general or specific groups of people perceive risks. Perceived risk could be described as

> "the combined evaluation that is made by an individual of the likelihood of an adverse event occurring in the future and its likely consequences" (Royal Society, 1983, p. 94).

These risk perception studies examine the judgments people make when they are asked to characterize and evaluate hazardous activities and technologies (Slovic, Lichtenstein and Fischhoff, 1979; Vlek and Stallen, 1979; Stallen and Tomas, 1985; Midden, 1986; Slovic, 1987). This type of research aims to provide a basis for understanding and anticipating public responses to hazards and for improving the communication of risk information among lay-people, technical experts, and decision-makers.

We would argue that our study belongs with another group of risk studies, namely those which focus on the communication process between experts and lay-people in order to study and improve its effectiveness. This third type of study is less common although the interest among researchers seems to be increasing (Slovic, 1986; Boer, Gutteling, Houwen and Wiegman, 1988; Smith and Johnson, 1988). These risk communication studies are in our view related to both risk determination and risk perception studies: to the former as one would like the public or pupils to be able to identify some risks in a thoughtful way, i.e. not as an expert but as an informed citizen who is able to collect and use some objective information in decision making; to the latter as in communication one has to take into account what kind of perceptions are present in the target group of the risks involved.

As education can be seen as a form of communication it may be possible to use some of the findings of studies of the first and second type to improve educational practice. In our particular case, related to ionizing radiation, one might think of the following findings:

- procedures for assessing risks, which might be simplified for educational use;
- data about the risks related to nuclear power stations and other parts of the nuclear fuel cycle, to be used for clarifying what the probabilities of accidents are;
- data about the risks of general background radiation, X-ray examinations, radon exposure in homes and activities at high altitude (flying, skiing, mountaineering) to facilitate comparisons within the field of radiation risks;
- data about the risks of natural disasters, of other technologies, of diseases and of other human activities in order to compare them with the risks of radiation;
- procedures to measure the perception of radiation risks, which may prepare teachers for taking into account their pupils' perception of risks.

However, the use of these findings for educational purposes is not as simple as it looks for several reasons.

Firstly, although the majority of experts generally agree about the risks of radiation in various contexts, a minority have opposing views, for instance about the risks of nuclear power stations and the effects of low level radiation. According to Reaven (1987) these disagreements are based on differences of opinion about 'similarity' (such as extrapolating from animal experiments to humans) and on fundamental disagreement about the legitimate scope of applications and the very meaning of probability concepts. Whose data should be used?

Secondly, public perception of the risks of nuclear power and X-rays differs considerably from that of most experts (Cohen and Lee, 1979; Slovic, Lichtenstein and Fischhoff, 1979). Nuclear power appears to elicit an extraordinary level of concern, particularly because of the characteristics of the hazards it poses. Most prominent among these are the potentially catastrophic and involuntary nature of possible accidents, and the fact that it is an unknown hazard. Compared to other technologies nuclear energy emerges as the most extreme in terms of the size and seriousness of a potential accident (Van der Pligt, 1985). On the other hand, X-rays were judged much less risky by lay-people than by experts (Slovic, Fischhoff and Lichtenstein, 1980). Would presenting data from risk studies with such differences in perception of risks between lay-people and experts not give the dubious impression that lay-people should not be taken seriously?

Thirdly, several studies reveal that, especially regarding nuclear power, the public doubt the credibility of radiation experts, especially those working for the nuclear power industry (Covello, 1983). According to Lee (Arnold, 1986) experts have not taken sufficiently into account the fact that nuclear power is associated with the horrors of atomic bombs and have falsely assumed that if people could understand the physics they would accept the technology. Barnett (1983) looks at the public worry about radiation from a more optimistic perspective: "it may well have accelerated technologic improvements in mammography and hastened the dramatic dose reductions that have occurred in recent years". Would that suggest that in education the distrust of experts should be enlarged or reduced?

With these questions in mind we decided to study the risk literature more closely in order to get a better insight into the differences in ideas about risks in general and of radiation in particular between experts and the general public.

Lay- and experts' ideas about risks

In section 3.2 we studied the differences between lay-people's and experts' frameworks of ionizing radiation. Similar differences are reported in the literature about the ways in which experts and lay-people approach risks, including those of ionizing radiation. In a review of this kind of studies, Covello (1984) summarizes the findings under three headings:
a. human intellectual limitations;
b. overconfidence among experts and lay-people;
c. expert and non-expert estimates of risk.
We will deal with these aspects in turn.

a. human intellectual limitations

Covello states that human intellectual limitations and the general human need to reduce anxiety often lead to the denial that risk and uncertainty exist and to unrealistic oversimplifications of essentially complex problems. The following human intellectual limitations were reported:

1. the use of a limited number of heuristic principles. Lay-people particularly, but also some experts, often use inferential rules to simplify risk problems. These heuristics are in general quite useful but sometimes they lead to pronounced and systematic biases and errors. Tversky and Kahneman (1974) reported two sets of heuristics used by people in uncertain situations (for instance when risks are involved):
   (i) representativeness: probabilities are evaluated by the degree to which objects, classes, processes or events resemble others; for instance, when A is highly representative of B, the probability that A originates from B is judged to be high; on the other hand, if A is not similar to B, the probability that A originates from B is judged to be low;
   (ii) availability: instances of large classes are recalled better and faster than instances of less frequent classes, likely occurrences are

easier to remember than unlikely ones and the associative connections between events are strengthened when the events frequently co-occur. This might explain why people have difficulties imagining low probability/high consequence events happening to themselves, resulting in their overestimating low frequency events and underestimating high frequency events.
Another related consequence reported is that the very discussion of a low probability hazard increases the perceived probability of the hazard, regardless of what the evidence indicates;
2. once beliefs are formed, individuals will frequently structure and distort the interpretation of new evidence, and will often resist disconfirming information, labelling it as unreliable, erroneous and unrepresentative. Convincing people that a hazard they fear is safe is found to be extremely difficult even under the best conditions. Some authors (Sjöberg, 1979) attribute this to a defence of self-esteem which requires stability and consistency. Others (Douglas and Wildavsky, 1983) claim that beliefs about risks are embedded in a complex system of beliefs and values: perceptions of risk are likely to be shaped by the social system, the world view and the ideological premises of a group or a society. As regards beliefs about nuclear matters, Weart (1988) refers to the influence of a large number of news reports, books and films in forging associations that are similar and widespread, which he calls "public images".

b. overconfidence among experts and lay-people
Covello also refers to studies reporting overconfidence. Experts and lay-people are apparently overconfident about their risk estimates. Such overconfidence can produce serious errors of judgment, including judgments about how much is known about the hazards and how much needs to be known. It also leads people to believe that they are comparatively immune to common hazards: they underestimate the risk of activities that they perceive as familiar and under their personal control (such as driving, activities in the home).

c. expert and non-expert estimates of risk
Several studies have shown that experts and lay-people disagree about the magnitude of risks of various human and industrial activities (Fischhoff et al., 1981; Slovic, 1987). Explanations in the literature of this phenomenon are that experts and lay-people:
- define risk differently;
- are talking different languages;
- are solving different problems;
- see the facts differently.

Covello (1984) summarizes the differences reported between experts and non-experts in methods and approaches for estimating risks (Table 5.2).

Table 5.2 Differences in risk analysis methods and approaches between experts and non-experts (Covello, 1984)

technical experts	*non-experts*
- give equal weight to single events which cost many lives at once and multiple events each of which costs a single life	- give greater weight to single events which cost many lives at once
- give equal weight to statistical and known deaths	- give greater weight to known deaths
- give equal weight to voluntary and involuntary risks	- give greater weight to involuntary risks
- use quantitative terms to express risks	- express risks in qualitative terms
- use computational and experimental methods to identify, estimate and evaluate risks	- use intuitive and impressionistic methods to identify, estimate and evaluate risks
- give greater weight to quantitative estimates for decisions	- give equal weight to both qualitative and quantitative estimates
- give same weight to different ways of dying	- see some ways of dying as "worse" than others

Kasper (1979) notes that technical experts tend to view objective characterizations of risk as somewhat more real or more valid than the perceptions of the rest of the public, and regards this as a kind of arrogance. The view of some of these experts is that the differences are mainly due to lack of information, inadequate communication, extensive presentation of adverse health effects and one-sided media coverage of events (Strauss, 1983). On the other hand, common ways in which experts may overlook or misjudge pathways to disaster are reported (Slovic, Fischhoff and Lichtenstein, 1980), such as:

- failure to consider the ways in which human errors can affect technological systems;
- overconfidence in current scientific knowledge;
- insensitivity to how technological systems function as a whole;
- slowness in detecting chronic, cumulative environmental effects;
- failure to anticipate human responses to safety measures.

In a later article Slovic (1986) writes that the most important message from the research carried out to date on risk perception is that there is wisdom as well as error in public attitudes and perceptions. On the one hand, lay-people sometimes lack certain information about hazards. On the other hand, their basic conceptualization of risk is much richer than that of the experts and reflects legitimate concerns that are typically omitted from expert risk assessments. He uses this as an argument that both experts and the public have something valid to contribute and that risk communication will fail unless both sides respect the insights and intelligence of the other.

Earlier in this section it was shown that differences in assessment of risks between experts and lay-people also exist in the field of radiation risks. In the following section we will present the ideas in the literature about the role of education as regards public assessment of risks.

Risks of radiation and education: the role of knowledge

In various publications it is argued that a sophisticated judgement on the question of nuclear risk is hindered by a basic lack of factual knowledge (Pokorny, 1977; Delcoigne, 1979) on the part of a vast majority of people. With such a lack of knowledge scare stories, confusion and irrationality often triumph (Pokorny, 1977; Trunk & Trunk, 1983). After the Chernobyl accident, Nature (1986) claimed that the lack of general awareness of radiation and its potential consequences accounted for the near-panic that seems to have afflicted some of those living in Western Europe. Proper formal education is seen by many authors as a remedy for this: as "a prescription for fear and misunderstanding" (Strauss, 1983), to promote understanding of the choices involved and to encourage wise decision making (Pokorny, 1977). These authors seem to suggest that teaching factual knowledge would result in people reaching different conclusions about, for example, the risks of nuclear power.

To others this is not so evident. Weart (1988) concludes from a number of public polls in the sixties that the amount of knowledge a person had about fall-out had no relation at all to the amount of anxiety the person felt about nuclear war. According to him, when a person took a nuclear stance it was not from some special knowledge nor lack of it, but as part of a total approach to society. Midden (1986) claims that for nuclear power no relation was found between knowledge and attitude; he expects that new information would produce no effects on attitudes, in view of the strength of beliefs. And in his study conducted shortly after the Chernobyl accident, Lucas (1987) found little relationship between the public's understanding of radioactivity and nuclear waste and their views on the nuclear power issue.

Slovic (1983) agrees that programmes to educate and inform the public about risk are desirable but argues that research is needed to determine what people know and want to know and how best to communicate technical information. What is best, however, is debatable. For instance, Johnson and his colleagues (1988) found in a study about communicating radon risk that differences in presentation of information influence not only learning but also the formation of risk perceptions, and intended behaviour. It may be, however, that this effect only occurs if the information deals with an unknown risk, where people would be more open towards new information than in the case of familiar risks. Faden (1983) raises another argument to demonstrate the complexity of this matter: he claims that public education about radiation and nuclear power is not a morally neutral enterprise and attributes differences between the public and the experts to differences in moral beliefs. In his view education about radiation risks means trading in values as much as trading in facts. The question then arises about which values should be traded: should pupils be told that the risks of radiation are quite small, for instance, compared to other risks in life, or should they be persuaded that great effort should be expended to reduce further any radiation risk?

What conclusions can be drawn from the literature as regards our efforts to formulate recommendations for teaching radioactivity and ionizing radiation within a risk perspective? From the studies referred to above, it is not clear how large the influence of knowledge on risk assessments is. We tend to believe that this influence should not be overestimated, as affective aspects, such as personal and social values and beliefs, seem also to be important. On the other hand, it is also unlikely that knowledge is completely unimportant in assessing the risks of ionizing radiation. We would expect that some of the differences between experts and non-experts (Table 5.2) could be reduced through education, such as the use of quantitative terms to express risks and the weight given to the results of computational and experimental studies. We would not be in favour of trying to influence the weight which pupils attribute to adverse events, involuntary risks and ways of dying.

In our view the literature is not sufficiently conclusive to allow decisions to be reached on the complex issue of how to deal with radiation risk in secondary education. We expected that radiation experts would be able to give useful advice on how to approach this issue from an affective perspective, as they are used to dealing with lay-people who have particular attitudes towards ionizing radiation. We therefore decided to consult the group of radiation experts who were participating in our Delphi-study and included some questions on how to approach risk perceptions of pupils in the three rounds of the study. The results of this will be reported in the next section.

5.3 RADIATION EXPERTS VIEWS ON DEALING WITH RADIATION RISK IN EDUCATION

Introduction

In the preceding section we referred to the results of risk perception studies. These studies show that amongst the public a great deal of concern exists about radiation of nuclear origin. It was also shown that intellectual limitations, strong beliefs and lay-approaches to risk issues are seen as important factors in the formation of lay-ideas about risk, and relate to the attitude of lay-people towards new information. One might expect that this concern would also be present amongst pupils and that the same factors would influence the education of pupils about ionizing radiation and radioactivity. In view of the general aim of this study, this raises the question of how teachers and textbooks should cope with this.

As we might expect that radiation experts often encounter anxiety about radiation in their professional activities, we decided to use the opportunity of the Delphi-study about contents and contexts to consult the same group of experts on this particular issue. The aims of the study would be to get insights into their experiences and views on dealing with the public on matters involving radiation risks, and to collect their advice on how to deal with this topic in the context of risk.

Research design

In section 2.4 we outlined the procedure for the Delphi-study, the selection of the participants and the three rounds held. In the context of the study discussed here, it is important to remember that we tried to include in our group of participants, people from different fields of activity and with a variety of views on radiation risks.

This part of the Delphi-study started with two research questions:

1. What are the major reasons for the anxiety of the general public about ionizing radiation and its applications?
2. Which aspects should be emphasized by teachers when responding to this kind of anxiety amongst pupils?

The purpose of the first question was to get insights into the views of the participants on the causes of the public concern about radiation. It was expected that the answers to question 1 might be of use in interpreting the advice given in response to question 2.

In the first round the questions were based on research question 1. Some questions were also asked as an introduction to question 2, dealing with the experience of the participants with anxious people. In the second round the answers given were presented to the participants for their assessment. The respondents were further asked to elaborate on the aspects to be emphasized in science education (research question 2). Analysis of the second round showed that one type of advice - making risk comparisons - appeared to be insufficiently elaborated, due to some differences of opinion on the need for and pitfalls of this kind of comparison. This led to the formulation of a third research question in the third round:

3. Which kind of risk comparisons should be used in education when its aim is that pupils learn to assess radiation risks, and what conditions should be fulfilled in doing so?

In this part of the Delphi-study the aim was not to look for consensus about how to deal with anxiety about radiation as it was likely that views would differ. Rather the aim was to collect views on this issue based on the experiences of the participants and to challenge them to give arguments which would support or refute these views.

Results on reasons for anxiety

In one of the questions in the first round the participants were asked to give the most important reasons for the anxiety of people towards ionizing radiation and its applications. The answers can be classified into eight categories. In the second round these categories (except the miscellaneous category) were presented to the participants with a request to place these in order of importance. The results on both rounds are presented in Table 5.3.

Table 5.3 Importance of reasons for the anxiety about ionizing radiation among the public according to participants

reasons	number of times mentioned in first round	score in second round (*) average	s.d.
nature of possible effects	20	2.9	1.5
lack of knowledge	38	3.1	1.9
association with nuclear arms	17	3.3	2.0
not detectable with senses	14	3.4	1.9
biased news coverage	14	4.9	1.6
distrust of government and experts	17	5.1	1.6
occurrence of accidents	9	5.2	2.0
other reasons	9	-	-

(*: 1 = most important, 7 = least important)

In the first round (N=55) most participants gave more than one reason. Lack of knowledge was mentioned by the majority of participants, the occurrence of accidents by a small minority and the other reasons by about 25-35 % of them. However, when presented with all seven reasons more differentiation appeared in the perceived importance of the five reasons in the middle group: the distrust and media coverage were seen as less important than the nature of the effects, the association with nuclear arms and the non-detectability by the senses. It is remarkable that the four reasons which are seen as most important are cognitive in nature and are not beyond the influence of education.

Results on dealing with anxiety

Some questions in the first round asked participants to describe situations in which they had had to cope with people who were anxious about ionizing radiation and to outline the aspects which they emphasized in these particular situations. Almost all participants responded to these questions. A majority (58%) referred to questions from people during the

Chernobyl period, for instance about the hazards of foods, of going on holiday in Eastern Europe and of contaminated air filters. About 25% mentioned experiences with patients and nurses, especially regarding diagnostic techniques. Other cases dealt with irradiation of food, the handling of parcels with a radioactivity warning sign, the storage of nuclear waste and public debates about plans for new nuclear power stations. So the participants appeared to be quite experienced in dealing with anxious people.

Aspects said to be emphasized in these situations could be classified into five categories:

I comparing with other risks (n=34)
II giving scientific information (n=24)
III reassuring (n=20)
IV indicating how to reduce the risks (n=7)
V other aspects (n=11).

A majority mentioned more than one aspect. Category I included comparisons with the risks of natural or background radiation, X-ray pictures and risks in other human activities. Category II referred to scientific information about radiation and radiation protection. In category III we placed reassuring remarks about the severity of regulations, the accurate measurability of radiation, the small chance of effects with small doses, the many relevant results of research, panic-mongering media, the controllability of risks and the availability of expertise. Category IV included advice about safe behaviour and explanations of how certain measures and regulations work. The final category contained a variety of singular answers. About half of these included offers to anxious people of additional information, for instance by inviting them to visit a site where radiation is used.

In the second round, categories I to IV were presented to the participants who were asked to indicate to what extent teachers should give attention to these aspects when pupils appear to be anxious about radiation. Table 5.4 presents the results.

Table 5.4 The preferred emphasis on particular aspects in education when pupils are anxious about radiation (N=49)

category		average score (*)	s.d.
II	giving scientific information	3.3	.61
I	comparing with other risks	3.1	.86
IV	indicating how to reduce risks	2.9	.75
III	reassuring	1.6	.65

(*: 4 = a great deal, 1 = none)

The table illustrates that participants gave low priority to 'reassuring' in science education. Category I was most controversial of the four: 41% preferred giving it a great deal of attention, and 27% none or hardly any.

In order to get more insight into the ideas of participants about these categories a number of questions were included in the same round. Category II was not explored further as this aspect was the object of research in another part of the Delphi-study (section 2.4).

The aspect of *reassuring* was further explored in a question in which each respondent had to indicate which of seven ways of reassuring (taken from the answers in the first round) they would recommend for use by teachers in secondary education. The results are presented in Table 5.5.

Table 5.5 Recommended ways of reassuring in secondary education (N=49)

It should be emphasized that:	n	%
a. a lot of relevant research results are available	34	69
b. ionizing radiation can be accurately measured	34	69
c. the chance of effects of low doses are much smaller than estimated by the public	23	47
d. we have stringent legal rules	19	37
e. at relevant places the necessary expertise is available	13	27
f. the risks are controllable, even in the event of accidents	10	20
g. the media spread panic unnecessarily	5	10
h. other	10	20

The 'other' category contained mainly points which would fit into aspects dealt with in other questions, such as giving scientific information, comparing risks and indicating how to reduce risks. An exception is the reference made to the positive aspect of the use of ionizing radiation.

Looking back at the results presented in Table 5.4 it is at first sight surprising that so many ways of reassuring were recommended (on average three per participant). After all, in the same questionnaire about 50% of the participants expressed the opinion that in education no attention should be given to reassuring. Even that 50% were found to recommend on average 2.6 ways of reassuring! We suppose that these participants, when answering the question related to Table 5.4, had other ideas about reassuring than points a - c from Table 5.5. They may have assumed reassuring to mean for instance 'just soothing', and not 'giving information which might reassure people' (such as a, b and c).

Another question in the second round was devoted to the kind of attention which should be given in education to ways of *reducing the risks of radiation.* As this point was not elaborated very often in the answers to the first round we decided to ask this question in a more open way. The answers can be classified into four categories (Table 5.6).

Table 5.6 Recommendations about various ways of reducing radiation risks to be dealt with in education (N=49)

points for special attention	*n*
a. policy measures (inspection, licenses, control measurements)	14
b. general principles of radiation protection (time, distance, screening, ALARA, dose limits, justification)	15
c. prevention or limitation of contamination	10
d. no answer	10

Those answering the questions seem to have taken different viewpoints, i.e. what might be done by the government, by radiation experts and by individual citizens. It seems that the group felt that citizens could mainly reduce their radiation risks by avoiding radioactive contamination.

Finally, in the second round two questions were concerned with *risk comparisons*. The results obtained for these will be presented in the next part.

Results on risk comparisons

One question in the second round asked respondents to mention risks which could be recommended for making comparisons with radiation risks. Another asked which objections one might have towards risk comparisons. Table 5.7 summarizes the responses to the first question.

Table 5.7 Recommended risks for comparison with radiation risks (N=49)

type of risk	n
participating in traffic	24
industrial labour	22
use of hazardous substances	13
smoking	13
natural radiation	7
medical applications	7
energy alternatives	5
sport activities	5
natural disasters	4
drinking alcohol	3

Participants mentioned a wide variety of situations which were seen as suitable for risk comparisons. On the other hand, a majority (30) gave at least one objection to risk comparisons, which suggests that one should be careful with using risk comparisons in education. The objections can be summarized under eight headings, as presented in Table 5.8.

Table 5.8 A summary of objections to comparing radiation hazards with other risks in education

a. the nature of the effects might differ;
b. large- and small-scale risks are not comparable;
c. not only the total number of victims should be taken into account, but also the amount of social disruption;
d. the extent of control of the risk might differ;
e. risks might be voluntary or involuntary;
f. a distinction should be made between individual and collective risk;
g. risk perception is not a simple function of chance and effects; a judgement can never be fully objective and rational;
h. the acceptability of a particular application of ionizing radiation is determined not only by the radiation risk but also by other factors.

One might conclude that these objections apply to the use of risk comparisons in general. Some of the remarks of participants refer specifically to the use of risk comparisons in education:
- pupils might not be open to risk comparisons;
- real risk analysis is too difficult for secondary education;
- in education no conclusions should be drawn from risk comparisons.

The variety of answers about the risks which would be suitable for comparisons and about the objections to making such comparisons made it difficult to draw conclusions about the views of the participants. For instance, it might be that they had not considered all the points put forward by other participants. The variety seemed interesting enough to justify further investigations on the aspect of risk comparisons. The third round of the Delphi-study offered the opportunity for just such further exploration.

In the third round we wanted to find out what risk comparisons would be suitable given a particular risk and what objections should be taken into consideration when making such comparisons. In order to reduce the number of risks we categorized the risks mentioned in the second round (Table 5.7) into three sets:
A. risk of background radiation;
B. risk of toxic chemicals (carcinogenic and mutagenic);
C. other risks (traffic, smoking, industrial labour, sports, natural disasters).

Only set A refers to a radiation risk, one which is involuntary; set B contains non-radiation risks with a dose-effect relationship similar to radiation risks; set C contains all other risks of a non-radiation type.

In the questions we presented the participants with two specific radiation risks, quite different in context and nature:

I the emission of radioactive substances *after* an accident at a nuclear power station ;

II the use of ionizing radiation in medical diagnoses.

We then asked them how useful it would be - in view of the aim of promoting thoughtful risk assessment by pupils - to compare each of these risks with other risks (types A, B and C) and which objections (given in Table 5.8) should be taken into account when making these comparisons. Tables 5.9 and 5.10 present the results of the question about risk I.

Table 5.9 Views of the participants on the usefulness of three types of risk comparisons when discussing the risk of accidental release of radioactive substances by a nuclear power station (N=35)

type of risk comparison	always useful (%)	useful with some objections (%)	not useful (%)	no answer (%)
A. background radiation	26	57	12	6
B. toxic chemicals	31	37	23	9
C. other risks	23	46	22	9

Table 5.10 Objections of participants to comparing the risk of accidental release of radioactive substances by a nuclear power station with three types of risk (N varies (*))

objection (cf Table 5.8)	number of participants having objections A N=20	B N=13	C N=16	total
a. nature of effects	2	5	10	17
b. scale of risks	2	2	5	9
c. not only victims	10	6	5	21
d. controllability	7	3	8	18
e. voluntariness	8	3	9	20
f. individual/collective	7	4	9	20
g. risk perception complex	5	3	7	15
h. acceptability comprehensive	9	6	6	21

(*: only objections of people who find the comparisons in principle useful are included)

Table 5.9 shows that more than two thirds of the participants supported the use of each set of comparisons in education. All respondents who answered this question found at least one type of comparison useful. However, many of them had some objections to an uncritical use of these comparisons: less than one third of the participants saw no problems in the use of the comparisons. The risk of background radiation seems to be the most acceptable comparison, albeit with some qualifications.

Table 5.10 does not show much differentiation between the various objections: except for b, all objections are mentioned between 15 and 21 times. In risk type A the nature of the effects is not seen as a very important objection, the opposite of the perceived importance of this objection in set C. This is understandable as set C encompasses non-radiation risks with different effects. More surprising is the small number of objections in category b, as the risk perception literature (Slovic, Lichtenstein and Fischhoff, 1979; Van der Pligt, 1985) shows that 'scale' is an important factor in public perceptions of the risk of nuclear energy. The lower numbers in set B could be explained by the smaller number of participants who find this type of comparison useful with some objections.

In order to limit the time required to fill in the questionnaire we did not ask respondents to answer the same question about the risk of using ionizing radiation in medical diagnoses (risk II). Instead we asked them if their answers on risk II would differ from those on risk I. The answers show quite a variety of opinion among the participants, varying from "of course they would differ" to "they would differ slightly" or "no difference". Most of those who would answer the question differently (about 50%) argue that in medical diagnoses one has to make a cost-benefit analysis: it should be compared with the risk of doing nothing and with the risk of other diagnostic techniques. Some participants refer to the fact that the possibility of choice is different between risks I and II.

Those who would make no difference often take the position that radiation risks should not be seen as very distinct from other risks. In their view the radiation risk should have a place *amongst* other risks and not *above* all other risks.

Finally, we asked our participants to describe what should be the aim of using radiation risk comparisons in education. 70 % of them gave an answer to this question. The answers show a variety of aims.

Some answers emphasize the contribution comparisons would make to a general increase of knowledge about the effects of radiation and about radiation standard levels, to factors important for risk perception, and to learning to assess risks independently in a variety of situations. These participants seemed to be in favour of increasing the number of 'informed citizens', without promoting any particular attitude towards radiation risks.

Another group of answers could be labelled as 'putting radiation risks in perspective'. Some examples are:

"radiation is part of our environment"

"radiation risk is only one of many risks in our society"

"living without risks is impossible"

"not only radiation but also natural products can be hazardous or healthy"

"risks of toxic chemicals are less well known than those of radiation"

"radiation is a phenomenon which should be dealt with in a positive way: evolution etc.".

These participants seem to hold the opinion that radiation risks are exaggerated and not seen in perspective. They suggest an approach in which a less negative attitude towards radiation risks is promoted.

A few participants, however, took the opposite standpoint:

"clearly showing that any radiation dose means an additional risk"

"small mistakes might have big effects"

"radiation is risky, irrespective of its origin".

These seem to hold the opinion that education should not aim to downplay radiation risks.

This variety of opinions makes it difficult to draw conclusions about the suitability of risk comparisons for education. We will consider this point in the next section when summarizing and discussing the results of our investigations on the question of how to deal with radiation risk in education.

Conclusions and discussion

In this study use was made of the Delphi-technique, as the study had already been planned for other reasons. Before starting to discuss the results we will first discuss our experiences with this method in this partial study. Firstly, remarks made in the first and second round by a few participants became of major importance when the other participants were asked to take these into consideration. Examples were the importance of ways of reducing radiation risks, some ways of reassuring pupils, the importance of comparing with natural radiation risks, and some objections towards risk comparisons. Secondly, the opposite also happened. Remarks which seemed to be important in the first round appeared to be less important later, for instance the role of reassuring in general and some ways of reassuring in particular. Last but not least, we should mention an advantage of the organization of the study in three rounds: because of this it was possible to identify points which could not have been foreseen beforehand and which appeared to be worth exploring in subsequent rounds, in our case the issue of using risk comparisons in education.

When interpreting the results of this study we have to bear in mind that what we found are the considered opinions of radiation experts about causes of radiation anxiety and about ways of dealing with this in education, no more and no less: no more, as we could not claim to have revealed what the causes of radiation anxiety really are, nor that we have found ways of dealing with radiation anxiety in education which definitely work; on the other hand no less, as we were able to initiate a structured communication between the participants about how to deal with radiation anxiety in education and to reveal arguments which could play a part in discussions among curriculum developers and teachers about how to cope within education with feelings in education about radioactivity and ionizing radiation. With these considerations in mind we will now summarize and discuss the results of our study.

As important reasons for public anxiety about ionizing radiation (research question 1) we found four aspects (Table 5.3):
- the nature of possible effects;
- lack of knowledge;
- association with nuclear arms;
- radiation is not detectable by the senses.

The first aspect refers to acute radiation diseases and cancer (a disease which in our society is very common and is dreaded), but possibly also to the effects of the explosion of nuclear bombs (including those of fire and blast), which relates this aspect to the third one. We assume that the second aspect deals with both the existence of persistent lay-ideas about radiation and the lack of scientific notions, as discussed in chapter 3 of this thesis. The fourth aspect relates to feelings of fear about an 'enemy' (such as cancer) which is not visible or audible and therefore difficult to avoid, an 'enemy' which might strike any moment.

Aspects seen as less important include the influence of the media in giving biased information, for instance about accidents, and the distrust of information given by government bodies and experts regarding nuclear matters. The latter aspects are more of a socio-political nature: people are seen as being brainwashed to a greater or lesser degree and as lacking the proper attitude towards experts which is necessary to become well informed. The first four aspects are more cognitive and may in principle be more affected by science education.

How science teachers can respond to anxiety amongst pupils was the main question of our study. According to the participants greatest attention in education should be given to imparting scientific information, comparisons with other risks and ways of reducing the risks; 'reassuring' was given a low priority, although participants themselves often used 'reassuring' in dealing with anxious people. This is understandable as the situations in which the participants meet radiation anxiety differ considerably from education: during their professional activities they meet anxious people in situations in which decisions have to be taken (e.g. on eating food, having a treatment, travelling, protection against a hazardous source) whilst in education there is no actual danger at hand which evokes fear nor an urgent dilemma in which a choice is required.

Giving scientific information probably refers to aspect 2 mentioned above (lack of knowledge), and reassuring seems to be related to the influence of the media and the distrust of experts (maybe they would believe teachers). So the low priority of reassuring is not very surprising. However, some ways of reassuring seem to be less objectionable than others. For instance, pointing out the availability of a large number of research results and the measurability of radiation is acceptable for over two third of the participants. Perhaps these are seen as part of 'giving scientific information'; measurability certainly modifies people's ideas about radiation not being detectable by the senses: measuring devices can be seen as an extension of human senses. Drawing attention to research counteracts the popular idea (Wagner, 1983) that "we don't know *everything* about radiation" means "we don't know *anything* about radiation".

Three approaches to reducing risks were found in the answers of the participants: policy measures, general principles of radiation protection, and ways of reducing the risks of contamination. Another way of looking at these approaches to reducing risk is the extent of control of the individual citizen. Policy measures are established by bodies on which the individual citizen has hardly any influence. Education about the policy measures might help him/her to understand why the measures are taken, replacing a dependence on the extent of trust in the bodies which take these measures. The principles of radiation protection and the ways of limiting contamination by radioactive substances are in our view more within the locus of control of the individual citizen. They may be of use, for instance when a person is faced with a medical diagnostic procedure or treatment, with the use of radioactive sources as a worker in industry or with an accident which has taken place.

Risk comparisons emerged as the second important recommendation for science education. This became a focal point in the third round of the Delphi-study. Nearly all participants were in favour of using risk comparisons, but they differed in their views on the aim of such comparisons and on the precautions to be taken when using them. Some saw it as an important tool for risk assessment, others as a way to reduce the exaggerated risks of radiation, and a small minority as a way of raising awareness about the additional character of these risks. No consensus seems to be possible on these aims. The same might be said about the objections to the use of risk comparisons. These are probably related to the aims one has in mind.

Although these controversies prevent the formulation of generally agreed recommendations on how to compare risks, some lessons can be drawn from our results on this point. Firstly, the results emphasize the importance of teachers being aware of the aims of using risk comparisons. Textbooks might be analyzed on the way they use these comparisons and hidden aims might be identified. Secondly, hardly anyone denies the importance of risk comparisons: although each (radiation) risk is in a way unique, it is not so unique that it is incomparable with any other risk. But further consideration is needed to establish which kind of comparisons are suitable for which aim, and which limitations of these comparisons need to be taken into account. Thirdly, it raises the question of what knowledge is required in order to make risk comparisons.

5.4 TEACHING IONIZING RADIATION WITHIN A RISK PERSPECTIVE

Introduction

In section 1.2 we have outlined the reasons for choosing as an educational aim to promote more informed radiation risk assessment. A teacher who chooses this aim will find that his/her pupils will have certain ideas and attitudes about the risks of ionizing radiation. We will start this section with a summary of our findings related to pupils' initial conceptualizations towards the risks of radiation.

The aim itself has not been discussed in the various reports of our investigations. At the end of this chapter we will focus on this aim as we have learned from our studies that risk assessment is a complex process with a number of components which could only partly be dealt with in physics education. We will try to answer the question which components of the aim of risk assessment are most suitable for developing curriculum materials for our target group. This will result in recommendations for a set of more specific objectives within the general aim.

Pupils' initial conceptualizations of radiation risks

What might a teacher expect of his/her pupils when starting to teach the topic of ionizing radiation? We will answer this question by summarizing the results of our studies which are, in our view, most relevant:

a. pupils are interested in matters of risk and safety, probably more than in the scientific aspects of radiation;
b. pupils will have heard about the risks of ionizing radiation: about the possible effects, about its invisibility and about the general anxiety which exists about radioactivity;
c. pupils will have developed certain general attitudes towards these risks: they tend to see radiation as always dangerous or consider the risks to be low;
d. the perceived risks of this kind of radiation depend partly on the context in which the radiation is emitted: in the medical and background contexts the risks are perceived to be lowest;
e. general attitudes towards radiation risks and perceptions of specific radiation risks are not easily changed: they are part of a complex system of personal and social beliefs and values; often disconfirming information is rejected as unreliable, erroneous or unrepresentative;

f. some preconceptions about ionizing radiation (e.g. its 'conservation' and the perceived similarity between irradiation and contamination) obstruct a thoughtful risk assessment;
g. pupils will approach the risks of ionizing radiation in a non-expert way which differs considerably from that of experts: in this approach scientific information (especially of a quantitative nature) and statistical or experimental evidence plays a minor role.

Analysis of the aim of risk assessment

In section 5.2 it was shown that risk assessment is a complicated concept. It encompasses risk identification, risk estimation and risk evaluation. Each of these components includes a number of methods and requires specific knowledge and understanding of concepts, processes, risk parameters, weighing procedures, etc. Pupils cannot be expected to become experts in all these fields, especially taking into account the limited number of periods which can be devoted to teaching the topic. This requires choices and a clearer analysis of the aim of promoting risk assessment than assumed at the start of our investigations.

Before actually analyzing this aim it should be realized that these choices strongly depend on the purposes of teaching ionizing radiation in a risk perspective. In our view these purposes are value laden. Quite different purposes could lie behind the aim of risk assessment, for instance:

- pupils should have a more positive attitude towards radioactivity;
- pupils should be more aware of the potential hazards of ionizing radiation;
- pupils should know when and how to be careful with ionizing radiation;
- pupils should be able to appreciate the effectiveness and limitations of radiation safety measures;
- pupils should be able to make decisions in matters of personal and social relevance related to the risks of ionizing radiation.

In our view changing attitudes towards ionizing radiation (first and second purposes) should not be a purpose of education. This does not mean that education should simply reinforce existing attitudes. We would be in favour of opening up the possibility of changing attitudes, for instance by widening the scope of pupils' ideas: showing which aspects should be taken into account, making distinctions where appropriate. As purpose we would prefer the fifth one above, although we realize now that this cannot be fulfilled in the time available. Taking into account the recommendations of radiation experts (emphasizing scientific information, risk comparisons and ways of reducing radiation risks), it may be more realistic to adopt the third and fourth purposes above, as these are quite close to the initial interests of pupils and can be seen as prerequisites for decision making.

Another aspect to be taken into account is the knowledge and experience of teachers. As may be concluded from our interviews with teachers and from our analysis of current physics textbooks, teachers are not generally familiar with 'risk assessment' or with all the concepts, processes, parameters, perceptions and values involved. This is an additional reason for not setting the aim of risk assessment at too advanced a level.

Finally, we will analyze further the general aim of promoting better risk assessment. Taking into account the results of our studies so far, we suggest making a distinction between the following objectives which would fit in with the general aim:

1. Being able to estimate the consequences of particular doses of ionizing radiation, such as:
   - making the distinction between acute and late effects;
   - roughly relating the dose equivalent of 1 Sv to the increased chance of getting cancer;
   - giving the mean lethal dose equivalent.
2. Being able to identify some relevant points for determining the risks of radiation in a particular situation, such as:
   - did irradiation or contamination take place?
   - how much is the received dose equivalent?
   - over what period was the radiation received?
   - are any additional doses to be expected?
   - in the event of internal contamination: which nuclides were involved, do these nuclides accumulate in specific parts of the body, what radiation is emitted, what is their half-life, how quickly does the body excrete these nuclides?
3. Being able to judge the effectiveness and limitations of safety measures, for example:
   - taking iodine tablets;
   - keeping at a distance;
   - remaining inside;
   - avoiding an area;
   - evacuation;
   - taking a shower;
   - shielding;
   - using a dosemeter or badge;
   - issuing standard levels for food and maximum permitted doses within a certain period (for radiation workers and ordinary citizens).
4. Being able to compare applications of radiation with other methods of achieving the same aim without radiation: compare advantages and disadvantages, such as risks, side-effects, costs, for example:
   - nuclear energy vs other methods of producing electricity;
   - irradiation of tumours vs chemotherapy or operation;
   - use of X-rays vs other diagnostic methods;
   - irradiation of food vs other food preservation methods.
5. Being able to compare radiation risks with other risks in daily life, such as smoking, sports, traffic, alcohol, which includes:

   - comparing annual number of victims;
   - comparing other detrimental consequences;
   - recognizing limitations of comparisons of this kind.
6. Being able to analyze the risks of failure in installations and procedures, such as nuclear reactors, transport of radioactive substances, storage of nuclear waste, which includes:
   - indicating the chances of failure in a procedure or an installation;
   - estimating the consequences of these failures;
   - making a fault-tree analysis.

Within the time constraints it would be impossible to deal with all of these six objectives in any depth. So a selection has to be made, based on explicit criteria. Considering the recommendations of the radiation experts for selecting context domains and scientific contents (section 2.4) and the complexity of risk assessment (section 5.2), and taking into account the fact that our study focusses on physics education, we propose the following four criteria for selecting objectives:

a. knowledge of physics should play an important part in achieving the objectives: otherwise it may be difficult to argue that they should be dealt with in physics education;
b. knowledge of other disciplines should not be too great: physics teachers may otherwise avoid this kind of teaching and pupils may also have difficulties accepting the topic as part of physics education;
c. knowledge elements should preferably not be too context-specific: elements are more useful if they are applicable in a variety of contexts;
d. assessment procedures should not be too complicated: risk assessment can be carried out at various levels of expertise and general secondary education is not vocational training.

It should be acknowledged that criteria a and b are relevant only if teaching of the topic of ionizing radiation takes place within one discipline, as is the case in senior secondary education in the Netherlands. It should not be read as a plea for single-discipline education. If the topic is taught in science courses, the term 'physics' should be replaced by 'science'.

If we apply these criteria to objectives 1-6 above, we reach the following conclusions:

- objectives 1, 2 and 3 seem to fit all four criteria;
- objective 4 requires a great deal of knowledge which is quite context-specific and from areas other than physics, for example to answer the questions:
  - what is chemotherapy?
  - what are its benefits and its side-effects?
  - what is the price?

  so objective 4 does not meet criteria b and c;

- objective 5 evokes similar comments, considering questions to be answered such as:
  - what are the risks of these other activities?
  - why are they (not) comparable?
- objective 6 does not meet criteria b, c and d; it requires answers to questions such as:
  - how does the installation work?
  - what are its weak points?
  - what is the chance of an accident?
  - what is the risk once the accident has taken place?
  - what are the costs of reducing these risks?

What are the implications of this for teaching with the aim to promote through physics lessons a thoughtful assessment of the risks associated with ionizing radiation? Such an aim is rather wide and essentially accommodates all six objectives. We would propose limiting this aim and focussing on the first three objectives; the fourth and fifth objectives should receive minor attention and objective 6 should not be dealt with. In the following chapter we will outline the implication of this analysis of our risk assessment aim for developing curriculum materials, for teaching and for the preparation of teachers.

6. RECOMMENDATIONS FOR TEACHING ABOUT IONIZING RADIATION AND RISK

6.1 INTRODUCTION

In chapter 1 (section 1.2) of this thesis it was stated that the point of departure of this study was the PLON-unit *Ionizing Radiation*, with its specific aim of increasing pupils' ability to assess risks of ionizing radiation in various fields of application. The study aimed to explore the nature of the problems detected in an earlier evaluation study on the use of the unit in physics lessons (Eijkelhof, Wierstra, 1986; Eijkelhof, 1986), and to lead to recommendations for curriculum development, teaching strategies and teacher training.
The general research question was formulated as:

> Which curricular and other teaching conditions must be fulfilled in order to promote thoughtful risk analysis and assessment as regards applications of ionizing radiation, through physics lessons in senior high school?

The investigations carried out and reported in earlier chapters approached this question from various angles, taking into account the views of radiation experts, writings about radiation topics in the news media and in school textbooks, pupils' ideas before and after teaching, and class experiences. The results led to recommendations by radiation experts about contexts and contents for teaching about ionizing radiation and for dealing with radiation anxiety, to an increase of our insights into lay- and pupils' ideas and forms of reasoning in this field, to a better understanding of learning problems and teaching difficulties, and to amended views on the aim of risk assessment. All these points have been discussed in the chapters 2 to 5.

In this chapter we first reconsider these points together, in an attempt to formulate an answer to the general research question above. The resulting recommendations concern curriculum contents, teaching strategies and teacher training.

In a final section we will present recommendations which go beyond the general research question, such as recommendations for further research on the topic of this thesis and recommendations for similar research in other areas of science, and as regards STS-education and preconceptions research.

6.2 RECOMMENDATIONS FOR THE SELECTION OF CURRICULUM CONTENTS

Introduction

In the previous chapter (5) it was shown that, although the general aim of 'promoting thoughtful risk assessment' could be retained, it is important to be more specific about the objectives of learning to assess risks. Using several criteria, the following main objectives were proposed and defended:

1. pupils should be able to estimate the consequences of particular doses of ionizing radiation;
2. pupils should be able to identify some relevant points for determining the risks of radiation in a particular situation;
3. pupils should be able to judge the effectiveness and limitations of safety measures, i.e. their contribution to the reduction of radiation risks.

Lower importance was given to the following objectives:

4. pupils should be able to compare applications of radiation with other methods of achieving the same aim without radiation: compare advantages and disadvantages, such as risks, side-effects, costs;
5. pupils should be able to compare radiation risks with other risks in daily life, such as smoking, sports, traffic, alcohol.

In this section we focus on recommendations concerning points which should be taken into account in selecting suitable contents and contexts for a curriculum which has these objectives.

The recommendations are not particularly geared towards rewriting the PLON-unit *Ionizing Radiation* but are intended to be valid for any curriculum materials with the above mentioned aim.

Recommendations about contexts

In section 2.4 we reported the opinion of radiation experts about contexts involving ionizing radiation which should be included in the physics curriculum. We repeat in Table 6.1 this list of recommended context domains.

The experts agreed with the following criteria for the selection of contexts:

- the coverage of the total collective dose by the set;
- the degree to which people may get involved in the contexts;
- the variety of existing applications of radiation in society;
- the importance of the social implications.

The general nature of these four criteria is that pupils should get a wide overview of those applications which exist and are of personal and social importance.

In our view some additional criteria should also play a part in the selection. One criterion arises from one of our findings in the interviews

Table 6.1 Context domains recommended by radiation experts for the physics curriculum

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category I (important)
1. Background radiation: from the cosmos, food, rocks, building materials etc.
2. Medical applications: diagnostic and therapeutic uses of X rays and nuclear radiation.
3. Nuclear energy: emission of radioactive substances, normally and after an accident.
4. Storage of nuclear waste: underground, above ground, on the ocean-floor.
5. Fall-out (as a consequence of nuclear weapons explosions).
6. Some applications of ionizing radiation in scientific and industrial research (e.g. tracers).

category II (fairly important)
7. Other industrial applications (materials research, sterilization, measurement and control).
8. Immediate consequences of nuclear weapons explosions.
9. Radioactivity from coal fired power plants.

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with pupils: pupils appear to be quite familiar with some contexts, such as some medical applications, nuclear energy and nuclear waste, and less with others, such as food irradiation and radon. Probably because of social influences they have developed certain ideas and attitudes about the familiar contexts which seem to be quite strong and resistant to change. Here we meet the dilemma noted by Novak (1988) that pupils' prior knowledge is both an asset and a liability for subsequent meaningful learning. An advantage of including familiar contexts is that they could be used in class to promote discussion of pupils' ideas and to provide opportunities for pupils to apply scientific knowledge. A disadvantage is that it may be difficult to change their ways of thinking and arguing in these contexts. Their present ideas may obstruct the development of more scientific viewpoints. So it could be very useful also to include contexts with which they are not yet familiar and in which they may be better able to develop and use scientific ideas and ways of reasoning. So this criterion could be labelled as 'variety in familiarity'.

A second additional criterion we propose is that the contexts selected - and selection is necessary due to time constraints - should offer opportunities for attending to those lay-ideas and scientific concepts and processes which are of significant importance in a number of contexts. Examples are lay-ideas, which we have shown are often related, about the nature, propagation, absorption and effects of ionizing radiation, concepts such as 'ionizing radiation', 'radioactivity', 'activity', 'half-life' and 'dose (equivalent)', and processes such as irradiation, absorption of radiation and the dispersal of radioactive substances in the human body and in the environment. This would be an additional argument against contexts which mainly involve very specific knowledge, in agreement with criterion c for selecting the objectives of risk assessment (section 5.4).

If we apply these six criteria to the context domains of Table 6.1 the following conclusions may be drawn:

a. context domain 9 should not be included as it requires very specific knowledge related to one method of generating electricity;
b. context domain 8 deals with effects which occur only when nuclear weapons explode. The social significance of nuclear explosions cannot be denied but knowing how disastrous these weapons are does not require detailed scientific knowledge. The main direct consequences are not due to ionizing radiation but to blast and heat;
c. context domain 7 contains an application which people could meet in daily life (food irradiation). Although pupils appear not to be familiar with this context, it appeared in the interviews (section 3.4) and in the classroom (section 4.3) to be a useful context for discussions with pupils about ionizing radiation. Lay-ideas in this field appeared to be resistant to change (section 4.5);
d. context domain 6 does not have much direct social and personal relevance, but the context of tracers may be helpful in clarifying the distinction between irradiation and contamination;
e. context domains 1 to 5 seem to be in accordance with all the criteria.

Therefore we propose that curriculum materials should focus mainly on contexts within domains 1, 2, 3, 4 and 5, and on some in 6 and 7.

Recommendations about contents

In this section we will discuss what kinds of additional content elements (such as concepts, processes, apparatus) should be recommended for curriculum materials. Table 6.2 lists those subject-matter items which have been recommended by radiation experts (section 2.4).

The items are classified into two groups: basic knowledge about atomic and nuclear physics, and about radiation protection. With exception of the concept of activity, the first group of items are characteristic of most school textbooks. Knowledge of these items is required in order to be able to answer questions such as:

- what are the characteristics of substances which emit ionizing radiation?
- how do you express the strength of a radioactive source?
- at what rate does the strength of such a source decrease?
- what new substances are formed during the emission of ionizing radiation?
- which kinds of ionizing radiation exist and what are their characteristics?
- how is it possible to detect ionizing radiation?

- what is the nature and origin of radioactive substances which might be emitted by a nuclear power station?

Table 6.2 Subject-matter items recommended by radiation experts

A. Basic knowledge about atomic and nuclear physics
  - *structure of the nucleus*: nucleon, proton, neutron, atomic number, mass number, (Z,N)-diagram, isotope, atomic mass unit;
  - *radioactive sources*: stable and unstable nuclei, energy levels of a nucleus, disintegration, activity [Bq], radioactive decay curve, half-life;
  - *ionizing radiation*: alpha-, beta-, gamma- and neutron-radiation, X rays, nature and properties of these types of radiation, X-ray spectrum;
  - *detection of radiation*: Geiger counter, photographic plate, cloud chamber;
  - *nuclear energy*: nuclear reactions, nuclear fission, chain reaction, principles of a nuclear reactor.

B. Basic knowledge about radiation protection
  - *irradiation*: absorption, dose [Gy], interaction with living matter, dose equivalent [Sv], influence of distance and medium;
  - *contamination*: spreading of radioactive substances in the environment and in the human body;
  - *effects of ionizing radiation*: early and late effects of low and high doses, somatic and genetic effects;
  - *safety aspects*: film badge, lead apron, radiation norms, ALARA-principle, safety measures.

Some of these questions were already formulated in the PLON-unit (section 2.3); some new ones have been added, for instance the last one, to take into account the nature of the recommended contexts. These questions are neither directly about risks nor purely of scientific interest. These are the kinds of question which seem to be helpful in focussing on the background to radioactivity and ionizing radiation. Someone who is able to answer these questions is likely to be better able to interpret risk information, as often in this kind of information some basic knowledge about the origin, nature, characteristics and measurability of ionizing radiation is assumed. This criterion has probably been used implicitly by the participants in the Delphi-study in selecting scientific contents. An advantage of formulating questions of this type is that they may be used in teaching to illustrate the function of scientific contents, showing the fruitfulness of learning about these.

The second group of items (about radiation protection) is less common in school textbooks. These deal with irradiation, contamination, effects of ionizing radiation and safety aspects. Knowledge of these items is required to answer questions such as:

- what may happen when radiation falls upon living matter?
- how do you express the amount of radiation which someone receives?
- what are the health effects of ionizing radiation?
- how much radiation is (relatively) safe?
- how can one protect oneself against ionizing radiation?
- which safety measures are effective in particular situations?

These questions are much more geared towards the risks of ionizing radiation. They fit within the three main objectives of our risk assessment aim, as recommended above. Some of these questions were already addressed in the PLON-unit (section 2.3); others have been added, particularly the first one - in view of some persistent lay-ideas -, and the last one - in response to objective 3.

An important item in view of objective 2 (but missing in the present PLON-unit) is 'the spreading of radioactive substances in the environment and the human body'. This applies to almost all recommended contexts domains. The contents of this novel item deserve further attention, for instance by consulting some experts in this field. The inclusion of the following aspects may be considered:

- particle size: molecules, aerosols;
- adsorption process: the adhering of, for example, gases to solid particles;
- distribution of radionuclides by weather processes: inversion, wind, precipitation;
- behaviour of radionuclides in the human body: biological half-life, storage in specific organs.

We would recommend that curriculum materials should give attention not only to the effective dose equivalent which radiation workers and the public are allowed to receive in one year, but also to radioactive contamination standards for food, in view of objective 3. From the same objective it could also be argued that a range of personal and governmental safety measures deserve attention, such as those mentioned in 5.4. These safety measures are good opportunities for applying scientific knowledge. At the same time pupils are prepared to interpret future situations in which these safety measures may be applicable.

Some general outcomes

The preceding two sections deal exclusively with recommendations which are specific to the aim and objectives of teaching about ionizing radiation and risk. A general conclusion may be that most of the contents and contexts of the PLON-unit have been legitimated by the participating radiation experts. Differences principally involve the inclusion of some new contexts, the accentuation of parts of context domains, and a new emphasis on contamination and safety aspects. We also introduced a criterion for selection related to the incidence and persistence of particular lay-ideas associated with ionizing radiation.

How useful is the approach we have adopted when seen from a more general viewpoint? Consulting experts in order to seek consensus about aims and contents of science education has been attempted before, for instance by Häussler and his colleagues at IPN (Häussler et al., 1980). Their Delphi-study in three rounds covered the importance of physics topics for general education. Atomic and nuclear physics were identified as important, one argument being that basic knowledge of nuclear physics might contribute to a better assessment of risks and benefits of nuclear technology. The question of *which* basic knowledge would be most suitable for this purpose was not addressed, instead some examples were simply given.

In science education and especially in STS-education, the approach of consulting experts to formulate aims and contents of the curriculum is not common. A similar approach has been followed for mathematics education in the UK (Cockcroft, 1982), by analyzing the mathematical needs of adult life and of employment. In the Netherlands, such an approach is more common in vocational training. An example is the study of Engels and De Jager (1988) about the training of medical nuclear workers.

An approach like ours may fit more easily within a new trend in Dutch educational policy for vocational training and senior secondary education, namely the development of modules: more or less autonomous parts of curricula (O&W, 1988). These modules are supposed to be based on an analysis of situations (such as vocational practice, courses of further study or daily life). Our approach may be suitable for formulating the aims and contents of some science modules, especially those which deal with a variety of contexts and with controversial issues.

6.3 RECOMMENDATIONS FOR TEACHING

Introduction

In this section we will focus on recommendations for teaching ionizing radiation with the aim of promoting conceptual change. The recommendations are mainly based on the results of our investigations with pupils inside and outside the classroom (chapters 3 and 4). First we provide a background to our recommendations by discussing some views from the literature on conceptual change. Then we will present our recommendations for dealing with concepts in this area of the science curriculum.

Teaching for conceptual change

Most researchers in the field of science education seem to agree with the view that learning consists of the restructuring of knowledge (Vosnadiou & Brewer, 1987; Novak, 1988). The 'tabula rasa' view (described by Gilbert, Osborne and Fensham, 1982) assuming that pupils are blankminded may still be held by many practitioners but is not defended in the science education literature. The general view now is that most learning involves either incorporation within prior knowledge (Piaget's 'assimilation') or modification of prior knowledge (Piaget's 'accommodation'). Piaget attributed developmental change to global restructurings known as 'stages', brought about by the growth of a child's logical abilities. This kind of restructuring has been labelled as 'global' (Carey, 1985). This view has been seriously criticized by several people, including Carey. She claims that restructuring is not the result of the child's logical capabilities per se but the product of increased knowledge of a domain ('domain-specific' restructuring). Similar views to that of domain-specific restructuring have been proposed by researchers working in the area of science education (Driver and Easley, 1978; Posner, Strike, Hewson and Gertzog, 1982; Osborne and Wittrock, 1983) and by those studying differences between novices and experts in physics (Chi, Feltovich and Glaser, 1981; Clement, 1983; McCloskey, 1983).

Reif (1985) also appears to have a similar view when he summarizes the difficulties in learning scientific concepts and principles. He distinguishes two factors. The first is formed by the intrinsic characteristics of scientific concepts and principles: the knowledge required is considerable and sometimes subtle, and meticulous attention is required to details and fine discriminations. The second factor relates to the pupils: they bring into learning situations many concepts and principles acquired in daily life or from formal prior learning situations; they approach learning from the vantage point of daily life where concepts or principles are adequately useful even if they are specified vaguely and applied somewhat inconsistently.

Related to Reif's first factor, Ravetz (1971) has argued that scientific concepts are too complex and rich to be comprehended with a single schematism such as a definition. This view is supported by others (Polanyi, 1958; Johnson-Laird, 1983; Pines, 1985; Lijnse, 1988) who defend that a definition of a concept is always incomplete, for instance because each concept is involved in an immense network of relations and has various meanings within different contexts. Gilbert and Watts (1983) discuss the distinction between the 'classical', 'actional' and 'relational' views of concept. For the area of ionizing radiation, the complexity of the scientific meanings of concepts is well illustrated in the latest UNSCEAR-report (1988), especially as regards the various dose concepts which are in use.

Reif's second factor underlines the importance of research in which the prior ideas of pupils within a particular domain are investigated (Driver and Erickson, 1983) and of studies in which the changes brought about by science teaching, often quite different from those intended (Osborne and Wittrock, 1983), are investigated.

Another perspective on conceptual change is provided by Strike and Posner (1985). They are convinced of the important role of current conceptions of pupils in generating new knowledge. They have postulated a theory of conceptual change which describes four conditions which must be fulfilled:

1. There must be dissatisfaction with existing conceptions.
2. A new conception must be intelligible.
3. A new conception must appear plausible.
4. A new conception should be fruitful.

A theory of conceptual change of this sort allows for a variety of teaching strategies. Some teachers may believe that once they are armed with a knowledge of pupils' ideas, further instruction can then refute these ideas by teaching in a didactic way. Others may choose an approach in which the pupils are required to be more active. Millar (1989) suggests that, although active mental involvement by pupils is what matters for conceptual change, this does not necessarily mean learning through activities which explicitly follow the constructivist learning model (Driver and Oldham, 1986).

Driver, Guesne and Tiberghien (1985) suggest several teaching activities of the active type to promote conceptual change with pupils, such as:

A. Providing opportunities for pupils to make their own ideas explicit
The aim is that pupils come to appreciate which ideas they have at present. We consider this an orientating activity which lays the foundation for other activities in which new conceptions are introduced.

B. Introducing discrepant events
These events are aimed at inducing cognitive conflict in the pupils. These cognitive conflicts may result in pupils experiencing some dissatisfaction with the set of ideas which they have (Strike and Posner's condition 1). Resolving such cognitive conflict may contribute to condition 3: initial plausibility. A problem to be noted here, however, is that pupils do not automatically perceive the dissonance which teachers anticipate (Wittrock, 1986; Licht, 1987; Van 't Hul et al., 1989).

C. Socratic questioning
This technique is used mainly to facilitate the awareness of inconsistencies in an individual's current scheme. Often anomalies are used for this purpose, but the recognition of anomalies is not always seen as the optimal way to acquire new knowledge (Vosnadiou and Brewer, 1987). These authors also recognize that this technique puts high demands on the teacher who has to be interested in understanding pupils' points of view, propose alternate frameworks, create conceptual conflicts and lead pupils into constructing conceptually consistent theories of the domain. Socratic questioning may serve especially Strike and Posner's conditions 1 and 3.

D. Providing practice in using ideas in a range of situations
Driver et al. (1985) refer to opportunities for pupils to check out the range and limits of applicability of experimental results. In this way the activity can contribute to pupils' idea of fruitfulness of the concepts just learned: Strike and Posner's condition 4.

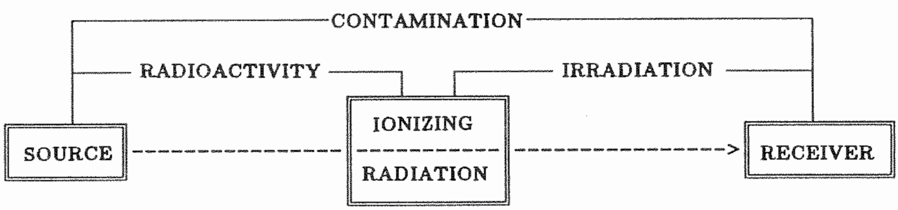
We tend in most cases to choose for our purpose activities in which the pupils are actively involved. One argument for this is that it was shown that some lay-ideas are quite resistant to change, probably because they are quite sufficient for pupils to explain events they have come across previously. A second argument is that a number of pupils' ideas are likely to be acquired through interaction with other people (Solomon, 1987). One may expect that changing ideas would then also require this kind of interaction. By analyzing protocols of dialogue in the classroom Ten Voorde (1977) has shown the importance of productive discussions in science education. However, it may be that some concepts, especially those which are not part of common culture, could well be explained by teachers without the use of a number of time-consuming social activities in the classroom. Research is required to investigate the effectiveness of both approaches for various concepts.

Recommendations for teaching

Our research findings show that pupils have considerable problems with some scientific concepts in the field of radioactivity and ionizing radiation. They appear to bring a number of lay-meanings into the classroom. Using these lay-meanings in interpreting messages in this field is likely to result in misunderstanding and distortion of information.

From our analysis of school textbooks, from class observations and from interviews with teachers we tend to share the conclusion of Tasker (1981) that pupils spend much of their time making executive type decisions and very little time really thinking about concepts in science.

In order to promote thinking about concepts we have developed a simplified conceptual scheme, which clarifies the relations and distinctions between concepts. This scheme is presented in figure 6.1.



radionuclide	types	dose (Gy)
activity (Bq)	properties	dose equivalent (Sv)
half-life		effects

Figure 6.1 Relations between scientific concepts regarding radioactivity and ionizing radiation

In this scheme a distinction is made between the basic concepts of SOURCE, IONIZING RADIATION and RECEIVER. This basic structure of the scheme would not be unfamiliar to pupils as it is also applicable to other fields of physics, such as sound, light and radio waves. All relevant concepts could be related to either SOURCE, IONIZING RADIATION or RECEIVER or to a combination of these. Some concepts relate only to one basic concept, for example, half-life and activity to SOURCE. Other concepts are intermediate between two basic concepts, such as irradiation which links IONIZING RADIATION and RECEIVER. The scheme clarifies, for instance, that the term 'radioactivity' is used in various meanings in daily life and in textbooks, such as denoting 'radioactive substance' and 'activity' (related to the SOURCE), 'radiation' (as belonging to IONIZING RADIATION) or as 'phenomenon in which ionizing radiation is emitted by a source' (in between SOURCE and IONIZING RADIATION).

It is not recommended that one should start teaching this topic with the full scheme. One may start at a phenomenological level with the bare scheme, making analogies with light and sound. New concepts could be located in the scheme as they are introduced. Pupils' ideas could be related to this scheme, clarifying how lay-meanings are different from the scientific ones. We expect that in such a way the scheme will assist pupils in accommodating their cognitive structure so that they are able to assimilate new concepts.

The scheme will become more complicated as the series of lessons proceeds. For instance, the SOURCE may be divided up into 'big sources' (such as nuclear reactors or sources used to irradiate tumours or food) and 'small sources' (such as radioactive substances released by these 'big sources'), both emitting radiation. These 'big sources' could be seen as 'closed sources' (i.e. emitting only radiation) which could by accident become 'open sources' with the possibility of releasing 'small sources'. Another way to make the scheme more complicated is to include in SOURCE those processes which result in the formation of radionuclides, such as radioactive decay of a 'mother' radionuclide, nuclear fission and capture of neutrons by a nucleus. On the RECEIVER side one could distinguish between effects at the molecular, cellular, organ and organism level.

Once the scheme becomes very complicated some of its limitations become apparent. For instance, the energy released per disintegrated nucleus is specific to a particular radionuclide (SOURCE), is characteristic of the radiation (IONIZING RADIATION) and determines which interaction process is likely to take place at absorption (such as Compton-scattering, pair-formation or photo-electric effect) (RECEIVER). We do not expect this problem to arise within the range of recommended objectives, contexts and contents. So our general recommendation is that teaching materials should give explicit attention to the relations between concepts.

It may be, however, that the full scheme above is too abstract to be used in teaching. In this case the teacher should use other methods, for instance pictorial representations, to illustrate the relationships between concepts. This may be especially so as regards the concepts of radioactivity, irradiation and contamination.

A second general recommendation is to deal with the existence of the most common lay-meanings amongst pupils and in society. One reason for this is that our findings among 6VWO pupils indicate that resistance to change of preconceptions, as reported in the literature for various fields of physics, also occurs in the field of ionizing radiation. Neglecting these kinds of meanings apparently does not remove their influence on the learning process.

A second reason is that, even if pupils have never heard of certain lay-concepts before education, these concepts will be met when reading articles in newspapers and magazines, or when speaking with others about radiation issues. Understanding what others mean by certain words would improve communication.

A third reason for making a plea for explicit attention to lay-ideas is that it will increase insight into the scientific meaning and into the applicability of the concept in question. Being conscious of various interpretations can help to delineate the scientific meaning and its relation to other scientific concepts.

Our third set of recommendations concerns the question of how pupils' prior knowledge should be taken into account. In the previous section we described four teaching activities (A-D) in a general way. We will now discuss the value which each of these approaches may have for teaching the topic of ionizing radiation.

A. Making pupils' ideas explicit
Such an approach seems to be especially useful in contexts such as health care, food irradiation, nuclear energy and nuclear waste. Many pupils' ideas relate more to the size of the risk than to explanations of phenomena. As the number of opportunities for making pupils' ideas explicit must be limited for time reasons, we recommend focussing on the set of ideas which seem to be most resistant to change. The most important ones seem to be ideas about the 'conservation' of radiation after emission and after absorption.

B. Introducing discrepant events
It is common to use experiments as discrepant events. For practical reasons it is difficult to do many classroom experiments involving ionizing radiation which force pupils to accommodate their existing cognitive structure. One example of such an experiment has been developed by Klaassen (Klaassen, Eijkelhof and Lijnse, 1989). In this experiment the teacher shows that radiation is not detectable at a certain distance from a source. This is then compared with the Chernobyl accident where radiation was detected at large distances from the reactor. This requires a different explanation and so the

distinctions between open and closed sources and between radiation and radioactive matter can be introduced.
Another useful approach may be the use of conflicting quotations from newspapers or pupils.

C. Socratic questioning
In our domain of ionizing radiation and risk, we recommend the use of Socratic questioning for topics such as:
- irradiation of food
- medical use of radiation
- ventilation for radiation safety
- safety measures.

All of these topics relate to the general lay-idea that radiation is conserved and to the lack of discrimination between contamination/irradiation, and radiation/radioactive substance.

D. Practice in using ideas in a range of situations
For this field of physics, first-hand experience of experimental results is not possible, other than in a few demonstration experiments. In our view it would be more useful here to provide pupils with a number of quotations to comment upon. These quotations could be about different contexts and should provide statements of lay- and scientific ideas which should be recognizable as such by pupils. Our various investigations, especially the interviews and analysis of newspapers, have provided numerous quotations which could be used for this purpose. The quotations may be particularly useful in clarifying and practicing the use of distinctions between pairs of concepts, such as:
- radiation - radioactive substance
- radiation - radioactivity
- dose - activity
- irradiation - contamination
- absorption - accumulation.

A variety of contexts, as recommended in section 6.2, should be used here.

Another activity, of a more didactic nature, which we recommend is the use of analogies by the teacher. Ionizing radiation could be compared with light rays, sound waves and radio waves. These also originate from a source, when absorbed they do no longer exist as such, and they can be transmitted through some substances. However, these analogies are not useful for explaining open sources, as they apply only to closed sources: materials emitting light and sound usually are not dispersable (except perhaps a cluster of fire flies). To provide a minimal understanding of open sources, analogies with dust, sand particles (for instance from the Sahara which are sometimes blown to Europe), and chemical waste could be used.

Our fourth recommendation concerns problems which pupils have with microscopic explanations, as revealed by the results of the 6VWO ques-

tionnaire. Although it is likely that these kinds of problems are more common amongst younger and less able pupils (Klaassen et al., 1989), we would recommend taking them also into account when writing teaching materials for senior high school. We recommend giving more attention initially to the macroscopic aspects of concepts, for instance:
- a radioactive source consists of substances which emit radiation;
- activity is a quantity which indicates the strength of a source;
- the effects of irradiation are acute radiation sickness, possible inducement of cancer and genetic effects;
- half-life is the time after which the strength of a source is reduced by half;
- radioactive decay is a process by which radiation is released and substances gradually change of composition.

This would allow pupils to develop a basic conceptual structure such as the one presented in figure 6.1 without all the complexities introduced by the micro-approach. Later, more attention could be paid to microscopic descriptions of concepts and phenomena (as is common in most school textbooks), such as the radioactive decay process, the effects of ionizing radiation at cellular and molecular level, and absorption processes. An outline of such an alternative teaching approach for junior secondary education is described by Millar, Klaassen and Eijkelhof (1990).

A final recommendation concerns the teaching of risk assessment skills. If we wish to teach such skills, further investigation and analysis is necessary, as it is likely that a better knowledge of concepts and their interdependence is not the only condition which needs to be fulfilled for thoughtful risk assessment. Experts use heuristic procedures in assessing the risks of new situations (section 5.2). It is likely that the kinds of questions (section 6.2) which can be answered using the recommended subject-matter items form part of these procedures. We recommend using these questions to analyse the risks of radiation in various contexts. New investigations are needed to explore further the nature of these professional heuristic procedures and to study how they may be successfully adapted for use in secondary education.

6.4 RECOMMENDATIONS FOR THE PREPARATION OF TEACHERS

Introduction

The recommendations in the previous section are directed towards an improvement of teaching materials and teaching strategies in relation to the risk assessment aim. Following up these recommendations would of course not automatically lead to good teaching. From the interviews with teachers who were experienced in using the present unit we learned that many of them are not very familiar with pupils' ideas and with risk assessment as regards ionizing radiation. They also had not noticed a number of learning problems which were detected in some of our other studies, until these were drawn to their attention. In the following section we will formulate a number of recommendations for teachers who are prepared to teach the topic in the way recommended in section 6.3.

Preparing to teach about ionizing radiation

Cosgrove and Osborne (1985) recognize that teacher preparation should include the following points if teachers are to be successful in modifying some of the firmly held beliefs that pupils usually have already:

- ascertaining the typical ideas which pupils will bring to the topic, together with the prevalence of these views in the class concerned;
- understanding the ideas that scientists use to describe and explain phenomena;
- an open appreciation by the teacher of the ideas he or she tends to use to describe and explain the phenomena.

To this Hewson and Hewson (1988) add:

- being aware of the role played by pupils' existing knowledge in understanding new material;
- knowing about, and being convinced of the need to use, instructional strategies which take into account pupils' existing conceptions, especially when they conflict with those being taught.

In another article, Hewson and Hewson (1987) argue that it is reasonable to expect that teachers in both pre- and in-service training have some conception of teaching, because they have themselves been taught over a period of some 15 years. Some of these conceptions will conflict with a conceptual change view of teaching. Teacher education programmes therefore also need to take account of these conceptions of teaching (Wubbels, 1990). In this way one may partly prevent those difficulties in implementation of educational innovations which are due to the fact that teachers transform and distort new curricula to fit their implicit theories about good teaching (Olson, 1981).

Taking into account these ideas, the literature on conceptual development (section 6.3) and the results of our own investigations, we would make the following recommendations:

A. Teachers should familiarize themselves with the lay-ideas about ionizing radiation which pupils will bring to the classroom

It should be recognized that many of these ideas are not invented in the minds of individual pupils but that they are formed by social influences: by reading newspapers, listening and/or watching radio- and TV-programmes, and in discussions with others. These ideas are part of common culture. Of course some ideas will be idiosyncratic, often invented by pupils in a situation in which they are pressed or feel provoked to give an explanation for an unfamiliar phenomenon. Being familiar with the most common lay-ideas is a necessary precondition for a teacher to be able to recognize these ideas in the utterances of pupils, to distinguish them from more idiosyncratic ideas, and to take them into account in teaching.

B. Teachers should familiarize themselves with the scientific meanings of the concepts in the unit

This recommendation is less trivial than might appear at first sight. Our analysis of school textbooks has shown that a variety of scientific meanings circulates. These meanings are also often not made explicit. Teachers should know which meanings are available and which are most useful for their aim and objectives of teaching. This also allows them to compare lay- and scientific meanings and to become more conscious of the implicit meanings of concepts which they use themselves in teaching.

Not only should the specific meanings of scientific concepts be known, but also their relation with other concepts, partly because these relations could be seen as part of the concepts themselves, partly as these relations might help pupils to see these concepts as more than a number of separate items.

C. Teachers should be able to apply teaching strategies which might achieve conceptual development

Here we refer to some of the class activities recommended in section 6.3, such as pupils making their ideas explicit in plenary or group discussion and Socratic questioning by the teacher. Teachers should realize that asking pupils to express their ideas freely requires that pupils see the purpose of these kinds of activities and that the classroom climate is such that they are not 'punished' by the teacher or by other pupils for peculiar answers. So teachers should make clear why attention is being paid to their initial ideas, should praise pupils for expressing these ideas and show respect for pupils' ideas and ways of reasoning.

Preparing to teach about ionizing radiation and risk

Most of the recommendations in the previous section are also applicable to teaching ionizing radiation without the risk assessment aim. Some other recommendations deal specifically with teaching ionizing radiation with this aim:

D. Teachers should familiarize themselves with the recommended contexts

Most teachers are not familiar with all the contexts recommended in section 6.2. They will be familiar with carbon dating and with the principles of working of nuclear reactors, as these are common contexts in current teaching of the topic radioactivity. However these are contexts which are not recommended for our aim. Of course teachers do not have

to be specialists in the recommended contexts but they should be informed about the following aspects of these contexts:
- the radionuclides which are most important in each context and their relevant characteristics;
- the advantage of using these radionuclides;
- the radiation risks involved for the general public and radiation workers, in normal and accidental situations;
- the safety precautions taken in each context to reduce the risks;
- the possible social implications of the use of these radionuclides;
- current developments in some of these contexts which may lead to the same objectives without radiation risks or with considerably smaller risks.

E. Teachers should have some knowledge about the radiation risk perception of the public and of pupils

Our results indicate that pupils' risk perception about ionizing radiation depends on the context: some applications are seen as much more dangerous than others. For instance X rays and natural radiation are seen as less dangerous than the radiation which originates from substances released by nuclear power stations. This confirms findings reported in the risk perception literature. As this perception may influence learning it will be useful if teachers are familiar with the perceptions of their pupils.

Teachers should also appreciate that attitudes do not change easily: just providing new information usually does not change attitudes. People often have well developed ways of dealing with information which does not suit their existing attitudes.

F. Teachers should be familiar with the effects of ionizing radiation and with safety measures

Although the effects of ionizing radiation could be labelled as biological knowledge they are so important for risk assessment that it was recommended that they are included in physics lessons. Most physics teachers will not be familiar with this field and therefore some additional training is required. Safety measures have the function of reducing and limiting the risks to the public and to radiation workers. Here some basic physical principles are applied, such as absorption, time and distance, in addition to accepted standards of dose equivalent. Teachers should for instance know how activity levels of food are determined by a government. In this procedure one takes into account the activity of a radionuclide in the food, the energy of the radiation from a particular radionuclide, the effective dose equivalent received after the intake of the contaminated food, the amount of this food which is on average consumed, and the acceptable annual additional effective dose equivalent.

G. Teachers should appreciate some of the complexities of comparing radiation risks with other risks in society

Part of the results of the Delphi-study (section 5.3) showed that comparing radiation risks with other risks in society, such as traffic, chemical pollution, smoking and drinking alcohol, has many pitfalls. So we have not recommended to give emphasis to these particular comparisons in curriculum materials. If teachers still wish to make such comparisons they should consider the inherent problems, such as differences in nature and scale of effects, the factors of voluntariness, controllability and disaster, and the complexity of deciding about the acceptability of particular risks.

Recommendations for teacher training

Often the main preparation of teachers for teaching a new topic is reading a teachers' guide. For instance, the PLON-unit *Ionizing Radiation* is accompanied by a teachers' guide (PLON, 1985b) amounting to 114 pages of teaching suggestions and relevant information. In view of the recommendations above, information should be added about the scientific meanings of concepts and about the relationships between these concepts, about pupils' ideas and ways of reasoning, about suitable class activities, and about risk perception, safety measures and the complexities of risk comparisons.

However we do not expect that written information is sufficient preparation for teaching in the way we have proposed. This approach is quite different from the way the topic is currently taught presently in three ways:
a. its aim of learning to assess radiation risks;
b. the use of a variety of real-life contexts;
c. the taking into account of preconceptions and common-sense reasoning.
We expect that many teachers are not able to 'assimilate' these aspects into their teaching: some 'accommodation' of their ideas about teaching this topic is required. Teachers have to be conscious of their aims in teaching, of the problems of teaching in the present way, and of the limitations inherent in this way of teaching. Referring to Strike and Posner one might say that for their restructuring of ideas about teaching this topic, some conditions must also be fulfilled. Especially, they should be sufficiently dissatisfied with their present teaching approach, and the new teaching approach should be plausible and be experienced as fruitful for teaching other topics as well. Such 'accommodation' is probably supported most by workshops in which teachers are actively involved, for instance in:
- finding scientific term definitions which are acceptable for use in teaching;
- recognizing preconceptions in protocols of interviews and classroom discussions;

- devising suitable teaching activities;
- reflecting about their current views of teaching;
- discussing all these topics with teaching colleagues.

Experience of such workshops is limited, as is shown by the inventory of teacher training for conceptual development carried out by Licht, Eijkelhof, Boschhuizen and Bouma (1989). Hewson and Hewson (1987) have reported their experience of such workshops. The comments of participants were generally favourable, although student teachers did not to any appreciable extent incorporate strategies which explicitly allow for conceptual change into their teaching. These two authors suggest that more attention should be given in teacher training courses to the identification of conceptions of teaching and that attempts should be made to reduce the plausibility of conflicting conceptions.

6.5 RECOMMENDATIONS FOR RESEARCH AND DEVELOPMENT

Introduction

This study is part of a long-term working strategy in which research and curriculum development activities are closely linked (Eijkelhof and Lijnse, 1988). The recommendations given so far in this chapter deal with curriculum development and related teacher training. In this final section we will make some recommendations for research within the theme of this thesis. Then we will suggest some research and development activities for other areas of science education in which the risk perspective may be a useful one. Finally we will make an attempt to draw some lessons from our study which may be applicable to the two fields of research and development to which this thesis is closely connected: STS-education and conceptual change research.

Recommendations for further research on teaching ionizing radiation within a risk perspective

In our view improvement of science education should be based on both research and development. Therefore we do not see implementation of the recommendations made so far in this chapter as the final solution to the problems revealed. More research is required to acquire insight into the effectiveness of these recommendations. For instance, we have not been able to evaluate the use of teaching materials in which attention is given to lay-ideas, as such teaching materials are not yet available for senior high school.

We propose to continue with work in the field of teaching ionizing radiation in a risk perspective in the following ways:

1. Devise teaching materials in which the above recommendations about teaching strategies and teacher training are incorporated.
2. Investigate the effectiveness of these teaching materials and teacher training activities. Important research topics are:

- the teaching and learning of concepts in the field of radiation protection, with which only a few teachers have experience;
- the experiences with the recommended set of contexts;
- the various ways of taking the lay-framework about ionizing radiation and risk into account in education;
- the use of the conceptual scheme (figure 6.1) by teachers and pupils;
- the strategy of focussing initially on macro-aspects of concepts;
- the effects of implementing the recommendations for teacher training.

In these investigations attention should be given to both qualitative and quantitative aspects. The former aspects include the learning process of individual pupils and of small groups of pupils as influenced by specific teaching strategies. Appropriate research methods are classroom observation, interviews with pupils, analysis of answers of individual pupils to exercises and test questions, and analysis of protocols of dialogue between pupils and between pupils and teacher. The latter aspects refer to the evaluation of learning outcomes of pupils who have been taught in specific ways. Research methods should include pre- and post-tests and comparison with control groups.

The prospects for using the risk perspective in other areas of science education

Risks are not confined to the field of ionizing radiation. In many other fields adults and pupils run risks. Lowrance (1980) identified six classes of hazard:

1. infectious and degenerative diseases;
2. natural catastrophes;
3. failure of large technological systems;
4. discrete small-scale hazards;
5. low-level, delayed effect hazards;
6. sociopolitical disruptions.

Ionizing radiation fits into the third and fifth types and we have argued that particular attention should be paid to the fifth one. In physics education attention could be paid to other risks, such as in class 4 (electrocution and short-circuits, traffic safety) and 5 (UV-radiation). The risks of UV-radiation resemble the risks of ionizing radiation.

Widening our scope to science education we can identify another area which resembles the theme of this thesis. This is the risks of toxic, carcinogenic and mutagenic substances for human beings, flora and fauna. To be able to assess risks in this area one should have some basic knowledge of chemistry and biology. If an aim of education is that pupils learn to assess the risks of these substances, similar questions arise to the ones which are the topic of this thesis:

- which scientific contents and concepts are most suitable?
- which ideas do pupils have about these concepts, contexts and related risks before they follow formal instruction on the topic?

- how resistant are these lay-ideas to present forms of instruction?
- what are the consequences of these lay-ideas for risk assessment?
- which kinds of risk assessment abilities are feasible for pupils after instruction?

The answers to these questions will be different from the ones which have been found in this thesis. Despite these differences, similar methods may be considered for such a research project. Such a study could be very fruitful in view of the introduction of environmental aspects into science curricula in the Netherlands (Brunsting, Van der Loo and De Vries, 1989).

Other recommendations for research and development

In chapter 1 of this thesis two fields were outlined to which the topic of this thesis is connected: STS-education and preconceptions research. Our final recommendations are concerned with these two fields.

One of the main merits of STS-education may be that it introduces new aims for science teaching. These new aims are based on the idea that scientific knowledge is essential for modern life, as pupils very often meet applications of science and technology. Several problems then arise. In this thesis, detailed attention has been given to these in one small part of science, including the selection of suitable contexts and contents, the role of lay-ideas and the effectiveness of current teaching strategies. In order to improve the quality of this relatively new STS emphasis in science education, it is essential that its quality is continually monitored, for instance by research that evaluates claims made, and that its quality is further improved by research which seeks answers to the problems of selection of contexts and contents and of the role of lay-ideas in learning. Both kinds of problem are in our view important in STS-education (see section 1.1). In our study we identified some learning problems and recognized the need to limit the wide scope of the risk assessment aim. It may be expected that similar studies in other areas of STS-education could play an important role in the improvement of quality, which is essential in order to make STS credible to scientists, science teachers, parents, pupils and policy makers.

As regards research on preconceptions one cannot easily argue that not enough research has been done. One may only suggest that in this kind of research the focus should be less on the detection of preconceptions and their resistance to change. Instead more attention should be paid to the sources of preconceptions. Some of these ideas may indeed be expressions of children's views of the world, but others may be rooted in our common culture, in the ways lay-people look at the world and at science and technology. Perhaps it would be useful to bring the common culture roots more into the classroom. In order to do so the common culture view needs to be better described for various areas of science.

A second recommendation concerns the usefulness of conceptual change. It is possible to make long lists of lay-ideas, to study their persistence and to evaluate the influence of various teaching strategies to deal with these ideas. But are these lay-ideas really very important? And if they are important, why: for scientific literacy or for becoming a scientist? In our study we have tried to collect cases in which lay-ideas played a role in risk assessment in real life. We recommend collecting and analyzing similar cases of lay-ideas in other areas of science. These cases could be used to decide at the curriculum level about the importance of conceptual change and, if it is decided that it is important, how they can be used in class to fulfil the condition of fruitfulness.

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APPENDIX A: PHYSICS EDUCATION IN THE DUTCH SCHOOL SYSTEM

(from: Lijnse, P., & Hooymayers, H.P. (1988). Past and present issues in Dutch secondary physics education. *Physics Education, 23*, 173-179.)

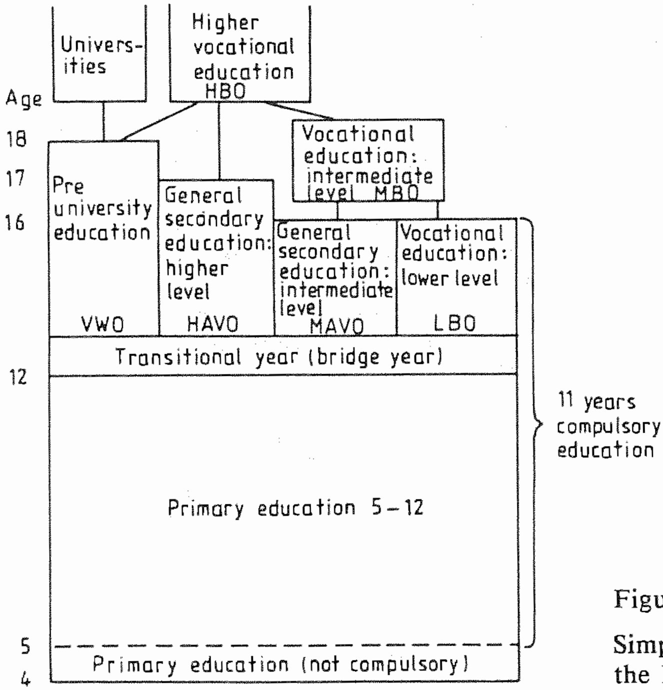

Figure 1

Simplified diagram of the Dutch school system

Figure 1 shows a simplified diagram of the Dutch school system with its various types of education. The most salient points of this structure (as regards the topic of this thesis) may be summarized as follows.

- Compulsory education is for eleven years, from age 5 to 16.
- Secondary education comprises all education after primary school, with the exception of universities and higher vocational education.
- The most important types of secondary education to be distinguished are:
  - pre-university education (VWO);
  - general secondary education (MAVO and HAVO);
  - vocational education (LBO and MBO).
- Secondary education starts with a transitional year. From this transitional year it is possible to pass on to the second year of the various types of school.
- Pre-university education takes six years. In form 6 there is a final examination in seven subjects. The VWO certificate imparts the right to enter university.

- General secondary education is given at two levels, an intermediate level (MAVO) and a higher level (HAVO). The MAVO course takes four years, the HAVO one five years. The HAVO certificate gives entrance to higher vocational education. The final examination of either type comprises six subjects.
- The final examination of MAVO, HAVO and VWO courses comprises two parts of equal importance for the final rating:
  (1) A written examination that is organized and drawn up by a central government commission.
  (2) A school examination, drawn up by the school teachers themselves. In this examination the achievement of pupils is tested by means of various methods, such as written and oral work and laboratory work.
- Physics education in the Netherlands does not start before the second form of secondary education. Figure 2 shows the number of periods per week for physics in secondary education and also indicates the percentage of pupils who follow these lessons in the second and third years and in the top forms (shaded area). In addition the distribution of the inflow of 12-year-olds to the various types of school is shown.

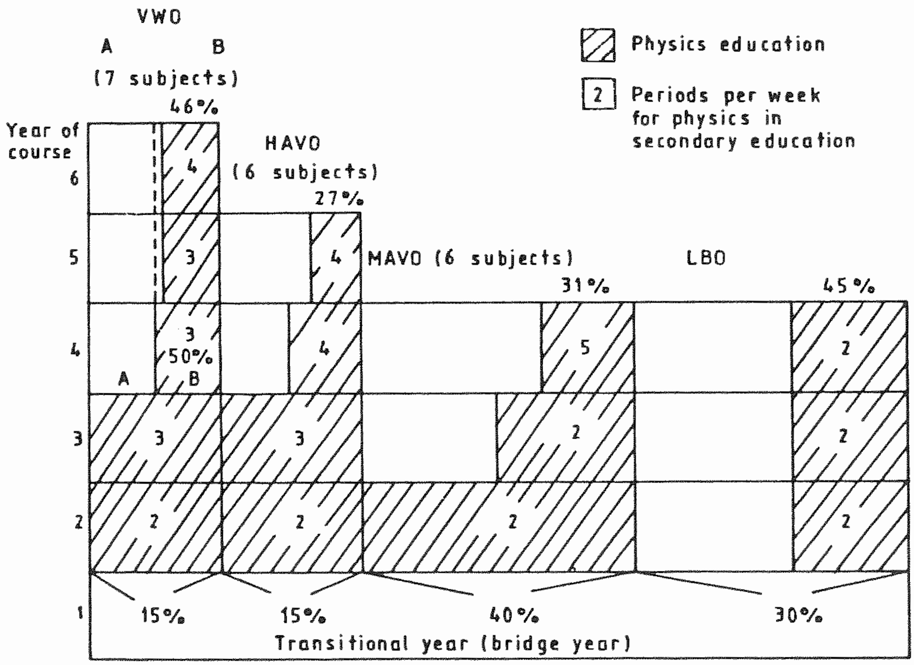

Figure 2 Timetable for physics lessons

The number of physics lessons differs somewhat from school to school because every school (within limits) may draw up its own timetable. The number of lessons shows the most common distributions.

APPENDIX B: TABLE OF CONTENTS OF THE UNIT IONIZING RADIATION (PLON, 1984)

APPENDIX C: QUESTIONNAIRE FORM 6VWO

The purpose of the following questions is to find out what ideas and conceptions people have regarding radiation and radioactivity. It is not intended to be a knowledge test but rather to learn what notions people have about these concepts, which have become so important in recent years.

Please try to read the following questions carefully and answer them as best as you can. The first set of questions have three or four alternatives. Choose one and only one answer by crossing the appropriate square. Please make sure that you answer all questions, even those on which you feel uncertain.

1. During a school experiment pupils examine an apple in front of an X-ray tube and observe an image of the apple on a screen. Eating the apple afterwards is:
   [] dangerous because the apple contains radiation
   [] dangerous for some time, as long as the radiation in the apple is active
   [] not dangerous.

2. Radioactive contamination of a person means:
   [] that the person holds too much radiation
   [] that the person holds a too high level of radioactive substances
   [] both answers above are correct.

3. X-rays might:
   [] cause cancer
   [] cure cancer
   [] cause and cure cancer
   [] neither cause nor cure cancer.

4. Iodine tablets are sometimes prescribed against radioactive contamination. Their effect on the human body is best described as:
   [] neutralizing radiation
   [] preventing radiation from remaining in the body
   [] immunizing the body against radiation
   [] none of the above.

5. After a visit to an area that is radioactively contaminated you are often advised to take a shower:
   [] in order to wash off any radiation left
   [] in order to wash off any radioactive substances left
   [] in order to wash off any radiation and radioactive substances left
   [] but not for any of the reasons mentioned above.

6. Some people are opposed to the dumping of radioactive waste into the sea:
   [] because radioactive substances might contaminate the water
   [] because the radiation may be spread by sea currents
   [] for both reasons.

7. A room in which X-rays are daily made contains a fan to suck off the air. What would be the best time to use the fan in order to reduce the radiation risk:
   [] any time an X-ray is made
   [] as long as patients and staff are in the room
   [] day and night
   [] the fan is not useful for this purpose.

8. Radiation from radioactive sources may:
   [] cause cancer
   [] cure cancer
   [] cause and cure cancer
   [] neither cause nor cure cancer.

9. How long does the radiation remain active in the body of a cancer patient who has been irradiated by an external radioactive source:
   [] zero weeks
   [] some weeks
   [] it depends on the corresponding half-life
   [] it depends on how long the patient has been irradiated.

10. Pregnant women are advised to be careful with X-rays:
   [] because the radiation may reach the fetus through the blood and the placenta
   [] because the radiation may directly harm the fetus
   [] for both reasons mentioned above.

11. Which patients it is better not to approach:
   [] people who have been administered with a radioactive substance
   [] people who have been irradiated by an external radioactive source
   [] both kinds of people
   [] nonsense, both kinds of people can be approached.

12. In certain industries it is common to compensate employees for being exposed to certain risks. Suppose that the night cleaners of an X-ray department in a hospital claim such a premium for the risk they take while cleaning the department at night. This claim is justified because:
   [] radiation has not completely vanished
   [] the air has not yet been completely purified
   [] both reasons mentioned above are correct
   [] the claim is not justified.

13. As you may know, it is not recommended to be X-rayed several times within a short period (e.g., half a year) unless there are urgent reasons. This recommendation is based on the fact that:
   [] radiation remains in the body for some time
   [] all radiation carries a small risk
   [] both reasons are valid.

14. Citizens are not to receive, in any given year, more than 5 mSv (= 500 millirem) of radiation. What is the limit above which you would expect a rather quick death (within a month or two) resulting from radiation sickness?
    [] above 50 mSv
    [] above 500 mSv
    [] above 5000 mSv
    [] above 50000 mSv.

15. A fruit contains a radioactive substance at 4 times the acceptable level. With a half-life of 8 days it may officially be sold after:
    [] 9 days
    [] 17 days
    [] 25 days
    [] 33 days.

16. Somebody recommends washing vegetables if there is any chance of radioactive contamination:
    [] that can be useful since you may wash off some radiation
    [] that is not useful since the radiation would have penetrated into the food
    [] that can be useful as you could wash off some radioactive substances.

The next part of the questionnaire contains statements which are either correct or incorrect. For each question make your choice by crossing the appropriate square.

	correct	incorrect
1. *Half-life* is the time in which:		
a. a nucleus loses half of its radiation	[]	[]
b. a radioactive substance is dangerous	[]	[]
c. a radioactive substance has been reduced to half its amount	[]	[]
d. the nuclei of a radioactive substance have been split in half	[]	[]
e. after which a radioactive substance emits radiation at half its original level.	[]	[]
2. Which of the following descriptions of *radioactivity* are correct/incorrect:		
a. radioactive rays	[]	[]
b. radioactive substance	[]	[]
c. phenomenon of radioactive decay	[]	[]
d. property of radioactive substances.	[]	[]

	correct	incorrect
3. The meaning of *radiation dose* is:		
a. the amount of radiation released	[]	[]
b. the amount of radiation received	[]	[]
c. the amount of radiation which is really gangerous	[]	[]
4. When a person suffers from radioactive contamination we mean that:		
a. he or she contains radioactive substances	[]	[]
b. he or she is contaminated with radiation	[]	[]
c. his or her body contains too much radiation	[]	[]
d. the body became itself radioactive.	[]	[]
5. Which of the following statements are correct/ incorrect:		
a. after an accident in a nuclear power station the radiation might never be spread around by the wind	[]	[]
b. the human body is immune to natural radiation	[]	[]
c. radiation cannot be stored in the human body	[]	[]
d. a person who is radioactively contaminated has too much radiation in his/her blood	[]	[]
e. as long as a person receives less than the permitted annual radiation dose his/her radiation risk is zero	[]	[]
f. when someone gets cancer the cause of it will never be certain	[]	[]
g. X rays have completely different effects compared with radiation from radioactive sources	[]	[]
h. the environment contains natural radioactive substances	[]	[]
i. normally, a person receives most of his/her annual radiation from natural sources	[]	[]
j. radiation cannot be stored in food.	[]	[]

SAMENVATTING

In dit proefschrift wordt onderzoek beschreven naar de voorwaarden waaraan lesmateriaal en onderwijs zouden moeten voldoen om bij te kunnen dragen aan het leren afwegen van risico's van röntgenstraling en van straling uitgezonden door radioactieve stoffen (beide voorbeelden van ioniserende straling). Dit onderzoek richt zich op leerlingen in de bovenbouw van HAVO en VWO.

In hoofdstuk 1 worden twee recente trends beschreven in het denken over het onderwijs in de natuurwetenschappen. De eerste is de opkomst van 'Science, Technology and Society (STS)' onderwijs, waarin meer aandacht wordt geschonken aan de wisselwerking tussen wetenschap, techniek en samenleving. De tweede is het groeiend besef van het belang van voorschoolse denkbeelden ('preconcepties') van leerlingen voor het leren van natuurwetenschappelijke kennis. Het gerapporteerde onderzoek sluit aan bij beide trends. Bij de eerste omdat het leren afwegen van risico's een onderwijsdoel is dat uitgaat van het nut van natuurwetenschappelijke kennis in buitenschoolse situaties, en omdat getracht wordt de keuze van leerstof en buitenschoolse situaties te legitimeren bij praktijkdeskundigen. Op de tweede omdat 'ioniserende straling' een gebied is waarvoor leerlingdenkbeelden nog niet in kaart gebracht zijn. Op beide trends sluit het streven aan om die preconcepties aan het licht te brengen die (a) geworteld zijn in de buitenschoolse cultuur, (b) resistent zijn tegen het huidige onderwijs en (c) een goede risicoafweging in de weg staan. Het hoofdstuk wordt besloten met een plaatsbepaling van dit onderzoek in het licht van recente ontwikkelingen in het Nederlandse natuurkundeonderwijs en met een beschrijving van de onderzoeksvragen.

In hoofdstuk 2 staat de vraag centraal naar de keus van geschikte natuurwetenschappelijke kennis en van daarmee te verbinden praktijksituaties in het licht van de gekozen onderwijsdoelstelling (risicoafweging). Eerst wordt de traditie t.a.v. het onderwerp ioniserende straling in het Nederlandse natuurkunde-onderwijs in kaart gebracht middels een beschrijving van de leerstof in de voorstellen voor examenprogramma's vanaf 1928. Daarna wordt de inhoud beschreven van het PLON-thema Ioniserende Straling, waarin gepoogd is vorm te geven aan de genoemde doelstelling, en worden de resultaten van reeds gerapporteerd vooronderzoek naar de effecten van het onderwijs met dit thema samengevat. Deze resultaten vormden de aanleiding tot dit onderzoek.

Vervolgens worden de resultaten beschreven en besproken van een deel van een zgn. Delphi-studie in drie ronden onder ongeveer vijftig stralingsdeskundigen. Dit deel van de Delphi-studie heeft geresulteerd in aanbevelingen voor praktijksituaties (gebaseerd op een aantal criteria die volgen uit dit onderzoek) en voor onderwijsinhouden. Als belangrijkste soorten praktijksituaties worden door de deelnemers genoemd: achtergrondstraling, medische toepassingen, de uitstoot van radioactieve stoffen door kerncentrales, de opslag van radioactief afval, fall-out van kernwapens en toepassingen van straling voor onderzoeksdoeleinden. Ten aanzien van het leerplan wordt door de stralingsdeskundigen aanbevolen, naast de gebruikelijke kernfysica, aandacht te besteden aan aspecten van stralingsbescherming, zoals bestraling en besmetting, de verspreiding van radioactieve stoffen, de effecten van ioniserende straling en beschermingsmaatregelen.

Het hoofdstuk eindigt met een vergelijking van de aanbevelingen van de stralingsdeskundigen met de recente voorstellen van de Werkgroep Examenprogramma's Natuurkunde (WEN).

Hoofdstuk 3 handelt over lekendenkbeelden en daarmee verwante preconcepties van leerlingen over ioniserende straling. Eerst worden de reeds elders gepubliceerde resultaten van eigen onderzoek naar lekendenkbeelden in de Nederlandse en Britse media samengevat. Deze betreffen met name berichten over het ongeval met de kernreactor in Tsjernobyl (1986). Getoond wordt dat dergelijke denkbeelden ook voorkomen in andere berichten over nucleaire zaken.

Vervolgens worden de resultaten gerapporteerd van een tweede deel van de Delphi-studie, betreffende het denken van leken over ioniserende straling. Dit heeft geleid tot een verzameling lekendenkbeelden, geprofileerd naar geschat voorkomen en hinder voor risicoafweging, tot een voorlopige beschrijving van de verschillen in het denken over dit onderwerp tussen leken en deskundigen, en tot een aantal beschrijvingen van praktijksituaties waarbij het lekendenken risicoafweging beïnvloedde.

Daarna worden de resultaten gepresenteerd van een vragenlijst over het ongeval in Tsjernobyl, die door ruim 300 leerlingen van de klassen 4 HAVO en VWO is ingevuld. Veel van de lekendenkbeelden uit de media bleken ook bij leerlingen voor te komen. Met name het ongedifferentieerde gebruik van begrippen als 'straling', 'radioactiviteit' en 'besmetting' was wijd verbreid. Veel stralingstermen bleken nauwelijks bekend bij de leerlingen.

De preconcepties van leerlingen in 4 HAVO en VWO over dit onderwerp werden verder onderzocht met behulp van vijftien interviews. Deze interviews handelden over Tsjernobyl, medische toepassingen, radioactief afval, voedselbestraling, achtergrondstraling en stralingstermen. De resultaten van deze interviews bevatten een kleurrijk beeld van het denken van leerlingen over deze contexten. Natuurwetenschappelijke kennis bleek nauwelijks een rol te spelen in hun denken, dat gedomineerd leek door hun risicoperceptie (wordt het gevaarlijk geacht of niet) en common sense redeneringen, gebaseerd op flarden informatie uit de media en op analogieën met andere praktijksituaties.

Aan het eind van dit hoofdstuk wordt de karakterisering van de verschillen tussen het denken van leken en deskundigen (zoals volgend uit de Delphi-studie) becommentarieerd en aangepast op basis van de twee studies onder leerlingen.

In hoofdstuk 4 worden vier eigen studies besproken die te maken hebben met het onderwijs over straling en risicoafweging.

In de eerste studie is nagegaan hoe een vijftal huidige schoolboeken het onderwerp behandelen teneinde de gangbare inhoud van het onderwijs in kaart te brengen. Antwoord is gegeven op vragen als: welke contextgebieden en leerstof komen aan bod; welke betekenissen worden toegekend aan begrippen; hoe wordt aandacht besteed aan lekendenkbeelden; hoe wordt ingegaan op de risicoaspecten? Uitgezonderd het PLON-thema blijken de schoolboeken weinig in overeenstemming met de aanbevelingen van de stralingsdeskundigen. In alle boeken worden lekendenkbeelden genegeerd.

In de tweede studie zijn de ervaringen van zeven leraren met het PLON-thema Ioniserende Straling beschreven, met name ten aanzien van risicoaspecten, leerlingdenkbeelden en leerproblemen. In het algemeen was men tevreden over het thema. Gesignaleerde problemen waren het grote aantal begrippen en eenheden en de procedures om risico's af te wegen. Er werd geen of weinig aandacht besteed door de docenten aan leerlingdenkbeelden en leerproblemen werden nauwelijks opgemerkt.

In een derde studie werd een serie lessen met het PLON-thema in een klas geobserveerd en vastgelegd op videoband. Een aantal leerproblemen die verwacht konden worden op grond van de voorgaande studies (zoals het niet kunnen onderscheiden van verschillende natuurwetenschappelijke begrippen), deed zich in de betreffende lessen ook voor en uit de uitgeschreven dialogen (protocollen) werd duidelijk welke problemen zich kunnen voordoen als in het onderwijs lekendenkbeelden niet adequaat worden aangepakt. Enkele nieuwe leerproblemen werden gesignaleerd, betreffende 'natuurlijke straling', de voortplanting van straling, het begrip dosis en de samenhang tussen begrippen in een schema.

De vierde studie ging over de vraag naar de hardnekkigheid van leerlingdenkbeelden. Uit de antwoorden op een vragenlijst, ingevuld door 138 leerlingen van 6VWO, blijkt de hardnekkigheid van een aantal lekendenkbeelden, bijv. ten aanzien van de begrippen straling, radioactiviteit en besmetting. In dit opzicht was er nauwelijks onderscheid te bespeuren tussen leerlingen die met het PLON-thema of met een andere methode hadden gewerkt.

Uit de resultaten van deze studies wordt geconcludeerd dat het, met het oog op de gekozen onderwijsdoelstelling, belangrijk is in het onderwijs aandacht te besteden aan lekendenkbeelden en aan de relaties tussen begrippen. Dit vraagt aanpassing van de bestaande schoolboeken (inclusief het PLON-thema) en bijscholing van docenten op dit gebied. Na dit hoofdstuk blijft het de vraag welke didaktische structuur het meest adequaat is om, rekening houdend met de preconcepties van leerlingen, de eerder genoemde doelstelling van risicoafweging te bereiken.

Hoofdstuk 5 richt zich specifiek op de doelstelling van het leren afwegen van risico's. Het begint met een bespreking van de begrippen 'risico' en 'risicoafweging' en van de resultaten van onderzoek van anderen naar risicoperceptie, naar de verschillen tussen de manier waarop leken en deskundigen risico's benaderen, en naar de rol van kennis bij risicoperceptie.

Daarna wordt een derde onderdeel van de Delphi-studie onder stralingsdeskundigen besproken, betreffende de vraag hoe in het onderwijs ongerustheid t.a.v. de risico's van straling het beste tegemoet kan worden getreden. Een groot deel van de deelnemers beveelt aan vooral aandacht te besteden aan het onderwijzen van natuurwetenschappelijke kennis, aan het maken van risicovergelijkingen en aan manieren om de risico's van straling te beperken. Louter geruststellen acht men voor het onderwijs niet gepast. Ten aanzien van het vergelijken van risico's worden echter ook veel kanttekeningen gemaakt, met name wat betreft het vergelijken met andersoortige risico's.

Tenslotte wordt de onderwijsdoelstelling risicoafweging zelf besproken. Beargumenteerd wordt dat de doelstelling inzake risicoafweging kan worden bevorderd vanuit verschillende, soms tegenstrijdige overwegingen. Op grond van het gerapporteerde onderzoek wordt voorgesteld de onderwijsdoelstelling te onderscheiden in zes sub-doelstellingen. Deze worden geëvalueerd volgens enkele criteria die te maken hebben met de randvoorwaarden van het natuurkundeonderwijs in Nederland, met de bruikbaarheid van begrippen in diverse praktijksituaties en met de complexiteit van risicoafwegingen. De evaluatie leidt tot de aanbeveling de aandacht vooral te richten op drie subdoelstellingen:
- het leren inschatten van de gevolgen van bepaalde doses straling;
- het leren onderscheiden van belangrijke punten ter overweging voor het vaststellen van de grootte van een stralingsrisico;
- het leren beoordelen van de doelmatigheid van veiligheidsmaatregelen en van adviezen voor de vermindering van stralingsrisico's.

Hoofdstuk 6 bevat een serie aanbevelingen voor de keuze van inhouden en praktijksituaties, voor didaktiek, voor de scholing van onderwijsgevenden en voor verder onderzoek.

Ten aanzien van de keuze van inhouden en praktijksituaties wordt grotendeels aangesloten bij de aanbevelingen van de stralingsdeskundigen in de Delphi-studie. Benadrukt wordt het belang van het begrip 'radioactieve besmetting' en van de verspreiding van radioactieve stoffen in mens en milieu. Bij de praktijksituaties zou minder aandacht moeten worden besteed aan de precieze werking van kerncentrales en meer aan de uitstoot van radioactieve stoffen bij normaal gebruik en bij ongevallen. Speciale aanbeveling verdienen praktijksituaties die geschikt zijn om in klassediscussies lekendenkbeelden aan de orde te stellen, zoals bijvoorbeeld medische toepassingen en voedselbestraling.

Ten aanzien van didaktiek worden aanbevelingen uitgewerkt hoe rekening kan worden gehouden met preconcepties, bijvoorbeeld door gebruik te maken van een aantal lesactiviteiten die leerlingen aanzetten tot begripsontwikkeling. Verder wordt aanbevolen gebruik te maken van een bron-straling-ontvanger model, waarmee de relaties tussen veel begrippen kunnen worden uitgedrukt en aan de hand waarvan analogieën met andere soorten straling kunnen worden besproken. Ook wordt aanbevolen in een lessenserie aanvankelijk meer de nadruk te leggen op macroscopische beschrijvingen dan op microscopische.

De aanbevelingen voor scholing van docenten betreffen onder meer kennis van praktijksituaties, natuurwetenschappelijke begrippen en lekendenkbeelden, vertrouwdheid met activiteiten waarin begripsontwikkeling wordt bevorderd, en inzicht in zaken betreffende risico en veiligheid van ioniserende straling.

Tenslotte wordt het belang beargumenteerd van verder onderzoek naar de bruikbaarheid van de gedane aanbevelingen, worden mogelijkheden besproken om soortgelijk onderzoek uit te voeren voor onderwijs inzake andersoortige risico's en worden enkele meer algemene onderzoeksaanbevelingen gedaan ten aanzien van de kwaliteit van STS-onderwijs en van het belang van bepaalde lekendenkbeelden.

DANKWOORD

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Dit proefschrift is grotendeels een verslag van de eerste fase van SVO-project 6084. Aan dit project hebben Kees Klaassen, Rudolf Scholte en Piet Lijnse meegewerkt. Kees Klaassen heeft in dit project twee jaar lang geassisteerd bij het verzamelen en analyseren van gegevens en bij de interpretatie van de resultaten van de meeste deelstudies. Rudolf Scholte heeft bijgedragen aan de uitvoering van de Delphi-studie, de interviews met leerlingen en de analyse van schoolboeken. In die periode vervulde Piet Lijnse een waardevolle adviserende rol.

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CURRICULUM VITAE

Harrie Eijkelhof werd op 21 juli 1946 geboren te 's-Gravenhage. Het diploma gymnasium-B behaalde hij in 1964 aan het St. Janscollege aldaar. Tijdens zijn studententijd te Leiden ontwikkelde hij belangstelling voor onderwijs en voor de relatie tussen natuurkunde en samenleving. In 1971 legde hij het doctoraalexamen experimentele natuurkunde af, met bijvak economie en onderwijsbevoegdheid natuurkunde. Na een korte, tijdelijke baan als natuurkundedocent aan het Amsterdamse Montessorilyceum vertrok hij begin 1972 naar Zambia, alwaar hij een eenjarige Engelse leraarsopleiding volgde aan de Universiteit van Zambia (Post-graduate Certificate in Education).

Vervolgens gaf hij bijna drie jaar les in de vakken physics, agricultural science en general science aan Senanga Secondary School, Senanga, Zambia. Na terugkeer in Nederland werkte hij bijna vier jaar in deeltijd als docent natuurkunde aan de S.G. St. Agnes te Leiden. In dezelfde periode was hij vijf jaar lang verbonden aan de Vrije Universiteit te Amsterdam, o.a. als coördinator van het project Natuurkunde in de Samenleving.

In 1981 werd hij door de vakgroep Natuurkunde-Didactiek van de Rijksuniversiteit Utrecht voor drie dagen in de week aangesteld als medewerker van het Project Leerpakketontwikkeling Natuurkunde (PLON). Zijn werkzaamheden in het PLON-project betroffen het schrijven van lesmateriaal en docentenhandleidingen, en het medecoördineren van het project. Tijdens de laatste jaren van het project raakte hij betrokken bij vakdidactisch onderzoek, met name rond het mede door hemzelf geschreven thema Ioniserende Straling.

Na afloop van het PLON-project werd hij in 1986 voor vier dagen in de week benoemd als universitair docent bij het Pedagogisch-Didactisch Instituut (thans IVLOS) van de Utrechtse Universiteit. In deze functie kreeg hij de gelegenheid zich voornamelijk bezig te houden met het in dit proefschrift beschreven onderzoek.

Hij tracht zijn werkzaamheden te combineren met de gedeelde zorg voor zijn drie kinderen.