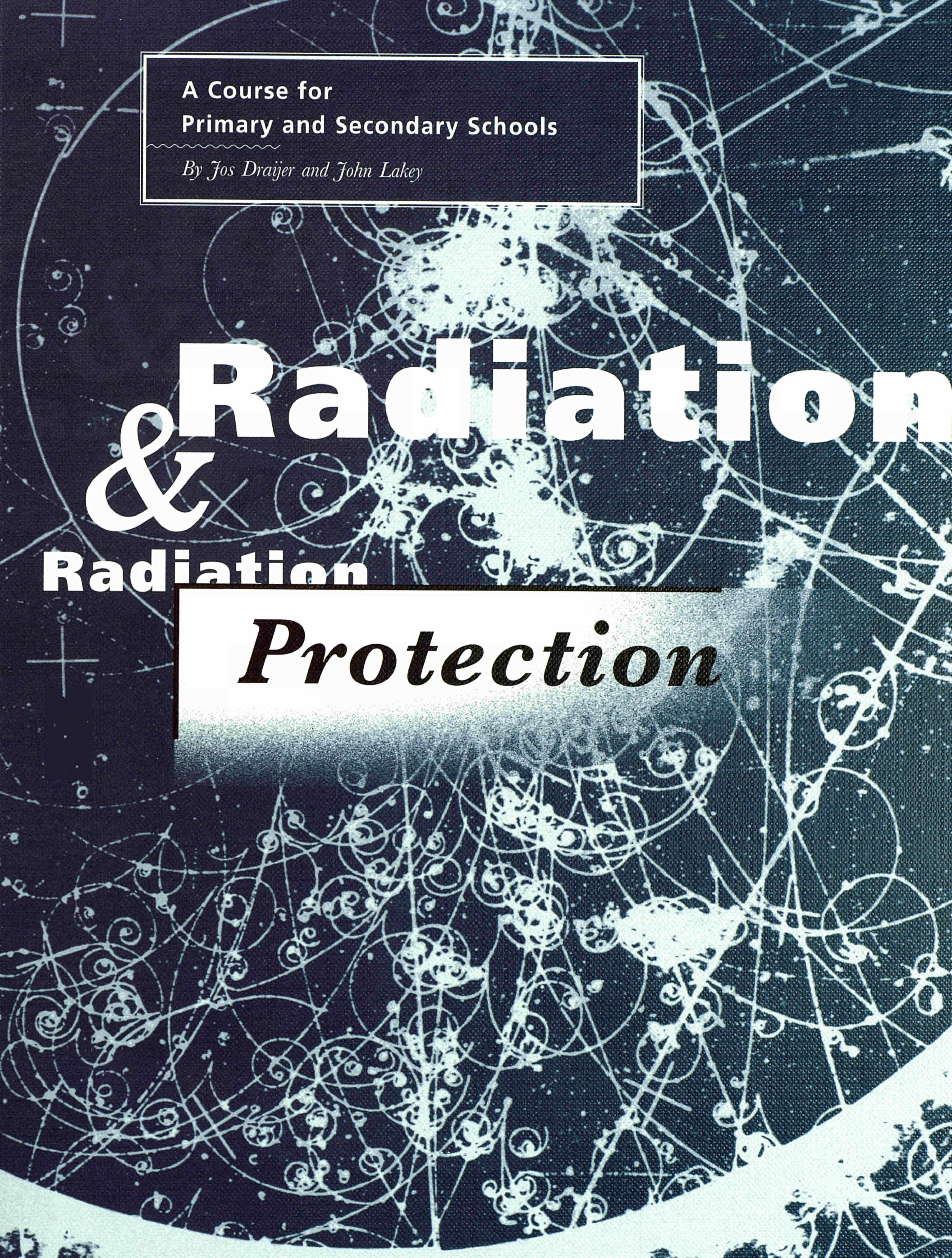
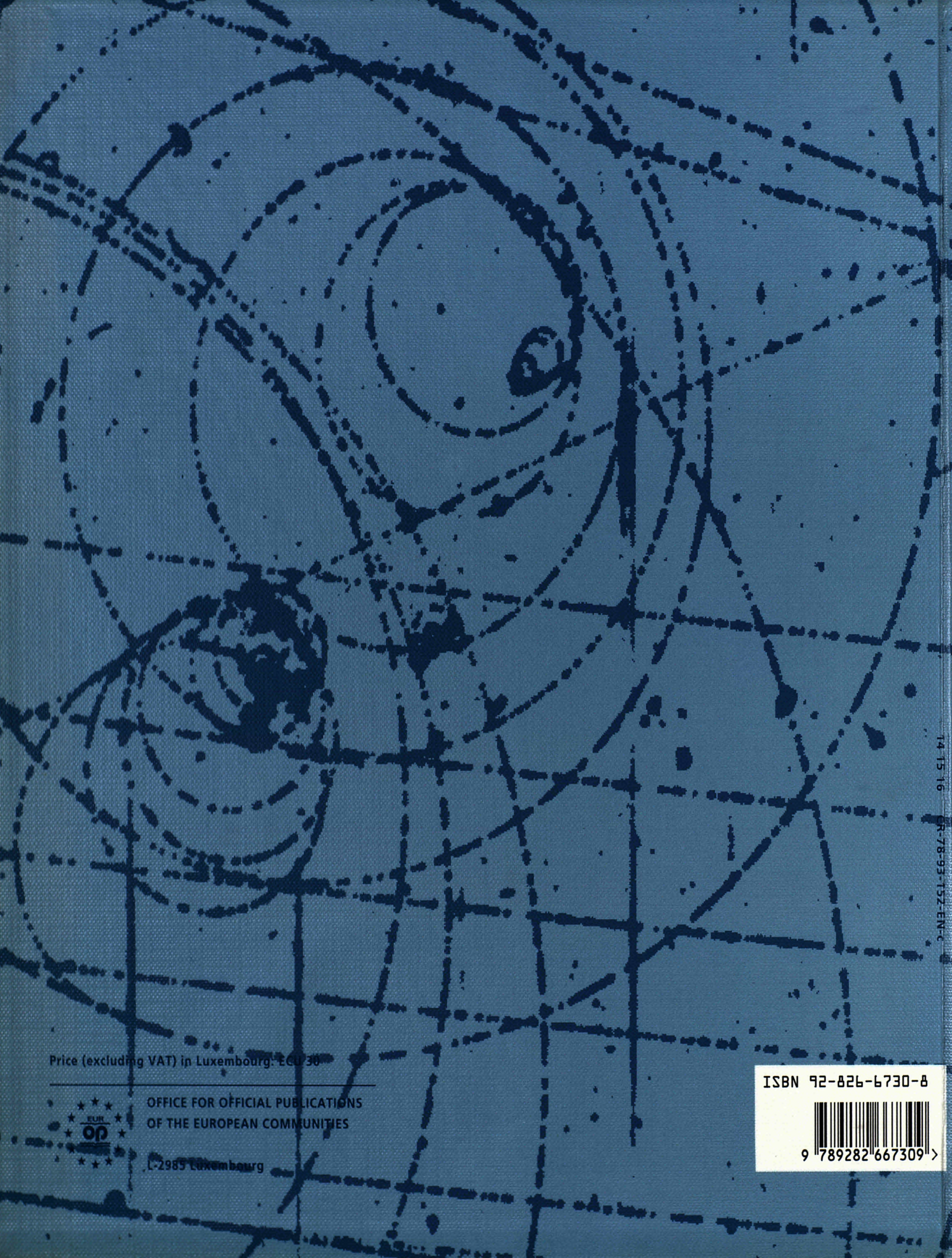
A Course for
Primary and Secondary Schools

By Jos Draijer and John Lakey

Radiation & Radiation *Protection*





Price (excluding VAT) in Luxembourg: ECU 30

OFFICE FOR OFFICIAL PUBLICATIONS
OF THE EUROPEAN COMMUNITIES

L-2985 Luxembourg

ISBN 92-826-6730-8

14 15 16 CR-78-93-152-EN-C

COMMISSION OF THE EUROPEAN COMMUNITIES

RADIATION AND RADIATION PROTECTION

A COURSE FOR PRIMARY AND SECONDARY SCHOOLS

By Jos Draijer and John Lakey

EUROPE
ENVIRONMENT
OUR JOINT FUTURE
DG XI FOR THE QUALITY OF LIFE

General Introduction

Lessons

Level V: pupils aged 14-16

Technical Supplement

Glossary of terms used in the course

Bibliography

Further information

FOREWORD

The work of DG XI in the field of radiation protection is governed by the Euratom Treaty. The treaty, and the directives made under it, stress the importance of keeping both workers and the general public informed. The aim is transparency: we want people to be aware of the potential dangers of ionizing radiation, but also to appreciate that it can be used safely. What is lacking, all too often, is a balanced appreciation of the fact that radioactivity is a part of the natural world, and that it has manifold uses under the stringent safety measures that are in force throughout the Community.

The Euratom Treaty was signed in 1957, and was designed to foster the peaceful uses of nuclear energy, which were then in their infancy. Now nearly one-third of the Community's electricity comes from nuclear energy. But radiation as such has thousands of everyday applications in medicine (X-rays, in particular), research, industry and even in the home (for example, in smoke detectors).

In 1989 the Council Directive on public information in the event of a radiological emergency was adopted. Its scope is not limited, however, to the action which must be taken if and when an emergency occurs; it is equally important that the public should understand the issues and be prepared in advance. The Commission has undertaken a range of activities to support the work done by Member States to implement this Directive. It has published a video on ionizing radiation and a brochure entitled "Radiation and You", both of which are available in several Community languages. It has also organised several seminars, and it was at one of these events, in 1988, that it was suggested that the Commission should draw up teaching material on radiation protection for use in schools. The idea was to give teachers a clear, scientifically valid and objective set of material to enable those who so wished to include courses on radiation protection in their teaching programmes. This was seen to be a task best carried out by the Commission at Community level, with the material being developed in all nine Community languages and put at the disposal of Member States.

The first draft of the material was developed by the Commission, with the assistance of two consultants – Jos Draijer, a specialist in teacher training, and John Lakey, an expert in radiation protection. From its inception, the competent authorities of the Member States also contributed their invaluable support. The material, in the form of a course, was then tested out by Utrecht University in schools in five Member States. Reactions were generally favourable, but a number of suggestions were made and the course was thoroughly revised in the light of the results of this pilot study. The final product represents, therefore, the fruit of a considerable joint effort, and I am grateful to all those, throughout the Community, who contributed to the realisation of this challenging project. But the publication of the course is not the end of the story: its success depends crucially on the use that teachers make of it. The aim of demystifying the subject of radioactivity and radiation protection for the future generations of the Community is a very worthwhile aim. I commend this course to the attention of teachers who share this aim, and I hope they will find it a useful aid in their work.

Laurens Jan Brinkhorst
Director-General
DG XI (Environment, Nuclear Safety and Civil Protection)

GENERAL APPROACH

Radioactivity, ionizing radiation and non-ionizing radiation are fairly complex and abstract subjects, in particular for younger and less advanced pupils. Moreover, the pupils for whom this coursebook is intended constitute a remarkably heterogeneous group in which cognitive abilities may vary considerably. It has also been necessary to take account of the fact that this course will be used in different educational systems within the European Community.

In preparing the course, the option of a "spiral curriculum" was chosen. This means that items recur in a gradually more complex form.

The selected material is divided into five age levels. The first three levels are designed for use in primary education while the last two levels are aimed at secondary education. Each level can be taught as a self-contained unit, although the teacher is free to use material from previous or subsequent levels. The course may therefore be regarded as a source of reference material with which the teacher can construct his own lessons.

In the first three levels emphasis is put on relating radiation to pupils' personal and everyday experiences and observations. Pupils are made aware of the risks and benefits of ionizing and non-ionizing radiation.

In the final two levels, a more detailed examination is made of the subject from both the technical and social points of view, the aim being to enable pupils to develop an informed and balanced view of radiation.

OBJECTIVES

The series of lessons have two general aims:

- to stimulate interest in imperceptible physical phenomena;
- to make the pupils familiar with different forms of radiation (ionizing and non-ionizing radiation), from natural and man-made sources.

There are, in addition, specific aims for each lesson. While the lessons can be taught according to individual teachers' insights and with the addition of personal contributions, much will depend in the initial stages on the interests and background of the pupils. These will no doubt differ according to the educational, social and cultural factors specific to each class or school.

In order to achieve these aims, a number of additional objectives have been defined relating to teachers themselves. Thus, teachers should:

- Acquire knowledge and understanding of radioactivity and ionizing/non-ionizing radiation as a physical and social phenomenon.
- Be aware of the difference between radiation from natural and from man-made sources.
- Acquire an insight into the main principles of radiation protection.
- Be able to explain radiation in a clear way to promote a well-informed and considered attitude among their pupils.

STRUCTURE

As was stated earlier, the course is divided into five age levels.

Level I: pupils aged 6-8
Level II: pupils aged 8-10
Level III: pupils aged 10-12
Level IV: pupils aged 12-14
Level V: pupils aged 14-16

Levels I, II and III are designed to be used in primary schools while Levels IV and V are intended for secondary schools. Each level consists of a number of lessons.

The course materials consist of the teacher's book and five pupil's books (one for each age-group).
The *teacher's book* contains all the material needed for the five levels, including the text of the pupil's books and a Technical Supplement. At the beginning of each level it gives general information followed by a number of evaluation exercises to test what pupils have learned once that level has been completed. At the beginning of each lesson it sets out the aims, indicates the minimum time needed, gives references to specific chapters of the Technical Supplement, proposes ways of teaching the lesson, and lists possible questions/assignments (with answers where appropriate).

The *pupil's books* contain the text for each lesson. This consists of an introduction, which is followed by a story (in many cases fictional) and/or explanatory information accompanied by illustrations, tables and figures. Key points – the essential facts to be learned and understood by the pupils – are listed, followed by a number of questions/assignments (the same as in the teacher's book but minus the answers).

The Technical Supplement at the end of the teacher's book contains background information on the various aspects of ionizing and non-ionizing radiation that are dealt with in the lessons. This background information is intended for teachers in both primary and secondary schools and is designed to be as clear and objective as possible. The Supplement, which also contains a glossary, is followed by a bibliography and a list of useful addresses.

Once again it must be stressed that the lessons are only intended as examples of how various aspects of radiation and radiation protection can be taught. Each teacher may use or adapt them as he or she sees fit.

CONTENT

LEVEL	BRIEF DESCRIPTION OF CONTENT	TOPICS COVERED	TITLES OF LESSONS
Level I: pupils aged 6 – 8	This contains three lessons. There are two main characters, Paul and Angela, who get involved in various situations in which they find out about sunburn and X-rays and learn how television works. Pupils learn something about radiation in their own environment.	The following topics are covered: • the sun (heat) • hospitals (X-rays) • television (electro-magnetic waves)	Lesson 1: Basking in the sun Lesson 2: Paul and the hospital Lesson 3: The television is not working
Level II: pupils aged 8 – 10	This contains four lessons. There are two main characters (Paul and Angela again) who talk about radiation or have experiences involving radiation. Pupils acquire a more detailed knowledge of radiation in their own environment	The following topics are covered: • radiation from the sun • biology of the skin • hospitals and dentists • radio waves and sound waves	Lesson 1: The sun and radiation Lesson 2: Your skin and radiation Lesson 3: Going to the hospital? Ugh! Going to the dentist's? Ugh! Lesson 4: Stone-age walkie-talkie
Level III: pupils aged 10 – 12	There are six lessons for the oldest pupils in the primary school. Paul and Angela are the guides throughout these lessons. They are 10-year-old children who learn more about radiation together with Angela's uncle, Dr. A. Tom. This level deals first with non-ionizing radiation, which includes heat and light. Sound (a form of mechanical energy wave) is also introduced as an example of the concept of "wave". Various types of ionizing radiation and some of their applications are then examined. Pupils are also encouraged to express their views on nuclear power.	The following topics are covered: • non-ionizing radiation (and sound) • ionizing radiation • applications of ionizing radiation • nuclear power	Lesson 1: Sound, heat and light Lesson 2: Becquerel? Who is he? Lesson 3: Ionizing radiation through thick and thin Lesson 4: Applications of ionizing radiation in hospitals Lesson 5: Could we get by without ionizing radiation? Lesson 6: What do you think of nuclear power?

LEVEL	BRIEF DESCRIPTION OF CONTENT	TOPICS COVERED	TITLES OF LESSONS
Level IV: pupils aged 12 – 14	The lessons at this level are intended for secondary school pupils. This level deals with the various topics in greater detail than earlier levels. As before Paul and Angela are the main characters guiding pupils through the lessons. The distinction between natural sources and man-made sources is introduced.	The following topics are covered: • sources of radiation • types of radiation • atoms and ionizing radiation • effects of ionizing radiation on the body • various applications of ionizing radiation • nuclear power stations	Lesson 1: Radiation is everywhere Lesson 2: What is ionizing radiation? Lesson 3: How do you detect ionizing radiation? Lesson 4: How does radiation affect your body? Lesson 5: Medical applications of radioactive substances Lesson 6: Applications of nuclear energy
Level V: pupils aged 14 – 16	There are eight lessons for the pupils. They contain increasing amounts of technical information on the structure of the atom, the applications of ionizing radiation, the effects of ionizing radiation on the body, and nuclear power stations.	The following topics are covered: • sources of ionizing radiation • atoms and ionizing radiation • effects on the body • medical and other applications • nuclear power	Lesson 1: Radioactivity and other sources of ionizing radiation Lesson 2: Ionizing radiation and its biological effects Lesson 3: Radiation protection Lesson 4: Everyday ionizing radiation Lesson 5: Medical and dental applications Lesson 6: Other applications Lesson 7: The atom and nuclear power Lesson 8: Nuclear power and the environment

6-8 YEARS

This contains three lessons for pupils aged 6-8.

INFORMATION

There are two main characters, Paul and Angela, who get involved in various situations in which they find out about sunburn and X-rays and learn how television works.

Each story can be read to the children. The important thing at this level is that pupils learn something about radiation in their own environment.

The topics for the 6-8 years are:

CONTENTS

- the sun (heat)
- hospital (X-rays)
- television (electromagnetic waves)

Background information and further detailed information about these topics can be found in the Technical Supplement. All the information needed for this level can be found in Chapter 1: Historical introduction, Chapter 3: Non-ionizing radiation, and Chapter 7: Applications of ionizing radiation and radioactivity.

LESSONS LEVEL I

EVALUATION

When you have given all the lessons at this level you can test what the children have learned with the following assignment.

Divide the class into three separate groups and get each to act a scene based on one of the Level I stories.

You can give your pupils the following instructions:

For those acting a scene from Lesson 1:

show how the sun's rays affect your skin and how you protect yourself against sunburn.

For those acting a scene from Lesson 2:

show how X-rays are used in hospitals to diagnose fractures.

For those acting a scene from Lesson 3:

show how a television set receives waves from the television station.

Basking in the sun

AIMS

At the end of the lesson the pupil:
- can describe how the sun's rays affect the skin
- knows how to protect him/herself against sunburn.

PROPOSED MINIMUM TIME

30 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 1: Historical introduction
Chapter 3: Non-ionizing radiation

TEACHING SUGGESTIONS

You can begin by finding out what pupils know about sunburn, for example by asking the question: "Have you ever got sunburnt?" You can also start a discussion in the class about sunburn and encourage all the pupils to say whatever comes into their minds. You can write all the pupils' ideas on the blackboard.

You can then carry out an experiment. Bring some suntan oil into the class and let the pupils put some onto their arms. Ask them to put their arms in water so they can see what happens to the oil. After that let your pupils see and feel the difference between suntan oil and after-sun lotion.

You then read or tell the story "Basking in the sun." After telling this story, get the pupils to answer questions on it. You will find the questions and the right answers below.

After the last question (No 4) you can ask the pupils to draw a picture based on the story, perhaps showing what happens if you stay in the sun too long. If there is enough time, two children can be allotted the roles of Paul and Angela. They begin acting the scene, and then two other pupils take over, followed by two others, and so on.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 What happened to Paul and Angela after they stayed too long at the swimming pool?
They got sunburnt.

2 What causes sunburn?
Sun, the sun's rays.

3 What had Paul and Angela forgotten to do when they sunbathed at the side of the pool?
They had not put on any suntan oil.

4 What eventually happens to your skin if you stay in the sun too long?
The skin peels, turns red.

It was a very warm day and the sun was beating down. Paul and Angela decided to go to the swimming pool. They forgot to do one important thing: protect themselves against the sun's rays. After this story you will know what happens if you do not protect yourself against the sun.

LESSON

Basking in the sun

"Phew! It is far too hot for me here," sighed Angela as she moved and sat down in the shade of the house. "Just wait for me", Paul said, "my ice lolly is melting in the sun". Angela, who had dark skin, and Paul, who had fair skin, had just finished helping their mothers and had been given money to buy an ice-lollipop at the newsagent's. Angela, who lives next door to Paul, took a red one. Paul first wanted a green one and then a yellow one – he loved them all so much he could not make up his mind!

"You've got to decide now", the shopkeeper said. "Alright, I'll have an orange one", Paul said.

"What shall we do this afternoon?" asked Angela. "I don't want to play any games that will make you feel hot."

"What about getting wet?" Paul asked mysteriously. Angela was puzzled at first, then the penny dropped.

"Yes, the swimming pool! That's a great idea! Come on, let's get our things ready." "Just a sec, can I finish my lolly first?" said Paul. But Angela had already rushed into the house and asked her mother if it was alright.

"But you will be careful, won't you?" said her mother anxiously. "Of course we will!" shot back the reply.

Paul put on his trunks and Angela changed into her bikini. Towels, clothes and lemonade were put into a bag. "My ball, my bucket and spade – oh yes, I mustn't forget my inflatable dolphin!" Paul said. "Come on, we're not going on holiday, you know!" said Angela impatiently. Then off they went.

The swimming pool was just around the corner. When they arrived, there were already quite a lot of people there. "Last one in is a wimp!" Angela yelled, then ran and jumped into the water.

The whole afternoon they splashed around in the pool. They played all sorts of games. Every so often they got out of the pool to sunbathe at the side. "A little sunshine will do you good", Angela teased Paul.

"Well, it won't hurt you either," Paul answered and emptied a bucket of water over Angela's back, making Angela scream at the top of her voice.
Far too soon it was time to go home again. "Ouch, my legs hurt!" Paul groaned while he was getting dressed. "I can hardly pull my shirt over my shoulders", he complained, "my skin is burning and itching so much." "Yes, so is mine", said Angela, "it's really throbbing".
When they got home, Paul's mother said: "Oh dear! Didn't you think of using the *suntan oil*? It was in your bag". "I forgot about it, mum", said Paul. "Can't you do anything about it?" he asked. "It really hurts – it feels as though I'm on fire!"

suntan oil

"You'd better put on your trousers", said his mother, "they're more comfortable. I'll put some oil on your skin first. It may hurt for a while but you will feel better tomorrow."

A little while later, Angela and Paul were sitting on the settee. Suddenly Angela started giggling. "What's the matter?" asked Paul. "Your face is all red!" said Angela. Paul at first gave her an angry look but soon he thought it was funny too.

KEY POINTS

In this story you learn that suntan oil protects you against the sun's rays. Paul and Angela stayed in the sun too long and forgot to put on suntan oil, so the sun's rays burned their skin.

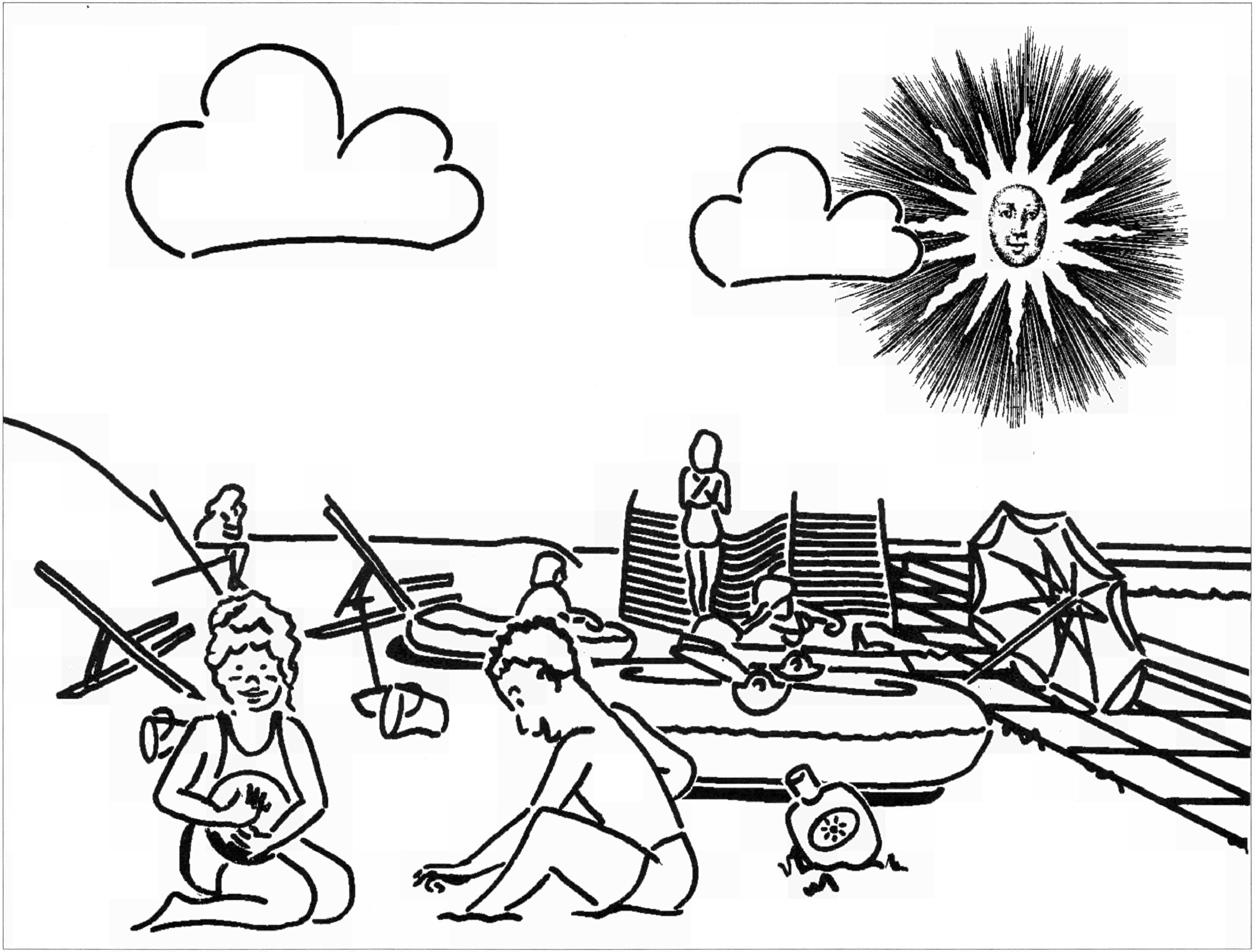
QUESTIONS

1 What happened to Paul and Angela after they stayed too long at the swimming pool?

2 What causes sunburn?

3 What had Paul and Angela forgotten to do when they sunbathed at the side of the pool?

4 What eventually happens to your skin if you stay in the sun too long?



Paul at the hospital

AIMS

At the end of the lesson the pupil:

- knows that X-rays are used in hospitals to diagnose fractures (i.e. pictures are taken with X-rays to locate where the bone is broken)
- is aware that all human beings have an "outside body", which we can all see, and an "inside body" which you can only see on X-ray pictures
- is able to describe in a general way how an X-ray machine takes pictures of the bones.

PROPOSED MINIMUM TIME

30 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 1: Historical introduction
Chapter 7: Applications of ionizing radiation and radioactivity

TEACHING SUGGESTIONS

Read or tell the story to your pupils and get them to react.
Ask them questions like: "Have any of you ever had a bone broken?" and "Have any of you ever had an X-ray picture taken?"

Ask the pupils to look at the X-ray picture and at the normal photograph in their books. Talk about the two pictures with the pupils and get them to describe what they see on both of them. Explain that there is a difference between pictures of "the outside" and pictures of "the inside"
You could also show another X-ray picture on which you can see that a bone is broken.

You can also mount a hospital display in a corner of the classroom.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Write down or say what you can see on an X-ray picture.
The inside of the human body, bones, whether there are any fractures.

2 Who can explain to the other children in the class how X-ray pictures are made?
A machine sends invisible radiation through your body and at the same time takes pictures of the bones.

3 Are X-ray pictures useful to a doctor? If so, why?
Yes, they tell the doctor exactly what is broken inside the body.

In this story you read that Paul has an accident and hurts his arm. It is probably broken because it hurts a lot. Paul's parents decide to take him to the hospital, where a doctor takes X-ray pictures of the bones in Paul's arm using a special machine.

This story tells you how an X-ray machine works and if Paul's arm is really broken or not.

LESSON 2

Paul at the hospital

"Sally, come down!" said Paul.
Sally, the cat, had climbed up into a high tree and was too frightened to come down again. Paul had heard Sally mew and had climbed up the tree straightaway to rescue her, but a branch was in the way and he could not reach her.
"If I can move over there I should be able to reach her," thought Paul. But the branch he was standing on was not strong enough and all of a sudden there was a loud crack sound and the branch broke. Paul came tumbling down, and the cat with him.

The cat got up at once and chased after a sparrow. But Paul stayed lying on the ground. His arm was hurting terribly. "Help, help!" he shouted. His father ran towards him. "What's the matter, Paul?" he asked.
"I fell off the tree and now my arm is hurting badly," Paul told him.
"Let me have a look. Can you still move your arm or clench your fist?" asked his father. Paul tried to, but it was too painful. Just then his mother came out.
"We've got to take Paul to the hospital – he may have broken something," her husband said. She looked startled and immediately went to fetch the car keys.

A little later Paul and his mother were in the out-patients' department. The doctor felt Paul's arm but when he tried to move it, Paul almost cried with pain. "We'll just X-ray your arm, Paul," the doctor said. He sent Paul along to a room down the corridor. Here, a lady put a sort of apron on Paul and asked him to sit down next to a machine. She told him to hold his arm still under the machine and then went behind a protective screen. Soon Paul heard some noises like a camera taking pictures. When this was over, he was taken to another room where, a few minutes later, a plaster cast was put on his arm. After this had hardened, his arm was put in a sling.
Paul was already feeling much better and most of the pain had gone now. Then he went back to the doctor again.

"Well, Paul, how do you feel now?" asked the doctor. "Much better, thanks," said Paul. "Good," said the doctor, "let me explain a little about what we have just done."
"Your body is full of bones which make it firm and strong. Together these bones make up your skeleton. From the outside I could not see if you had a broken bone in your arm. As I couldn't creep inside your arm to see what was wrong, I had to use a machine that can take pictures of the inside of your body. It's called *an X-ray machine*. This machine sends invisible rays through your body and at the same time it takes a picture of your bones. Just have a look at these pictures of your fore-arm. The one on the left is your arm, the one on the right is somebody else's. Can you spot the difference?"
"Yes, I can", Paul said, "one of the bones is broken."
"That's right!" said the doctor. "The picture told me exactly what was broken. It is all quite complicated but do you get the general idea?" "I think so", said Paul. "It's amazing. You must be ever so clever to think of something like that." His mother laughed and so did the doctor. "You're right," he said, "the man who invented it was very clever indeed. Anyway, Paul, I want to see you again in three weeks. Then we'll take another picture to see if your broken bones have grown together again."
"Okay, doctor! See you soon and thanks a lot!" said Paul.

an X-ray machine

KEY POINTS

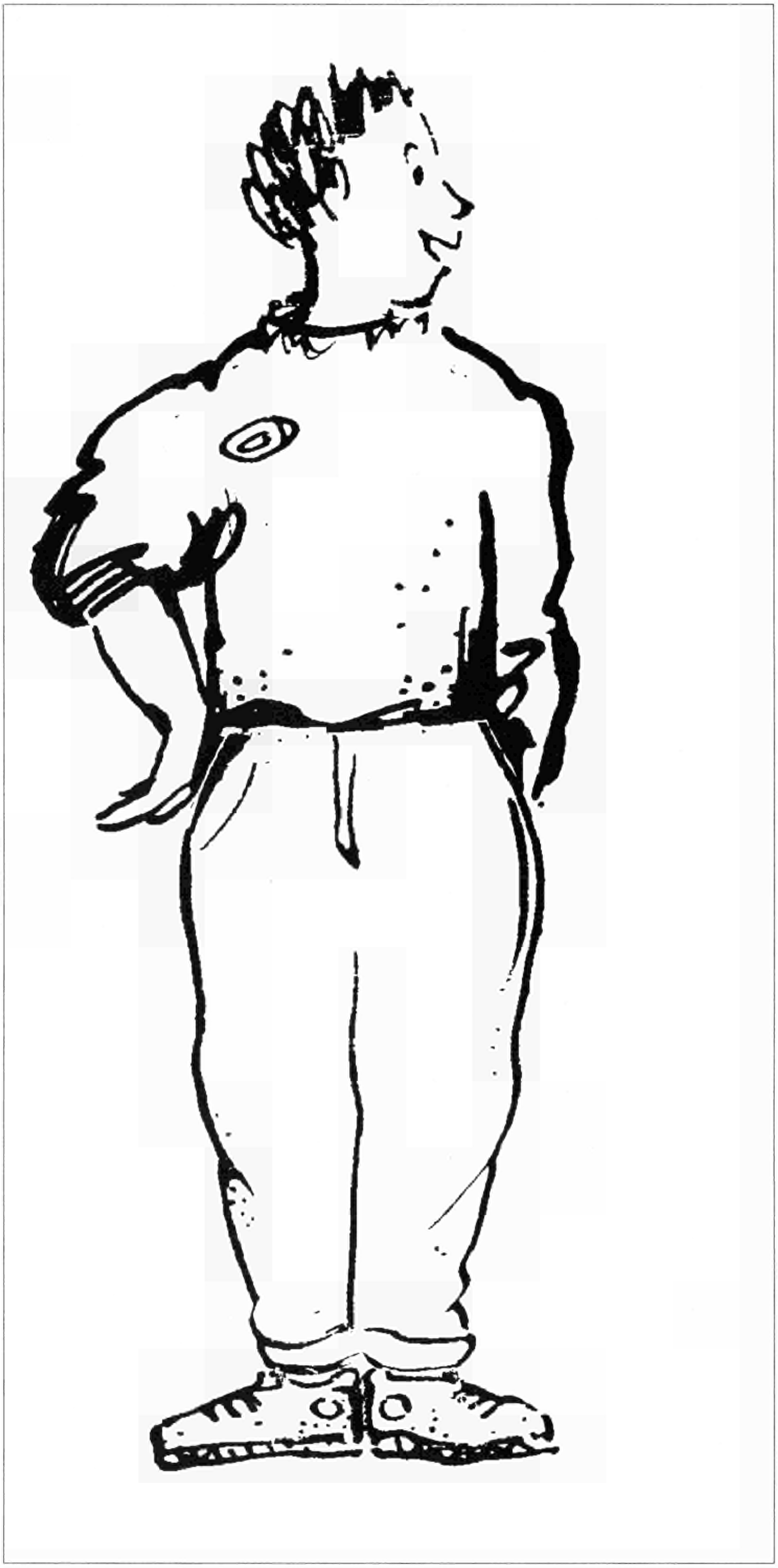
There are a lot of bones inside your body. You cannot see them. If a doctor wants to know whether one or more bones in the body are broken, he takes special pictures. We call them X-ray pictures. These X-ray pictures allow us to see inside the body.
X-ray pictures are taken with a special device called an X-ray machine. This machine sends invisible radiation through your body and at the same time it takes an X-ray picture of your bones.

QUESTIONS

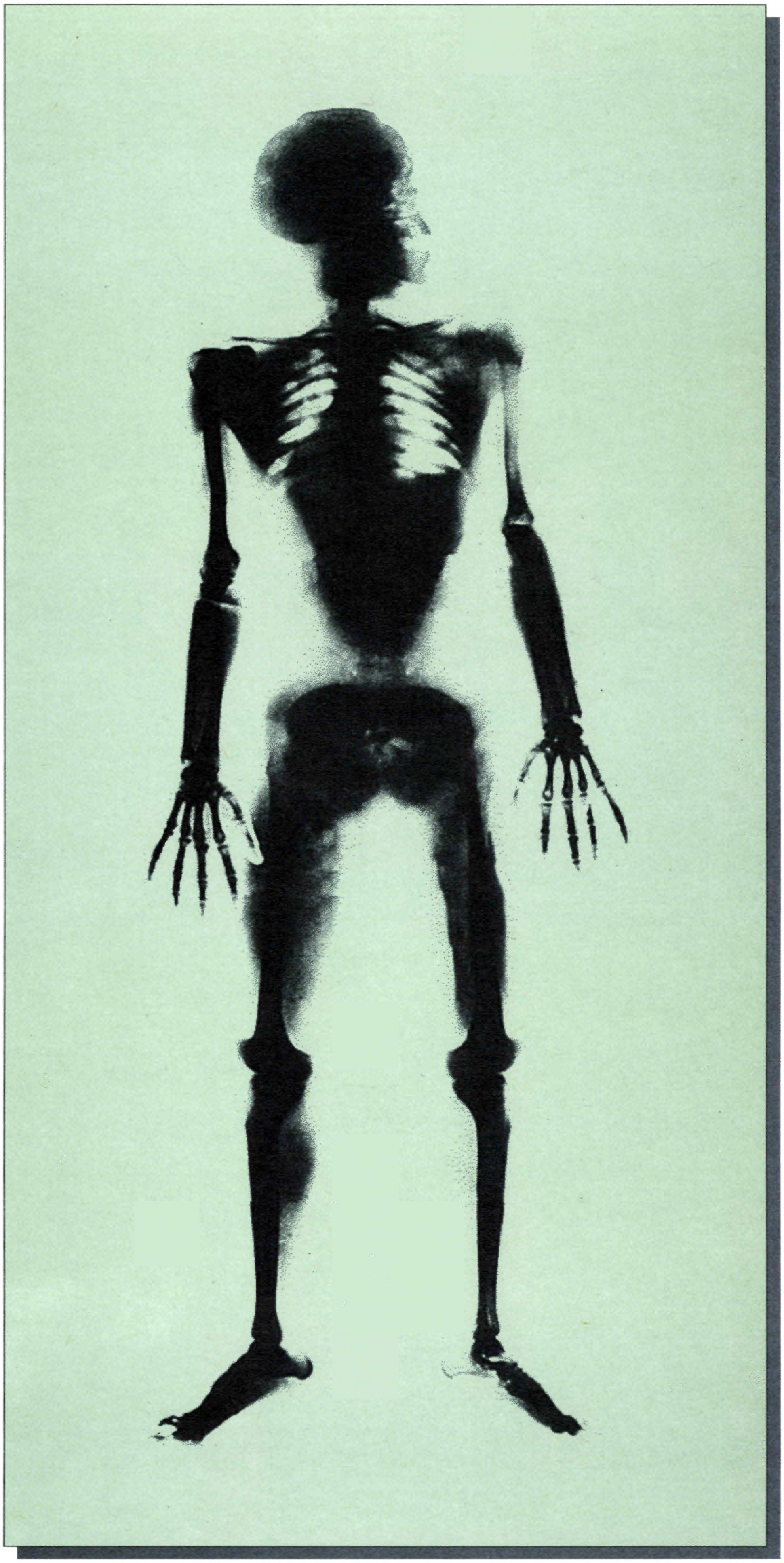
1. Write down or say what you can see on an X-ray picture.

2. Who can explain to the other children in the class how X-ray pictures are made?

3. Are X-ray pictures useful to a doctor? If so, why?



Normal photograph of Paul



X-ray-picture of Paul

The television is not working

AIMS

At the end of the lesson the pupil:
- is aware that television pictures are obtained by means of a kind of radiation (radio waves).

PROPOSED MINIMUM TIME

30 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 1: Historical introduction
Chapter 3: Non-ionizing radiation

TEACHING SUGGESTIONS

You can read the story to the children. You can then ask them if their TV screen at home has ever gone fuzzy. Then you can carry out an experiment. Turn on a television programme and let the pupils see what happens if you disconnect the aerial (the screen goes fuzzy).
Go over the main points concerning how television pictures are obtained. You can repeat what Angela's father tells her in the story, i.e. at the television studio a programme is recorded by a camera which transmits invisible waves to a huge aerial, and this aerial sends these waves all over the country, where television sets receive them.

After this experiment you can ask the pupils to perform their favourite television programme by acting the parts themselves or by using puppets.

Finally, you can ask the pupils the following questions.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Which TV programmes do you like watching?

2 Do real people live inside your television set? If not, how do the pictures get on to the screen?
No, they are somewhere else; people are inside a television studio and are recorded by a camera; the camera transmits invisible waves which are received by your television set.

3 Colour the picture
Ask the children to colour the picture accompanying Lesson 3.

Angela was bored. It was raining and Paul was staying with his aunt, so she decided to watch television. Suddenly the screen went fuzzy. In this story you can read what happened.

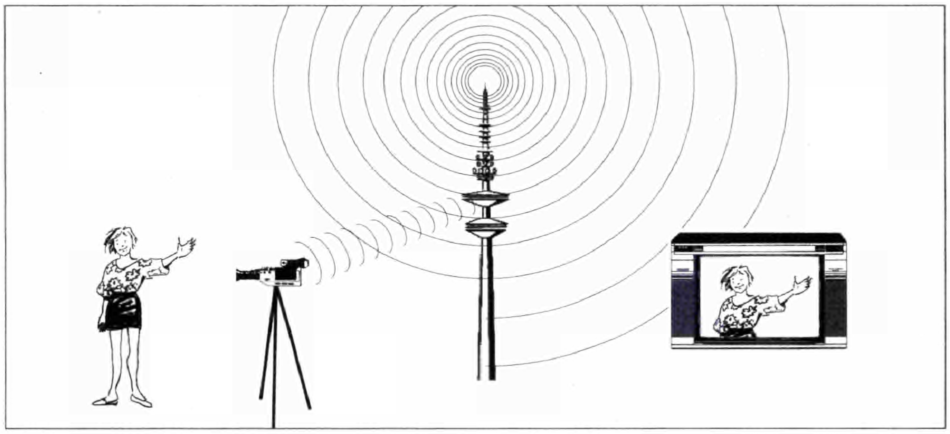
LESSON

The television is not working

"What awful weather," sighed Angela, "and it has been like this for three days now!"
Outside it was raining cats and dogs and there was a howling wind blowing. There were puddles everywhere. Even the playground, where Angela usually spent a lot of her time, was flooded. Angela walked from one window to the other, but outside it was wet everywhere. "There's nobody to play with. Just my luck that Paul is staying with his aunt," she complained.
"Do a puzzle or read something," said her father, who was reading the paper at the table. But she had already done all the puzzles and read most of her books as well as making drawings of all the things she could think of.
"Maybe there is something good on TV," sighed Angela, who had already tried all the channels one hour ago. She turned the TV on. "Wow, cartoons!" she exclaimed. "That's great!"
But suddenly the screen went all fuzzy. "Blow! The television has broken down," Angela groaned. Her father put down his paper and sat down next to her. "I don't think so," he said, "by the look of it there is just a break in transmission. It's probably because of the storm. I'll just call the television company". After the phone call Angela's father said: "Well, it's just as I thought, the wind has made one of the transmitters break down, so it may be quite a while before you get to see Donald Duck again". Angela was now curious to know more. "Can you explain how television works, dad?" she asked.
Her father scratched behind his ears. "Now you're asking! How television works is very complicated, but I'll try to explain it as simply as I can. At the *television studio* pictures are taken by a *camera*. These pictures are sent by a huge *aerial* all over the country. They are carried on *invisible waves* to our television sets, rather like a ball which is carried along by waves at the seaside".
Suddenly they heard Mickey Mouse's voice coming from the television. "Hey, it's working again!" Angela shouted. At last she could see her favourite programme again.

television studio
camera
aerial
invisible waves

Outline of the way that television works



A little later the two of them were sitting together watching television. Angela's father had a cup of coffee and Angela a glass of lemonade. "Did you understand my explanations,?" her father asked.
"Yes, I did," she said. "It is difficult, but I think I've got the general idea. I'll have to explain it all to Paul when he gets home because he thinks that Donald Duck and Mickey Mouse actually live inside the TV set!"
Both of them thought this was funny and had a good chuckle over it.

KEY POINTS

In this lesson you have read that television programmes are recorded in a television studio by a camera. This camera transmits invisible waves to a huge aerial. The aerial then sends out these waves. Your television sets receive them. Think about this next time you watch a television programme at home.

QUESTIONS

1 Which TV programmes do you like watching?

2 Do real people live inside your television set? If not, how do the pictures get on to the screen?

3 Colour the picture.

8-10 YEARS

This contains four lessons for pupils aged 8-10.

INFORMATION

Some stories can be read or told to the pupils, others can be read by the children themselves.
There are two main characters, Paul and Angela, who talk about radiation or have experiences involving radiation.
Some of the information given at Level I is covered again but in a more detailed way. Other information is new. The important thing at this level is that children acquire a more extensive and detailed knowledge of radiation in their own environment.

The topics for the 8-10 age group are:

CONTENTS

- radiation from the sun
- simplified biology lesson
- hospitals and dentists
- radio waves and sound waves

Background information and further information about the subject and the individual topics can be found in the Technical Supplement. It is advisable to read the whole of the chapter or chapters referred to at the beginning of each lesson.

LESSONS LEVEL II

EVALUATION

When you have given all the lessons at this level you can test what the children have learned with the following assignment.

Divide the class into four separate groups and ask each one to prepare an article for a newspaper. You can give your pupils the following instructions:

Group 1: produce an article about how the earth's atmosphere affects the sun's rays (the rays get weaker as they get closer to the ground).

Group 2: produce an article about the skin, describing what happens when the skin is exposed to the sun.

Group 3: produce an article about hospitals or dentists, explaining how and why people take X-ray pictures.

Group 4: produce an article about how a walkie-talkie works.

The sun and radiation

AIMS

At the end of the lesson the pupil:

- knows that the sun emits light, heat, ultraviolet rays and cosmic rays
- is aware that some of these rays are invisible
- is aware that the earth's atmosphere partially protects us from the sun's rays.

PROPOSED MINIMUM TIME

30 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

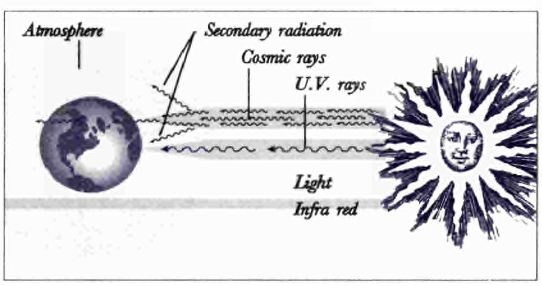
Chapter 1: Historical introduction
Chapter 3: Non-ionizing radiation

TEACHING SUGGESTIONS

As an introduction the teacher can start with an experiment demonstrating what happens if you place a sheet of paper between a torch (or lamp) and a globe. Ask the pupils what they can see. Then ask them to add more sheets and observe the effect.
After this experiment, read the story or ask the pupils to read it themselves.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Draw a picture showing the earth, the earth's atmosphere and the sun.



2 Write down what you know about the sun's rays, their effects on the skin, and what the earth's atmosphere does to these rays.
Make sure the following aspects are covered:
The sun's rays are partly absorbed by the earth's atmosphere, so they are stronger up in the sky or in the mountains than they are lower down. People cannot see all the radiation in the sun's rays. Ultraviolet rays can give

you sunburn. You should protect yourself against the sun's rays by wearing sunglasses and putting on suntan oil, especially if you go up into the mountains. Cosmic rays can go right through the walls of an aeroplane.

Angela talks about the sun's rays and what happens to them as they pass through the earth's atmosphere.

LESSON

8-10 YEARS

1

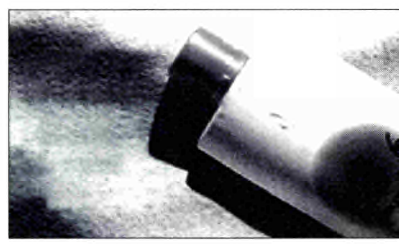
The sun and radiation

My name is Angela and I am going on holiday to get a nice suntan but George, who goes to the same school as me, says I should be careful because the sun can harm your skin. He has just come back from a school tour to the mountains where he was not allowed out in the sun without a lot of suntan oil on his skin and he had to wear a sun hat and sunglasses! The tour leader said that you must be very careful on top of a mountain because there is less atmosphere above your head to protect your skin from the harmful *rays of the sun*. But I know that the sun's rays are essential for us to live on earth and are needed for plants to grow so I can't believe this idea that they could harm us.

rays of the sun

George agreed that most of the rays from the sun must be good for us, but amongst the good rays he said there are some bad ones. I asked him how we know which are good and which are bad. "Just look at this bottle of suntan oil", said George, "it says it is to 'protect your skin from the harmful effects of *ultraviolet radiation*'. So the bad rays are the ultraviolet rays. Sunglasses protect our eyes from these rays. Actually, the *earth's atmosphere* acts rather like sunglasses and protects the whole earth from these rays, although it lets the light and heat we need get through".

ultraviolet radiation
earth's atmosphere



A way to protect your skin against the rays of the sun

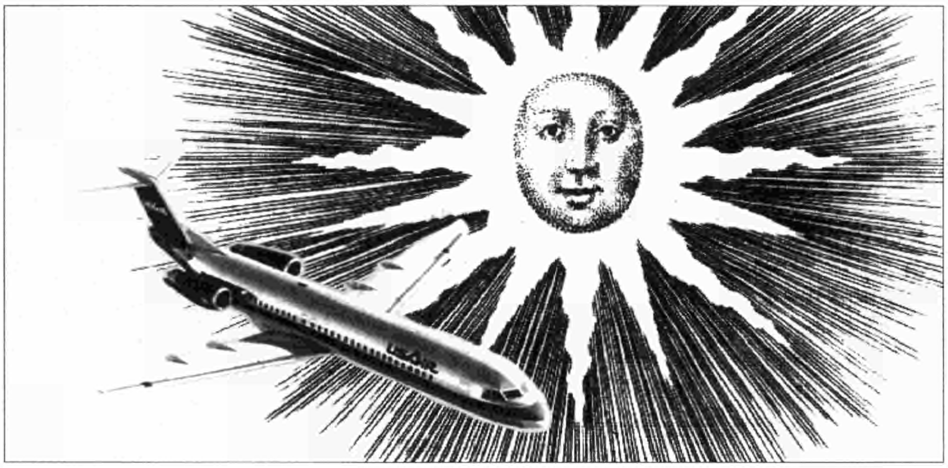
George said that the atmosphere doesn't stop visible light, otherwise we would not be able to see anything. "But it does stop the light at night", I said, "because then it goes dark". "Ah, that is because the earth turns and the sun goes down below the horizon so the rays which come straight from the sun are stopped by the earth", said George, "but wherever we are on earth and at all times we still get some invisible radiation from the sun which is called *cosmic rays*". The tour leader had also told George that these cosmic rays started off as little bits of the sun and travelled through space like little rockets bashing everything in the way including the earth! "That's enough", I said, "I am not

cosmic rays

Protect yourself against the sun's rays up in the mountains

going on holiday – it's too dangerous!" "Don't worry", said George, "the atmosphere stops most of the cosmic rays too. People who live on mountains get more cosmic rays than we do and they look pretty healthy". "Well", I said to George, "I'll still make sure I put on suntan oil. I wonder if I can buy some special oil to stop the cosmic rays as well?"

Just before going on holiday I remembered what George said about cosmic rays because I realised that I was travelling by air to my holiday. Surely the aeroplane would go higher than George's mountain and I would get some extra cosmic rays! I rushed round to George's house. I asked him if the cosmic rays could get into the aeroplane. "Yes", said George, "our leader said that they were like X-rays and will get through the walls of the plane. But you won't be up in the air for long and so the amount of radiation you get is quite small. Don't worry, your holiday will be good for your health – just be careful of the sun!"



Cosmic rays go through the walls of the aeroplane

KEY POINTS

The sun emits rays of various kinds. Some of these are filtered out by the earth's atmosphere. You need to protect yourself against the sun's rays, especially at high altitude.

QUESTIONS

1 Draw a picture showing the earth, the earth's atmosphere and the sun.

2 Write down what you know about the sun's rays, their effects on your skin, and what the earth's atmosphere does to these rays.

Your skin and radiation

AIMS

At the end of the lesson the pupil:

- knows that the skin consists of various parts
- can describe some functions of the skin
- is able to distinguish between the inner and the outer layer of the skin
- is aware that the outer layer of the skin becomes tanned through exposure to the sun's rays.

PROPOSED MINIMUM TIME

35 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 3: Non-ionizing radiation

TEACHING SUGGESTIONS

Start telling or reading the story but stop at the point where Paul's father sits down to tell the children about the inner and outer layers of the skin.

Then you can talk about the skin yourself instead of Paul's father. First, draw a picture of the inner and outer layers of the skin on the blackboard and describe the different parts and functions of the skin.

Get the pupils to make their own drawings of the skin. Each part can be coloured differently.

When they have finished their drawings, tell the pupils to write "outer layer of the skin" and "inner layer of the skin" in the right places on the drawing.

Let pupils see and feel that the outer layer of the skin varies in thickness.

Then blindfold the children and give them different kinds of things to feel. Ask them to guess what these things are.

After this game you can explain to the pupils that the nerves of the inner layer of the skin help them to know whether something is hard or smooth, hot or cold, and so on.

Finally, you can ask the following questions.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 In what part of your skin is the colour to be found?
The outer layer of the skin.

2 How can you protect yourself when you do not want to get sunburnt?
Sunglasses, suntan oil, sitting in the shade.

LESSON

Your skin and radiation

Paul and Angela were sitting in the garden under the hot sun. "What shall we play?" asked Angela. Paul thought for a while and then said: "I know! Let's pretend we're Indians. I'll be "Blue Eagle" and you be "White Eagle". We've got some canvas in the attic. We can make an Indian tent with it in the garden".
Very soon Paul and Angela had made the tent. A few minutes later Paul's father came along. "That's a nice wigwam!" he said.
"A what?" exclaimed Paul. "I can't believe it – don't you know what a wigwam is?" asked his father. "No", said Paul and Angela, who thought Paul's father was pulling their legs.
"Well", said Paul's father, "a wigwam is another word for an Indian tent".
"By the way", he added, as he went back to the house, "put some suntan oil on because the sun is very hot today".

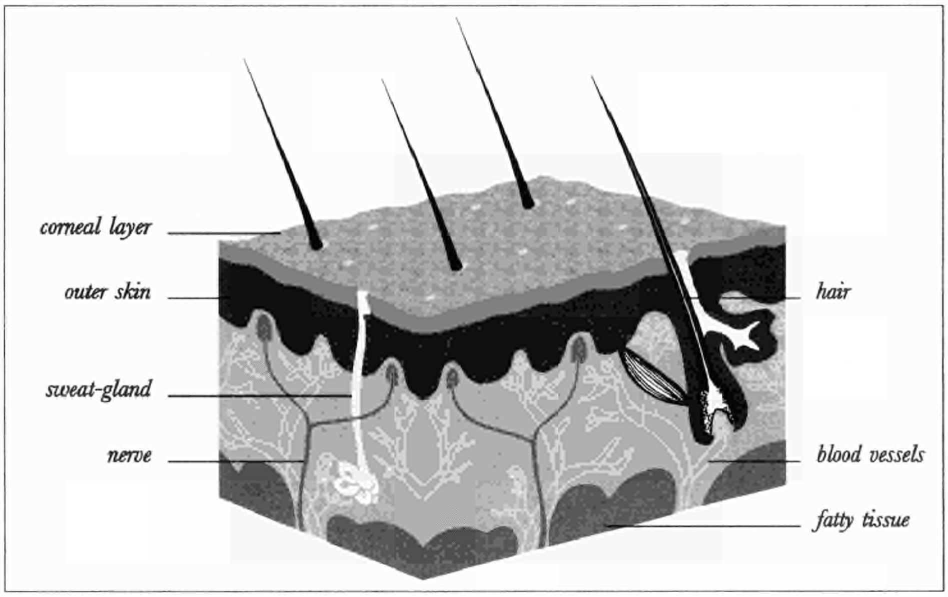
Paul started playing the game again. "White Eagle, get into the wigwam quickly, there are some cowboys galloping towards us and they don't look friendly. I'll stay outside and fight them off".
Paul stood outside fighting the cowboys for a long time. Meanwhile, Angela had fallen asleep because it was so warm inside the wigwam. When the sun went down, Paul stopped playing and looked around for Angela.
"Angela, where are you?" shouted Paul.
Angela came out of the wigwam, stretching and yawning. She took one look at Paul's face and started giggling. "Oh, Paul, you've got a red face! Now you don't need to pretend to be an Indian – you are one!"
Paul looked at himself in a mirror. "Oh", he said, "I forgot to put on the suntan oil and now I've got sunburn!"
Paul's father came out and burst out laughing when he saw Paul's face. "How, redface!" he said, trying to make Paul laugh.

Then he sat down in front of the wigwam and asked: "Shall I tell you what actually happens when your skin is sunburnt?" Paul and Angela nodded.

skin

"Well, let's talk about the skin first. Your *skin* is like a piece of clothing that covers you from head to foot. It protects you against things like bacteria, it lets you feel pain and helps to keep your body at a fairly steady temperature. Not all skin has the same thickness, though. The skin of your eyelids, for example, is thinner than the skin on the soles of our feet. See if you can feel the difference".
Paul and Angela felt the skin on different parts of their bodies. Then Paul's father took out a notebook. "Now let's take a look at the skin from the inside". He made the following drawing in his notebook:

Section of the skin



nerves

"Is that clear?" asked Paul's father. "Can you show me where your *nerves* are?" Angela pointed to the nerves on the drawing. "Yes, those are your nerves. They make you aware of pain, heat and cold and give you your sense of touch. Do you understand?"
Paul nodded but Angela asked: "But what exactly happened to Paul's skin?"

the outer layer of the skin

"That's a good question!" Paul's father replied. "Well, *the outer layer of the skin* contains the colour of your skin. Your skin changes colour and turns brown when it's in contact with the sun's rays. If you stay in the bright sun too long, like Paul, your skin might even turn red. Then it starts burning and itching. Eventually it peels and the sunburnt skin is replaced by a new skin".
"That's clear enough", said Angela and Paul.
"Well, Paul," said Paul's father, "your skin will stay red for a while so is it okay if I call you 'Red Eagle' for the time being?"

KEY POINTS

Everyone's skin has an outer layer of and an inner layer. The drawing which Paul's father made shows you the different parts of the skin. If you stay a long time in the sun and do not protect yourself, your outer skin turns red.

QUESTIONS

1 In what part of your skin is the colour to be found?

2 How can you protect yourself when you do not want to get sunburnt?

Going to the hospital? Ugh!
Going to the dentist's? Ugh!

AIMS

At the end of the lesson the pupil:
- knows that an X-ray machine emits invisible rays which can pass through your body
- is aware that pictures can be taken of the inside of the body with the help of X-rays
- is aware that X-ray pictures are of immense help to doctors and dentists in choosing the right treatment
- knows that protection is needed while an X-ray picture is being taken.

PROPOSED MINIMUM TIME

45 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 7: Applications of ionizing radiation and radioactivity

TEACHING SUGGESTIONS

Before reading the story, ask the pupils to talk about their experiences with doctors and dentists. Introduce the subject of X-rays taken by doctors and dentists.

Choose different pupils to read the two stories to the whole class. After the reading, ask the pupils to compare the two stories and identify what they have in common (X-rays, inside of the body, protection).

Show X-ray pictures of the human body and let your pupils guess what part of the inside of the body is shown on each picture.
After showing them the pictures, you can ask the following questions.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 What can a doctor or dentist see on an X-ray picture?
Bones, inside of the body, fractures.

2 Can you see the rays when an X-ray machine takes a picture of you?
No, X-rays are invisible.

3 Why do Angela and Paul have to wear aprons?
To protect themselves against the X-rays.

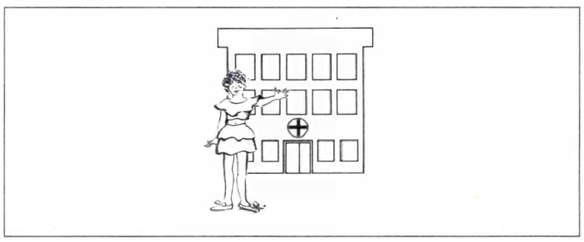
4 Why do you think the dentist has to stand well back when taking an X-ray picture?
To protect him/herself against the X-rays.

This story begins with Angela standing in front of the entrance to a hospital and she tells you about something that happened to her last year.

LESSON 3

Going to the hospital? Ugh!

Hello, Angela here! I'm standing in front of the entrance to the hospital where I had to come one year ago. One afternoon I had gone to my riding lesson and we were practising jumping but, as my horse wasn't in a good mood, it reared up at the second fence. I landed on the ground with a thud and immediately felt an excruciating pain in my right leg. I couldn't walk on it and was taken to the hospital straight away.



I was taken to the out-patients' department. Here, the nurse gave me a painkilling injection and then the doctor, Dr Gray, showed me to the X-ray room.

a lead rubber apron

He thought my leg was broken but he was not quite sure. You could not tell from the outside of my leg. In the X-ray room a picture was taken of the inside of my leg after the doctor had put *a lead rubber apron* over my tummy to protect my body against the X-rays.
On the picture, the doctor could see my bones and tell whether or not there was a fracture.

This is one of the pictures taken of my leg. You can see the kneecap, the shin, and the broken bone. Because I had had the injection I did not feel much

the X-ray machine

an X-ray picture

pain, so I wanted to know a bit more about X-ray pictures. Dr Gray said that *the X-ray machine* emits rays. Because ordinary light cannot pass through our bodies, ordinary pictures only show somebody's outside. On *an X-ray picture* we can see the inside.

X-ray picture of a broken leg

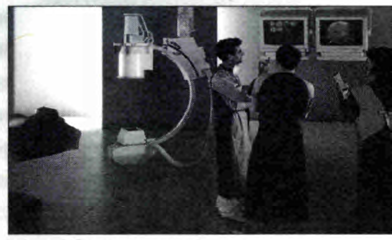
Well, my leg was beautifully wrapped up in plaster. Thanks to the X-ray pictures, Dr Gray knew exactly how to set my leg. After a while, I had to come back again and new pictures were taken, this time to see if the bone had grown together again. Fortunately, it had. The plaster was then taken off. I was glad when they told me I could take the cast home with me because there were a lot of signatures on it!

KEY POINTS

If a doctor wants to be sure whether something inside the body is broken, he has to take X-ray pictures with an X-ray machine.
Aprons are used to protect certain parts of the body against X-rays.

In this lesson Paul tells you about his experiences at the dentist's.

Going to the dentist's? Ugh!



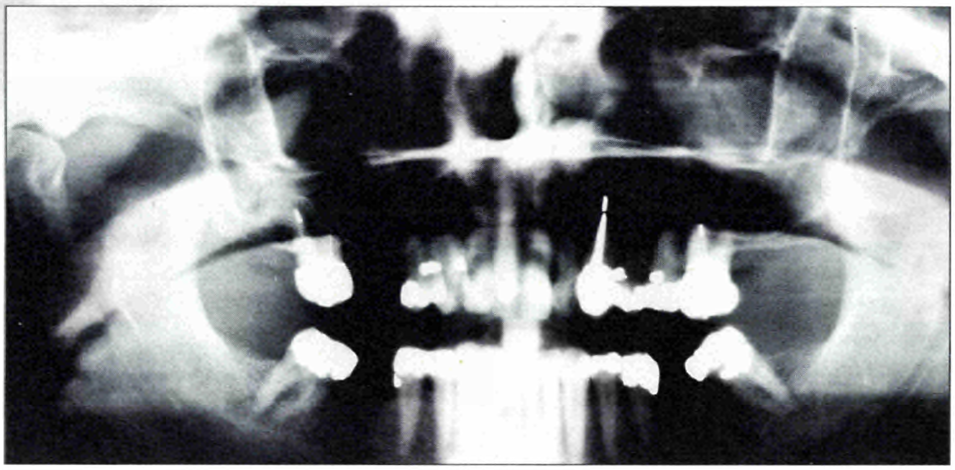
an X-ray room

an X-ray machine

Last week, after eating some toffee, I had a sudden pain in my mouth. It became a gnawing toothache and my jaw started to throb. The pain spread through my face and my mother immediately telephoned our dentist, Dr Bright, for an appointment. It was urgent so he saw me the same day. "Paul", he said, "you have a very bad abscess and I want to see how big it is. We have to use *an X-ray machine* to look inside your jaw."

rubber apron

I probably looked a little worried. He said I would not feel anything. All that I had to do was hold a little cardboard packet containing the film to the inside of my mouth behind the X-rays. He pulled out a machine on a mechanical arm and pointed it down on to my cheek. He put a heavy *rubber apron* on my lap and a sort of collar around my neck to stop the X-rays from entering the rest of my body. Then he and my mother left the room to avoid getting X-rays themselves.He must have switched on the machine from outside the room because he was back almost immediately to take away the cardboard holder. The picture had been taken but I had not felt a thing.



X-ray picture of teeth

the X-ray picture

I had to wait until the film was developed and he showed me *the X-ray picture* of my teeth. I could follow the tooth right down to my jaw and there he showed me a dark patch. "That is the abscess", he said, "we now know how to treat the tooth so it will be better in a few days". I felt better already, it was so nice to know exactly what was wrong with my tooth so that the dentist could treat it correctly.

KEY POINTS

X-rays are also used by dentists to examine patients' teeth and jaws. Aprons are used to protect certain parts of the body against X-rays.

QUESTIONS

1. What can a doctor or dentist see on an X-ray picture?
2. Can you see the rays when an X-ray machine takes a picture of you?
3. Why do Angela and Paul have to wear aprons?
4. Why do you think the dentist has to stand well back when taking an X-ray picture?

Stone-age walkie-talkie

AIMS

At the end of the lesson the pupil:

- is able to explain in his/her own words the basic principles of radio waves
- knows the basic principles of sound waves.

PROPOSED MINIMUM TIME

60 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 3: Non-ionizing radiation

TEACHING SUGGESTIONS

Tell or read the story to the pupils.
Then ask the pupils to answer the questions below.
When the pupils have answered the questions, you can ask them to make walkie-talkies in the same way as Paul's father did when he was a boy.
Finally, you can explain the principle of sound waves once again. (When people speak, the sounds they make come out in waves. These waves are called sound waves. The "walkie-talkie" experiment shows you what happens with sound waves. One person speaks into a tin. His sound waves hit the wall of the tin and then travel through the string. At the end of the string they go inside another tin. When you put your ear against this vibrating tin, you can hear what the person at the other end is saying.)

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Using the drawing, who can tell us how a walkie-talkie works?
Somebody speaks into the microphone of the walkie-talkie. Inside the microphone, sound is transformed into electrical signals. These signals are sent to a transmitting aerial which transmits the radio waves. Some of the waves are received by the aerial of the other walkie-talkie.

2 What are the similarities and differences between Paul's modern walkie-talkie and the "stone-age" walkie-talkie Paul's father made when he was young?
Similarities:

1. Both use a sort of microphone.
2. Both transmit words (sounds) from one place to another.
3. Both use waves to make the tranmission.

Differences:

1. The modern walkie-talkie uses radio waves for the transmission while the "stone-age" one uses direct (mechanical) sound waves.
2. The modern walkie-talkie has no wires but the "stone-age" one has a string connecting both tins.
3. The "stone-age" walkie-talkie is less complicated (no electrical signals involved) and cheaper.

Angela and Paul play with a walkie-talkie set. Paul's father explains the similarities between radio waves and sound waves.

4 LESSON

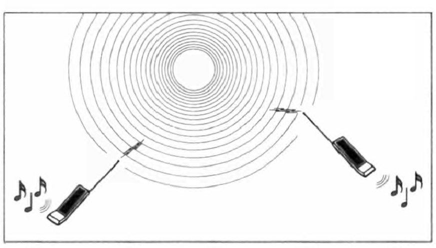
Stone-age walkie-talkie

Last Saturday was Paul's ninth birthday and he was going to have a birthday party. When he got up, his mother was already preparing some cakes. He had invited all his friends from school and from the neighbourhood, thinking that the more friends he invited the more presents he would get. At 2 o'clock, his friends began to arrive and half an hour later they were all playing games or running around the house. Paul, though, was sitting at the table surrounded by the colourful wrapping paper. As he was looking rather miserable, Angela asked him what the matter was.

"Everybody brought me a present", he answered, "except Dad!"

His father heard him saying this and said: "Oh, didn't I? I must have forgotten. How stupid of me!" He gave Angela a wink. "Here it is, Paul, I hope you like it!" Paul cheered up immediately when he saw the large parcel his father had given him. He quickly opened it and saw it was a walkie-talkie set – the present he had always wanted. "Thanks, Dad", he said, "now we can pretend to be policemen talking to each other by walkie-talkie. I'll go outside, Angela, and we'll see if we can hear each other". Paul ran out of the house into the garden.

Angela looked at the walkie-talkie and said: "But how does it work? I don't know what I have to do".

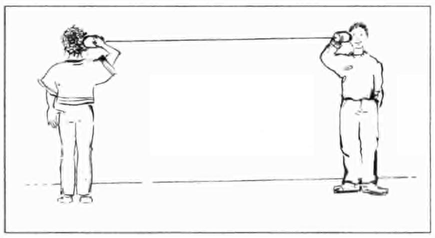


Sound is transmitted from one walkie talkie to another by radio waves

"Oh, it's easy," Paul's father explained, "you just press the button and speak into the microphone. Inside *the microphone* the sounds you make are transformed into *electrical signals*. These signals go to the aerial of the walkie-talkie, which transforms them into *radio waves*. These waves travel outside the house, where they are received by the *aerial* in Paul's walkie-talkie, which turns them back into sound waves and words".

the microphone
electrical signals
radio waves
aerial

"Hello, hello, this is Robocop speaking. Can you hear me, Angela? Over". Angela giggled and pressed the button on her walkie-talkie. "Loud and clear", she said, "Robocop can come back in again: the coast is clear!" "OK, over and out", Paul answered.
"It's fantastic", Angela said, "I can hear everything he says as if he was standing next to me". "You know", Paul's father said, "when I was young we made our own walkie-talkies." "Really? How did you do it?" Angela asked. "Well, we took two tins, made a hole in the bottom of each one and joined them together with a long piece of string". "And did it actually work?" Angela asked.



"Yes, it really did!" Paul's father said. "You see, what happens is the sound waves hit the wall of the tin, which acts as a microphone, and then are directly transmitted through the string to the other tin, where you can hear them. It works rather like Paul's walkie-talkie, but it's less complicated, of course, and less expensive".
Paul, who had overheard the end of their conversation, quickly said: "What you had, Dad, was a stone-age walkie-talkie!"
They all had a good laugh at this.

KEY POINTS

The figure on page 11 shows how sound is transmitted from one walkie-talkie to another by radio waves, but sound can also be transmitted directly as sound waves along a piece of string.

QUESTIONS

1 Using the drawing, who can tell us how a walkie-talkie works?

2 What are the similarities and differences between Paul's modern walkie-talkie and the stone-age walkie-talkie Paul's father made when he was young?

10-12 YEARS

There are 6 lessons for the oldest pupils in the primary school.

INFORMATION

The guides throughout the 6 lessons are Paul and Angela. They are two 10-year-old children who learn more about radiation together with Angela's uncle, Dr A. Tom. As the story in which they are involved continues throughout the 6 lessons, it is necessary to teach all the lessons at this level.

This level starts with a lesson about a type of radiation with which the pupils are familiar, i.e. non-ionizing radiation, which includes heat (infrared radiation) and light. Sound (a form of mechanical energy wave) is also touched upon in the first lesson as an example of the concept of 'wave'. Then we focus on the various types of ionizing radiation and look at some of their applications. The last lesson is designed to encourage pupils to express their own views on nuclear power.

The topics for the 10-12 age group are:

CONTENTS

- non-ionizing radiation (including sound)
- ionizing radiation
- types of ionizing radiation
- applications of ionizing radiation
- nuclear power

III

LESSONS LEVEL III

EVALUATION

When you have completed all the lessons at this level you can test what the pupils have learned with the following assignment:
Ask the pupils to write short articles on various aspects of radiation, e.g. explaining what ionizing radiation is, what types of radiation there are, describing how radiation is applied and expressing his/her own views. Assess the quality of the articles written.

Sound, heat and light

AIMS

At the end of the lesson, the pupil:
- can describe 2 kinds of non-ionizing radiation including sound waves.

PROPOSED MINIMUM TIME

40 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 1: Historical introduction
Chapter 3: Non-ionizing radiation

TEACHING SUGGESTIONS

This lesson is concerned with sound, heat and visible light. Sound is mechanical energy transmitted as waves through air, water or other media. Sound, heat (infrared radiation) and visible light are forms of non-ionizing radiation. All three forms are familiar to the pupils.

You can start the lesson by asking: "What do you think of when you see the word radiation?". You can write the word "radiation" on the blackboard and then get every pupil to write his or her words next to it. After this introduction you can do an experiment so that the pupils can experience at first hand what Angela and Paul are going to discover in this lesson.
For the experiment you need rulers. You can split up the class into 5 groups. Each group needs one ruler. The pupils take a ruler and place it on the table as shown in the illustration below.

Holding the ruler with one hand, they pull the other end down and then release it. They will discover that when the ruler is stationary, they hear nothing, but when they pull down one end and then let go it vibrates and then they hear sound. They will also discover that the more the ruler vibrates, the louder the sound is.

After completing this experiment, ask the pupils to read the text and tackle the assignments.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 The lesson dealt with sound, heat and light. Look at the table below. In the first column you see the three kinds of radiation. For each kind of radiation write down various sources in the second column and different ways of protecting yourself in the third column.

Types of radiation	Sources of radiation	Means of protections
sound	• radio, guitar, bell • low-flying aircraft	• earplugs, fingers in ears • distance from the source
heat	• sun, heater	• special clothes • distance from the source
light	• sun, lamp, fire	• sunglasses, hands over eyes, suntan oil

2 Like most birds, bats catch and eat insects; bats, however, are able to catch flying insects at night by emitting a high-frequency sound which bounces off the flying insects. The returning sound waves, like radar signals, are received by the bat which then knows where the insect is. This is a form of echo-location. Make a drawing showing what happens.

In the following lessons you will learn more about radiation. This first lesson deals with a type of radiation which you are quite familiar with. It is called non-ionizing radiation.
You will also learn about sound. You will be in the company of Paul and Angela and Angela's Uncle Arnold, who has a time-space machine...

LESSON

Sound, heat and light

Paul and Angela are neighbours and the best of friends. They are 10 years old and they go to the same school. This is very handy when they have homework to do; not that they do their homework together every day, but they sometimes help each other when Angela feels she does not understand some grammar exercise or when Paul is having problems with his maths.
One day last week they were chatting as they walked home from school. They had just finished a tiring physics lesson.
"I couldn't understand a word of what the teacher was saying in the lesson", Paul sighed. "All that stuff about 'ionozing' and 'non-ionozing' radiation ... or something. Did you understand it, Angela?"
"This time I felt it was pretty difficult myself", Angela admitted, "I'm afraid I can't help you."
"But", Paul said, "we've got a test on it next week! What am I going to do?"
Angela tried to reassure him: "Don't worry, we'll find something. I just don't know what yet."

Suddenly something occurred to Paul. "Don't you do have this genius of an uncle living near here? Isn't he a doctor or a professor or something like that?"
"Uncle Arnold!" Angela exclaimed. "Yes, he is a Doctor of Physics."
"Doesn't he do all those tests which blow up half his house?" Paul asked excitedly. "Well, half the house is exaggerating a bit," said Angela, "but he often has broken windows". Angela looked at her watch. "He lives just around the corner. Let's see if he's in."

Soon they were standing in front of a beautiful large house with some steps leading up to the front door. They went slowly up the steps and, at the top, they saw a door-plate with a name on it: Dr. A. Tom. Now Paul began to feel a bit nervous. He was impressed by the big house and the grand-sounding name. "Should we really...?" he asked, casting an anxious glance at Angela.

"Yes, of course," said Angela in her determined way, and firmly pulled the brass knob of the door bell. A few seconds later the door opened and there stood Angela's uncle. He was quite different from the professor Paul had imagined. Instead of a tall, thin man with glasses who was wearing a dark suit and looked grumpy and absent-minded, Paul saw a fat, jolly and friendly man wearing a T-shirt. After he had invited them in, Angela explained that they found it difficult to understand what their physics teacher had told them about radiation.

"You're right, it is a difficult subject", the scientist admitted. "But first of all, take your tops off and sit down over here. It's not cold because I have just turned on the heater. I think you'll find it's warm enough". Paul and Angela took off their tops and sat down near Uncle Arnold, who gave them a big smile. "If you want to know more about radiation", he said, "why don't we start with things around us. You see that *heater* there? Well, it gives out

heater

A heater gives out radiation

radiation that we can feel on our faces, hands, arms and legs. The closer you get to it the more you feel the radiation. Why don't you try it and see?" Angela and Paul went nearer to the heater. "Yes, I can feel it", Angela said. "Ow!", Paul exclaimed, "it hurts". He had got too close!

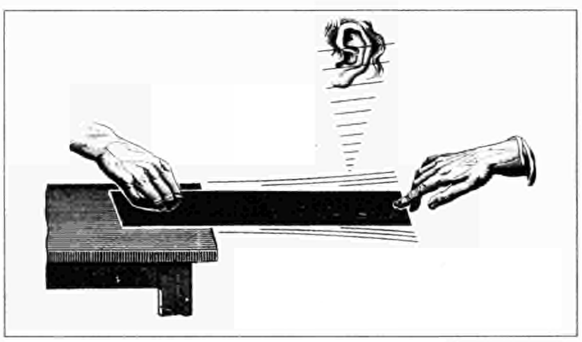
"That sounds just like the sun", Angela said. "I know that the sun gives out radiation too. You can feel it especially in the summer when you are playing outside. But you have to be careful not to stay in the sun too long, otherwise your skin burns. Like last year, Paul, when you got sunburnt". "Yes, I remember", Paul said, "I forgot to put on suntan oil".

Uncle Arnold started to say something but suddenly they heard a loud noise. Everything was shaking, even the windows. "What was that?" Paul asked as the noise died away.

"It was a low-flying jet", explained Uncle Arnold. He thought for a few seconds, then asked: "By the way, did you know that *sound* is a kind of radiation, too? I can give you a simple demonstration in my laboratory. Let's go over there now".

sound

When they arrived at the laboratory, Uncle Arnold pointed to a ruler on a table. "You see that ruler, Angela? Well, move it so that one end hangs over the edge. Hold the ruler down firmly, then pull down the end. Watch what happens when you let go". Angela did what Uncle Arnold said.



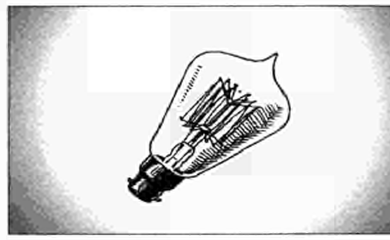
Sound travels through the air in the form of waves

vibrations

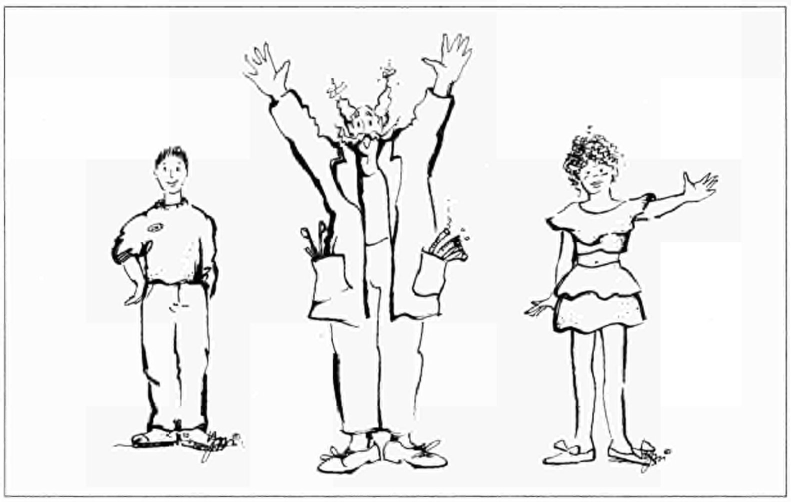
"Did you hear that, Paul"? said Angela. "When I let the ruler go, it started to shake and made a noise".
"Let me explain", said Uncle Arnold. "You made the ruler vibrate and this set up *vibrations* in the surrounding air. These fanned out until some of the vibrating air particles hit your ear drum. The more the ruler vibrates, the stronger and louder the sound becomes. In other words, sound travels through the air in the form of waves, just like other kinds of radiation".

light

"Well", he went on, "it must be quite late now – it's getting dark already. You have to go home, I expect. I'll put the light on so you can see where your tops are". When the light had come on, Uncle Arnold explained that the *light* from the lamp was also a kind of radiation. "So you see," he said, "there is more radiation around us than you realised".
"Well, thank you, Uncle Arnold", said Angela, "we'll come and see you again tomorrow". "Yes, please do", replied her uncle, "because then I want to tell you something about another type of radiation, one which is more complicated. To explain it, we need the time-space machine". Paul and Angela looked at each other. "What on earth is that?" they exclaimed.



A lamp emits light, which is a kind of radiation



KEY POINTS

In this lesson you learned about three types of radiation which are around you:

- ***sound***
- ***heat***
- ***light***

QUESTIONS

1 The lesson dealt with sound, heat and light. Look at the table below. In the first column you can see the three kinds of radiation. For each kind of radiation write down various sources in the second column and different ways of protecting yourself in the third column.

2 Like most birds, bats catch and eat insects; bats, however, are able to catch flying insects at night by emitting a high-frequency sound which bounces off the insects. The returning sound waves, like radar signals, are received by the bat which then knows where the insect is. This is a form of echo-location. Make a drawing showing what happens

TYPES OF RADIATION	SOURCES OF RADIATION	MEANS OF PROTECTION
Sound	•	• ....
	•	• ....
Heat	•	• ....
	•	• ....
Light	•	• ....
	•	• ....

Becquerel? Who is he?

AIMS

At the end of the lesson the pupil:

- can describe what Becquerel discovered
- can describe where ionizing radiation comes from
- can say what radioactivity is
- can identify the becquerel as the unit of activity of a radioactive substance.

PROPOSED MINIMUM TIME

30 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 1: Historical introduction
Chapter 2: The structure of the atom
Chapter 4: Radioactivity and ionizing radiation

TEACHING SUGGESTIONS

This second lesson deals with the discovery of ionizing radiation.
Paul and Angela accompany Uncle Arnold on a journey back in time and space in order to be present at the precise moment of Becquerel's discovery of ionizing radiation.
Begin the lesson by reading the introduction. Go over the material on non-ionizing radiation presented in the previous lesson. Also tell the pupils that this lesson is about the discovery of another kind of radiation, known as ionizing radiation. Ask them to read the story about Becquerel's discovery. The lesson may be expanded to include additional information about Becquerel, or you may choose to include other discoveries concerning ionizing radiation and to discuss these (consult Chapter 1 of the Technical Supplement).

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 What did Professor Becquerel discover?
He discovered that a particular kind of substance, which we now call uranium, emits ionizing radiation.

2 How did Professor Becquerel make this discovery ?
Uranium left marks on the photographic plates.

3 Give the names of two radioactive substances.
Uranium, thorium.

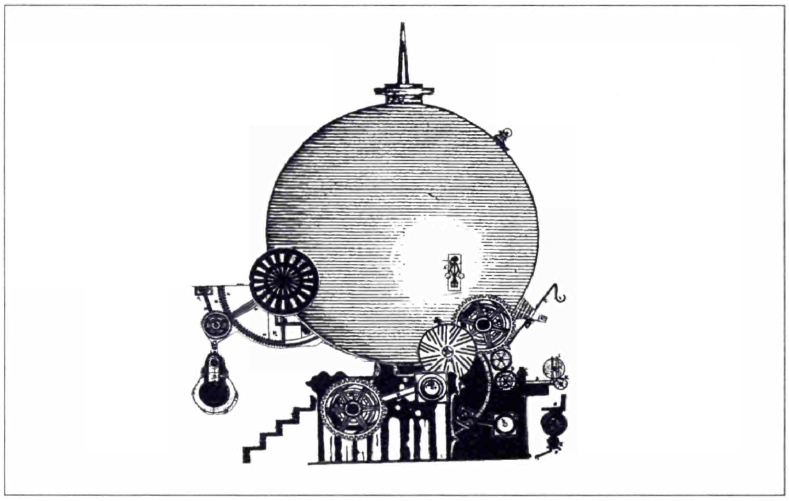
In the first lesson you learnt something about sound, heat and light, which are all types of non-ionizing radiation which you can either see, feel or hear. You are all familiar with these kinds of radiation. But there is another kind of invisible radiation which is present in our daily lives. Most of it occurs naturally. We call it ionizing radiation.
Let us join Paul and Angela again and see how they learn about ionizing radiation.

LESSON

Becquerel? Who is he?

Paul and Angela arrived at Uncle Arnold's place. He had promised to tell them more about another kind of radiation. "Hi, Uncle Arnold," Angela said, "here we are again. We are curious to know what else you want to tell us about radiation".

"Well, come in," said Uncle Arnold, "I wasn't expecting you this early but it doesn't matter – I have just finished one of my experiments. Yes, I promised to tell you something about ionizing radiation, didn't I? It is a rather difficult subject, but I know what we can do. We can go and see a famous physicist in my tispama".



Time-space machine

"In your what!" Paul and Angela both exclaimed.
"In my tispama", said Uncle Arnold, "it's what I call my time-space machine for short".

"Isn't that a machine for travelling through space?" Angela asked. "More or less", her uncle admitted. "With a time-space machine you can travel in space or anywhere in the world as well as backwards and forwards in time". "Is that really true?" asked Paul disbelievingly. "Yes, it's really true, Paul", Uncle Arnold assured him. "If you follow me, you can see the machine straightaway".

With mounting curiosity they followed Uncle Arnold. When they go to his laboratory, Uncle Arnold walked to the back where there was a big glass ball looking like the cockpit of a helicopter, with an opening in it. Through this opening, in the middle of the ball, they could see a panel full of buttons and dials.

"Why don't you get in?" said Uncle Arnold.

"What are we going to do, uncle?" asked Angela, as they stepped through the narrow opening of the glass ball.

Becquerel

"We are going to see a French scientist. His name is Becquerel and he played a very important part in discovering that other type of radiation I talked about – what we call 'ionizing radiation'". "Will we back in time for supper?" Paul started to say, but it was already too late. Uncle Arnold pushed some buttons and they felt a strange tingling sensation in their stomachs and heads.

During their journey, which was accompanied by lots of roars and flashes, Angela saw her uncle turning various buttons. "What's the matter, uncle?" asked Angela. "Well, as you can see on this time-clock, we are now in the 19th century". Uncle Arnold pushed some buttons and said: "Well, we're now in 1896 and, if my calculations are right, we are somewhere near Henri Becquerel's laboratory."

They got out of the rather cramped time-space machine and saw that they had landed in a square. "Let's just take a look over there" , Uncle Arnold suggested, "that looks like a laboratory to me."

Outside a building they saw a door-plate with these words on it written in large letters: "Professor H. Becquerel. Physicist".

Angela was just about to knock when she heard a noise from inside. A second later the door burst open and a man in a white coat was thrown out and fell down the steps.

"I don't need a lazybones like you!" thundered a man with a beard and flashing eyes who was dressed in a dark suit. "Not only that, you muck up more tests than anyone else. Bungler! Nom de Dieu!" Then he went back in and slammed the door. He was so angry that he had not even noticed the three visitors standing there.

Fortunately, the man at the bottom of the stairs appeared not to have broken anything in the fall because he had got up immediately. As he flicked the dust off his white coat, he muttered: "That man is completely crazy".

"Why do you say that?" asked Uncle Arnold, who had come up to the man to help him clean his coat.

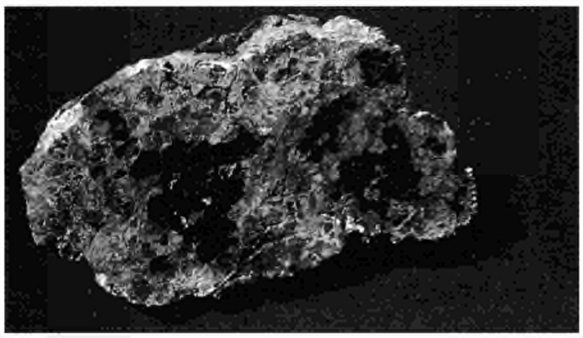
"Why? Well, just because he is!" answered the man, who began to get excited. "He always blames me when things go wrong"."What kind of things?" Uncle Arnold wanted to know. "Anything that ever goes wrong while I'm around, and then he says I'm responsible", the man said. "Just take the other day! That business with the photographic plates*!" "Photographic plates?" asked Angela in her best French accent.

"Yes, the professor had stored a few photographic plates in a dark cupboard. As you probably know, photographic plates must be kept in a dark place away from the light. If they are exposed to light, they can't be used again. Today, Professor Becquerel opened the cupboard to develop the plates and saw that they had been exposed because there were dark marks on them. He was furious! And just guess who got the blame? Right, I did. I am supposed to

* Photographic plates are light-sensitive plates and, just like unexposed film, should not be exposed to ordinary daylight otherwise the pictures taken will be spoilt.

have opened the door of the cupboard, and let the light in which spoiled the plates. I ask you! When the doors were locked all the time and he is the only one who has the keys!" The man shook his head indignantly.
"Was there anything else in the cupboard?" Uncle Arnold enquired. "Yes", the man answered, "a week before he stored those plates in the cupboard I was told to put a small lump of rock** in it". "I remember that quite clearly", he went on. "Anyway, it doesn't matter anymore, he has thrown me out. By the way, who are you?" he asked. "My name is Jean, can I offer you something to drink? There is a nice little cafe over there".
They introduced themselves and then ordered some drinks. Jean, who was now looking a bit more cheerful, began to talk about what had happened to the plates. "Maybe that substance I put into the cupboard had something to do with it. The photographic plates looked as if they had been exposed to light because they could not be used again. The substance I put in must have given off some kind of light. But that doesn't make sense, does it !"
"Maybe you can do it again as an experiment", Uncle Arnold suggested.
"Well," said Jean, "I'll go back to Professor Becquerel and tell him what I think has happened. He can't blame me now for that dark spots on the plates". He said goodbye to the three strange visitors and went back to Professor Becquerel's house.

A few days later Jean saw the Professor jump for joy when he repeated the test, and found that the piece of uranium left a mark on a photographic plate.



Uranium emits ionizing radiation and it is said to be radioactive

By then our travellers in time and space were already on their way home. After they had got back they talked about their adventure.

ionizing radiation

"Becquerel was the first person who discovered, by accident, that some substances such as uranium spontaneously emit radiation", Uncle Arnold told Paul and Angela. "This radiation is given a rather complicated name – it's called *ionizing radiation*. And if a substance emits ionizing radiation, we say it is radioactive. Later on they discovered that there are other substances, such as thorium, which also emit ionizing radiation."

radioactive substances

becquerel

"So substances like that are called *radioactive substances* and they emit radiation", said Paul, to make sure he had understood. "That's right", answered Uncle Arnold. Then Angela said: "And radiation from those substances is called ionizing radiation and is the other type of radiation you talked about before which is different from sound, heat and light. Is that right?" "Yes, right again", said Uncle Arnold. "And, do you know, later on the name '*becquerel*' became the name of the unit for the activity of a radioactive substance".
"I see", said Angela. "I think I understand it much better now". "I do, too,", said Paul.

** The rock was uranium ore.

KEY POINTS

In this lesson you learned that Becquerel, a 19th century French scientist, discovered that some substances such as uranium emit radiation. This type of radiation is called ionizing radiation. Substances which emit ionizing radiation are called radioactive.

QUESTIONS

1. What did Professor Becquerel discover?
2. How did Professor Becquerel make the discovery?
3. Give the names of two radioactive substances.

Ionizing radiation through thick and thin

AIMS

At the end of the lesson the pupil:
- can name four types of ionizing radiation
- can describe how alpha, beta and gamma radiation affect the body
- can make a distinction between natural and man-made sources of ionizing radiation
- knows that most of the ionizing radiation to which we are exposed comes from natural sources
- knows that the sievert is the unit used to express the dose of ionizing radiation received by the human body.

PROPOSED MINIMUM TIME

35 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 4: Radioactivity and ionizing radiation
Chapter 5: The biological effects of radiation
Chapter 8: Doses from ionizing radiation

TEACHING SUGGESTIONS

This lesson is about the various kinds of ionizing radiation and their characteristics. Four kinds of ionizing radiation can be distinguished: alpha, beta and gamma radiation and X-rays. We are also able to distinguish between man-made and natural sources of ionizing radiation. The teacher can begin the lesson by asking the pupils if they know the difference between the two concepts "natural" and "man-made". "Natural" means present in nature, "man-made" means produced by man.

Also ask the following question: Why do you think that people have to be aware of ionizing radiation? Emphasize that ionizing radiation can pose a health risk and may have (harmful) effects on the human body. After this question-and-answer session get pupils to read the text and encourage them to ask questions themselves.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Look at the picture of a hand; draw lines showing how deep alpha, beta and gamma radiation and X-rays can penetrate.

2 Under what circumstances can substances emitting alpha radiation become harmful?
When the substances are inhaled or swallowed.

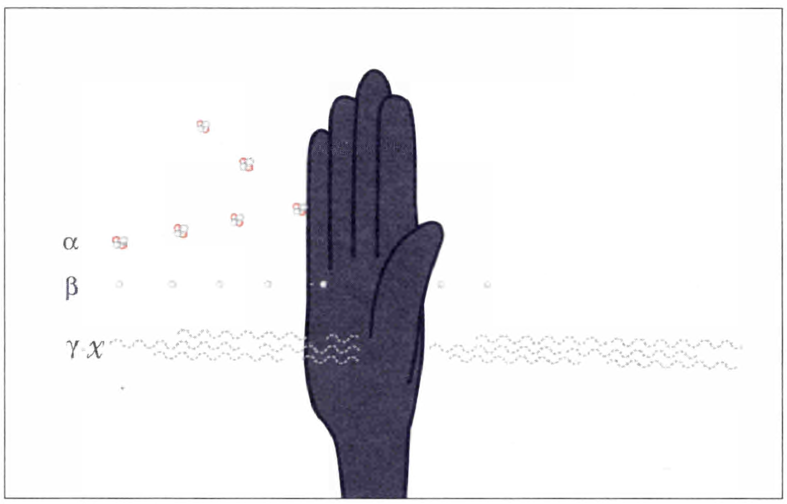
3 Describe in your own words what you can deduce from the pie chart.
- We are more exposed to ionizing radiation from natural sources than to ionizing radiation from man-made sources
- The most important source of exposure is radon gas
- Among man-made sources, the largest exposure by far is to medical sources.

Angela and Paul were in class for their weekly physics period. The teacher had told them that this time they would talk about sources of ionizing radiation.

LESSON

Ionizing radiation through thick and thin

The teacher asked: "Who knows the name of a type of ionizing radiation?" Paul raised his hand and answered: "Alpha radiation, beta radiation, gamma radiation and X-rays". "That's a perfect answer, Paul," said the teacher in admiration. "Who told you that?" Paul muttered something like "read it in a book" and chose not to talk about the visits to Uncle Arnold.
The teacher continued: "All these kinds of ionizing radiation affect the human body in different ways". He made a drawing on the blackboard.



Penetration power of the different types of ionizing radiation

alpha radiation

"*Alpha radiation*, named after the first letter of the Greek alphabet, alpha, is ionizing radiation which, for instance, bumps against the skin of your hand but can't go through it.

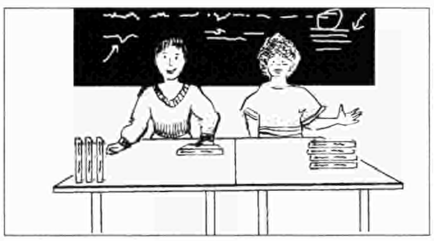
beta radiation

gamma radiation

Beta radiation, named after the second letter in the Greek alphabet, beta, goes a little way – but only a very short distance – into your hand, and so isn't very penetrating either.
And then there's *gamma radiation*, which easily goes right through your hand. Who knows the origin of the word gamma?" The girl who was sitting next to Paul raised her hand. "Yes, Wendy?" the teacher said. "Is it the third letter of the Greek alphabet?" she said hesitantly.
"Exactly!" said the teacher. "And if you look at this drawing on the blackboard, which kind of ionizing radiation is the most dangerous, do you think?" A boy at the back of the class put his hand up. "Yes, Peter?" said the teacher. "Gamma radiation seems the most dangerous to me," the boy said. "Why do you think so?" asked the teacher. Peter answered: "Because it may harm the inside of your body".
"Well, that's true", said the teacher, "gamma radiation can damage the cells inside your body, but you can also breathe in radioactive dust that is in the air, or swallow radioactive substances that are in food and drink. Even though alpha radiation doesn't penetrate very far, if these substances emit it inside your body it can be harmful because it is so close to various organs".
The teacher paused for a second. "In one of the earlier lessons we mentioned the various sources of radiation. We'll just write them down on the blackboard. Who remembers where radiation comes from? Yes, Janet?" "From the sun," Janet answered. "That's right, Janet", said the teacher, "but the sun is something different. I should have asked where *ionizing radiation* comes from".
Janet went on: "Apart from rays that bring warmth, the sun also gives us ultraviolet radiation – UV rays – as well as cosmic radiation, which are a kind of ionizing radiation". "Well done," said the teacher approvingly. "Any more, Janet?"

ionizing radiation

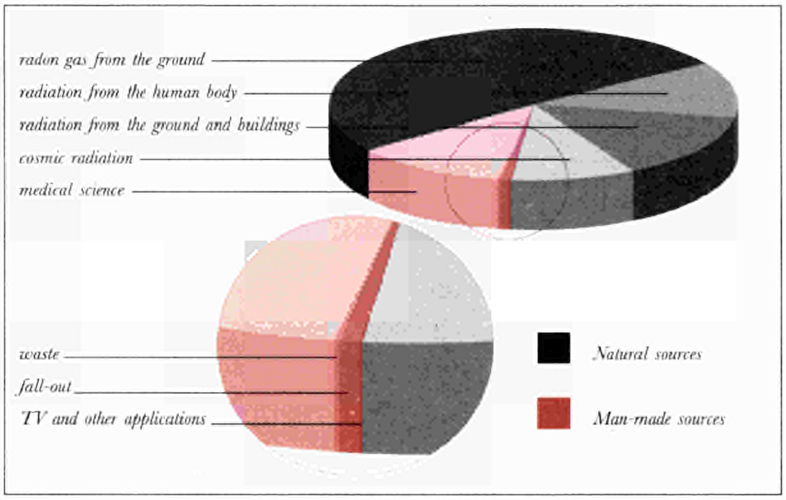
Janet continued: "Some ionizing radiation also comes from the ground, I think". "That's right," said the teacher. "Inside the earth there are radioactive materials like uranium and thorium which emit ionizing radiation and energy. And," he added, "this energy inside the earth sets free so much heat that stones are turned into liquid. Just think of the lava that comes out of volcanoes".
"Are there any other sources?" he asked, "I'll just write them on the blackboard. Yes, Angela?" "There's ionizing radiation from our food," said



Angela, "and someone told me that there is ionizing radiation from some of the materials that our houses are made of". "You are well informed," said the teacher. "Well, we've already got quite a long list. But there are still a few more sources. How about the medical use of ionizing radiation?" "You've already told us about that!" said several children all at the same time.
Then a boy called John said: "I think I know one more. Nuclear tests produce some radiation, don't they? And .... ", he stopped to think, "perhaps nuclear power stations too". "That's right," said the teacher. "Well, now I have a long list on the blackboard. I am going to separate *natural sources* from man-made or *artifical sources* and then make a drawing showing an estimation of how much radiation we get from each source".

natural sources
artifical sources

This is what the drawing looked like.



The distribution of the average radiation doses received in Europe

The teacher also wrote down the following list to go with the drawing:

NATURAL SOURCES

• cosmic radiation (sun and space):	10 %
• radiation from the ground and buildings (building materials):	14 %
• radiation from the human body:	12 %
• radon gas from the ground:	51 %
Total:	87 %

MAN-MADE SOURCES

• medical science:	12 %
• waste:	0.2 %
• fall-out:	0.7 %
• TV and other applications:	0.1 %
Total:	13 %

When the pupils had copied all this out, the teacher asked: "What does the information tell you? You will see that the drawing gives the same information as the list. What is the most important conclusion from this information?" It was Angela who answered: "Most ionizing radiation comes from natural sources and only a fairly small bit comes from man-made sources". "Well done!" said the teacher.

Angela put her hand up again and said: "I've got one more question about the drawing." "Yes?" said the teacher. "Well", said Angela, "under man-made sources of ionizing radiation you mentioned other applications. What are those?" "It would take too long to go into that now", answered the teacher, "we'll come back to that next week. But to end with I would just like to mention a unit used to express the effect of ionizing radiation on the human body. You already know units like the metre, kilogram, second, decibel, don't you? Well, this one is called the *sievert*. And just as you can divide one gram into 1 000 milligrams, so you can divide one sievert into 1 000 millisieverts". At that very moment they heard the bell go; school was over. As the children left the classroom, some had radiant looks on their faces!

sievert

KEY POINTS

In this lesson you learned that there are various kinds of ionizing radiation: alpha, beta and gamma radiation and X-rays. They affect the body in different ways.
You also saw that there are two types of sources of ionizing radiation: man-made and natural. Finally, the unit used to express the effect of ionizing radiation on the body is the sievert.

QUESTIONS

1 Look at the picture of a hand; draw lines showing how deep alpha, beta and gamma radiation and X-rays can penetrate.

2 Under what circumstances can substances emitting alpha radiation become harmful?

3 Describe in your own words what you can deduce from the pie chart.

Applications in hospitals

AIMS

At the end of the lesson the pupil:

- can describe what an X-ray picture is
- can describe how people can protect themselves against X-rays
- is able to identify the advantages and disadvantages of using X-rays in hospitals.

PROPOSED MINIMUM TIME

55 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 6: Protection against ionizing radiation
Chapter 7: Applications of ionizing radiation and radioactivity

TEACHING SUGGESTIONS

This lesson deals with the use of X-rays in hospitals, where they are used both for diagnosis and for treatment (the last application is also called radiotherapy).
You can invite a doctor or radiologist to talk about the use of X-rays in medicine.
At the end of the lesson, you could help the pupils to perform the scene in which Paul and Angela visit Andy in hospital. (Andy explains the use of X-rays. Paul and Angela ask him questions about it).

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Put in your own words what you think an X-ray machine is and make drawings if this helps your explanation.
X-ray machines are used to take pictures of the inside of a person, so that the structure of the skeleton or tumour development becomes clearly visible. They can also be used to treat malignant tumours.

2 What protective measures do medical staff take to avoid being exposed to ionizing radiation while a patient is being examined?
They leave the X-ray room or go behind protective screens.

3 What do medical staff do to protect the patient from unnecessary exposure to ionizing radiation?
They limit the use of X-ray examinations as much as possible, they protect the rest of the body with lead aprons and, in the case of radiotherapy, they limit the X-ray beam to the area where cells have to be destroyed so as to avoid destroying normal cells.

Angela entered her uncle's study. She visited him so often these days that he had given her a key to his house. As usual, she found him with his nose in his books.
Today they are going to help you learn about X-rays in hospitals.

LESSON

Applications in hospitals

"Hello, uncle!" said Angela. "Are you studying?" "Oh, hello!" her uncle answered, looking at her in an absent-minded way from behind a pile of books. "Yes, as a matter of fact I am", he said, taking off his glasses. "Since you came to ask me about radiation I've been thinking about it a lot". He pointed at a chair opposite his large desk. "Sit yourself down and I'll tell you what I've picked up from my books".

Mr Röntgen

When Angela had sat down, Uncle Arnold began. "Do you remember your trip to Professor Becquerel's house?" Angela nodded. "Well, at about the same time, approximately a hundred years ago, there was a man called *Mr Röntgen* who lived in Germany. He had invented a machine that could emit ionizing radiation. As you now know, you cannot see, feel or hear this radiation. That is because ionizing radiation is actually the emission of very tiny particles or waves which are even smaller than atoms. That's why you can't see it. Are you still with me?"

Röntgen

Angela nodded and asked: "But why did Mr Röntgen make a machine like that?"

X-rays

"I'm just coming to that," said Uncle Arnold. "The radiation produced by Mr Röntgen's machine is what we call *X-rays*. These X-rays can pass straight through your body!" "Straight through your body?" Angela asked incredulously. "Is that possible?" "Yes, it most certainly is," her uncle said, "although you don't feel anything when it happens".

At that moment somebody rang the bell. Uncle Arnold got up from behind his desk and went to answer it. Paul was standing at the door. "Is Angela here?" he asked. "Yes, she is," answered Uncle Arnold, "come in and join us for a cup of tea". "No, thank you, I don't have time and, as a matter of fact, neither has Angela," said Paul. "What's the hurry?" asked Angela, who had caught the last sentence.

"I've been looking for you everywhere", said Paul. "Don't you remember we agreed to visit Andy in the hospital?" "Oh, dear, I quite forgot!" said Angela.

She looked at her watch. "But we've still got time to go", she said. "You see, Uncle Arnold, our classmate Andy fell off his bike recently and broke his leg". "Well, we've got to go now", said Paul. "Bye, Dr T..., I mean, Uncle Arnold". "Bye!" answered Uncle Arnold, but they had already left.

On their way to the hospital Angela told Paul what she had learned from Uncle Arnold. "That's a coincidence", said Paul, "maybe Andy has had some X-rays too". When they got to the hospital they bought some flowers from a shop.
A little while later they were standing by Andy's bed. He proudly showed them his leg which was encased in plaster and held up by a pulley. "Whenever a nice nurse goes past," said Andy, "I wiggle my leg just to see if she gives me a nice smile".
"Are you comfortable like that?" Paul asked. "Oh, well, it's not too bad but I haven't been here for long yet," said Andy. "They took some pictures this morning and then my leg was put in plaster". Angela asked what had happened when the pictures were taken. "Oh, it was quite funny," said Andy, "I had to lie down on a large table and a big metal box attached to a complicated-looking machine was put over my leg. The nurse said she had to take some *X-ray pictures*. I said my hair was all rumpled and asked her if she had a comb. I was just kidding, of course. I knew that she had to take pictures of my leg. But she thought I meant it and began to explain everything about those X-ray pictures. She said that X-rays pass through your whole body but

X-ray pictures

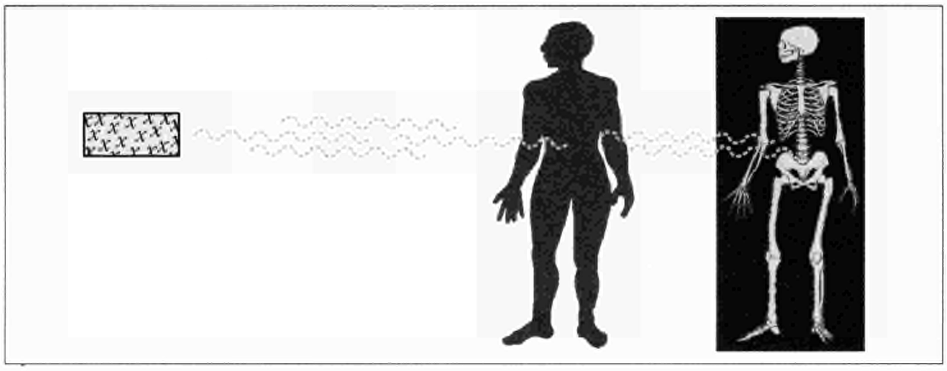


Diagram of how an X-ray picture is taken

less easily through your bones. And because of that, the doctor could see where and how the bone was broken. When she had finally finished the explanation, she put a *lead apron* over my tummy and went into a little booth. I heard a click and some buzzing noise, and then the nurse came back". "Did they only take one picture?" Paul asked. "No, they took about four of them. And each time the nurse disappeared into the little booth. When the last picture had been taken, I asked if she needed to go to the toilet every time. Well, I wished I hadn't asked because then she began to explain things all over again. She said she hid so that she wouldn't be exposed to radiation too often".

lead apron

"She told me that some of the ionizing radiation can bounce off the patient and then the radiation spreads across the room in all directions. A little bit of ionizing radiation won't hurt you, but when you take these pictures all day long it's better to protect yourself by standing in a special booth. Then she explained why they put a lead apron over my tummy – it's to protect parts of your body which don't need to be examined. She said that doctors only ask for X-ray pictures if it's absolutely necessary. Anyway, she gave me a picture to keep", Andy told them proudly. He showed it to his two friends. They saw a black and white picture where a crack was clearly visible in the white part. "A nice picture for your scrapbook", said Paul, handing it back.

The X-ray picture of Andy's broken leg

"Who's in the next bed?" asked Paul, pointing to an empty bed next to Andy. On the table beside the bed were fruit, books and a pair of glasses. "It's an elderly man", said Andy. "He actually doesn't belong to this ward but there was no room for him in the other ward. He told me that he's been X-rayed every day".

X-rayed

"*X-rayed*?" asked Angela. "Why did they do that?"
A male nurse who happened to be passing by overheard this and came up to them. "Would you like to know why?" he said. "Mr Johnson – that's his name – came here a couple of months ago to have a medical examination. On an X-ray picture the doctor spotted a malignant tumour in his left lung. Malignant tumours have to be taken away in an operation or else they affect other organs and may eventually kill the person who is sick. Nowadays, though, we can also use X-rays from an X-ray machine to destroy the sick, malignant cells in this kind of tumour. Of course, this has to be done very accurately because the rays mustn't touch any normal, healthy cells".
"Isn't that what you call cancer?" Angela asked. "Yes," answered the nurse, "cancer is actually a general name for a number of diseases".
"And will he be cured?" asked Angela, who had once heard that someone with cancer had died. "Mr Johnson is having his last treatment this afternoon", the nurse said, "and then he can go home".
"That's good news!" said Angela.
Angela and Paul then got up to leave. "Wait a minute!" said Andy. "First write your names on my plaster". When Paul and Angela had done this, they said goodbye to Andy and left the hospital. On their way home, Paul said: "That Mr Röntgen really came up with a useful invention, didn't he?". Angela thought so too.

KEY POINTS

Taking X-ray pictures involves using small quantities of ionizing radiation in order to view the inside of the human body. An X-ray picture can tell us whether there is a fracture, where it is located and what form it takes; it can also be useful in diagnosing certain diseases (e.g. lung tumours). In addition, X-rays are used to destroy unhealthy cells in the body. Certain forms of cancer can sometimes be successfully treated with X-rays. Each exposure to X-rays for medical purposes should be medically justified and kept as low as possible. A lead rubber apron is used to shield and protect the rest of the body which does not need to be examined and exposed to radiation.

QUESTIONS

1 Put in your own words what you think an X-ray machine is and make drawings if this helps your explanation.

2 What protective measures do medical staff take to avoid being exposed to ionizing radiation while a patient is being examined?

3 What do medical staff do to protect the patient from unnecessary exposure to ionizing radiation?

Could we get by without ionizing radiation?

AIMS

At the end of the lesson the pupil:
- can name various present-day applications of ionizing radiation.

PROPOSED MINIMUM TIME

25 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 7: Applications of ionizing radiation and radioactivity

TEACHING SUGGESTIONS

In this lesson the pupils, together with Paul and Angela, are introduced to present-day applications of ionizing radiation such as smoke-detectors, exit-signs and luggage screening equipment. However, we do not consider the technical aspects and uses of these devices; that would be beyond the scope of this course as well as the comprehension or ability of the pupils at this age. The purpose of this course is to familiarize pupils with these applications and with the idea that ionizing radiation may be useful, and to alert them to its potentially dangerous effects.
After the story has been read and questions/assignments have been tackled, you can end the lesson by turning the second question/assignment into a discussion. Ask the class for their opinions about the uses of ionizing radiation. Prepare a list of the advantages and disadvantages of such uses. You can expand the lesson by discussing additional uses of ionizing radiation, and their advantages/disadvantages.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 (A) Reread the story. Together with Paul and Angela you have learned about several uses of sources of ionizing radiation. List these uses.
Measuring and checking.

(B) Which uses of ionizing radiation do you already know about? Or: what uses were you aware of and which ones did you not know about?
Open question.

2 Bearing in mind that ionizing radiation involves risks, have another good look at the applications mentioned in the key-points section and decide which ones you think are necessary and which are not. Make two separate lists.
Open question.

In this lesson Paul and Angela accompany Uncle Arnold on another journey in the tispama. They are going to investigate the possible uses of ionizing radiation. There are several kinds of applications.

LESSON

Could we get by without ionizing radiation?

"Sometimes ionizing radiation is rather difficult to understand," sighed Paul. "Yes, but it's very interesting too," said Angela, "especially because it's all around us. Everybody is in contact with it, whether you like it or not".

They were enjoying their tea in the garden outside Uncle Arnold's study. It was the weekend and the garden was bathed in warm sunshine.

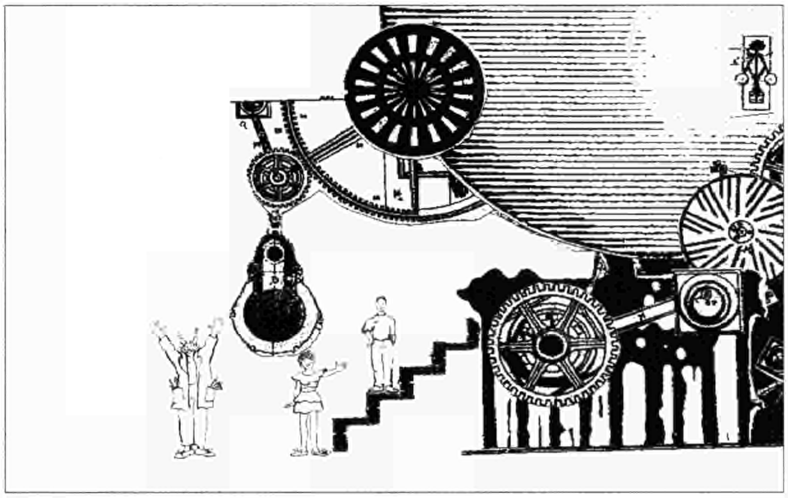
"One of the things the teacher mentioned", said Paul, "was man-made sources of ionizing radiation. Now, I know about hospitals and X-rays because of Andy but I don't know anything about the other sources". He took out his notes and read aloud: "*Man-made sources of ionizing radiation*: hospitals, science and technology, devices, and so on. What kinds of sources are used in science and technology, and what about 'devices'?" he asked.

man-made sources of ionizing radiation

"You're in luck", said Uncle Arnold, who was sitting with them wearing his old straw hat. "I was fiddling with my tispama earlier this week and I found out how to make it – and everything in it – invisible whenever I like". The two children looked at him incredulously. Angela said: "You're pulling our legs now, uncle!" "I'm not!" said Uncle Arnold cheerfully. "Just follow me".

They got up from their chairs and followed Uncle Arnold into his laboratory. When they got there, he turned and said in a loud voice: "There is just one thing: you must promise me not to tell anybody else about this. If you break your promise and people find out that I have a machine like this, then I'll have no privacy left and no time to myself. And then we won't be able to make any more trips. Have you told anybody about our first trip yet?" "No, uncle!" said the two children. "Perfect. Let's keep it that way. Is that a deal?" he asked. "Yes, uncle!" the children answered. "Fine," he said, "so that's settled. Now we shall see if everything is working properly. I haven't tested anything yet so you are going to be my guinea pigs. If you like, we can make a few visits straight away".

"Guinea pigs?" cried Paul, turning a bit pale. "Oh, I'm exaggerating a bit", Uncle Arnold reassured him. "It's just that I haven't travelled in the converted tispama yet. Come on, let's get in".



One by one, they entered the by now familiar time-space machine. Uncle Arnold had used up more space inside the machine with his new equipment so it was a bit cramped for the three of them. "All aboard? Ready for take off!" Uncle Arnold pushed some buttons and slowly the machine rose from the floor of the laboratory. Right above them a huge sliding roof opened and they shot through it, accelerating all the time.

"When is the machine going to become invisible?" Paul asked. "It already is," said Uncle Arnold, pointing at a flashing red light. "I don't really believe things can become invisible", said Paul, "if you can't see or feel something, it doesn't exist".

"You could say the same about ionizing radiation", replied Uncle Arnold. "You don't see, hear or feel that either. But you still believe it exists!" "Well, I think I do," said Paul slowly. "But are we ourselves invisible now?" "No," answered Uncle Arnold, "that won't happen till we put on these suits". And from a suitcase he produced three transparent plastic overalls.

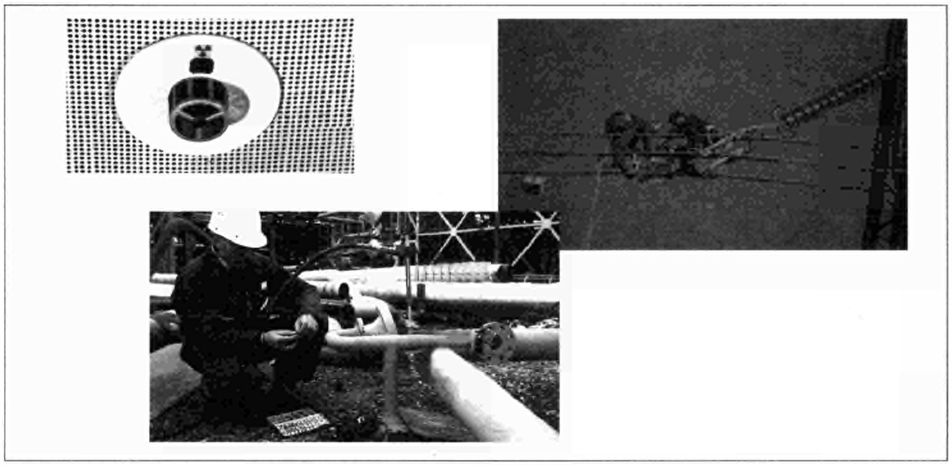
"That's all very well, but where are we actually going?" asked Angela. "To a very large office building," answered Uncle Arnold. "We are already there, in fact. We are about to land any second now".

They were hovering over a huge building some 50 storeys high. After landing on top of the roof, they got out and walked down to the fiftieth floor, where a large number of people were working. Uncle Arnold pointed to the ceiling. "Look, Paul, there you can see an example of the devices you were talking about at my place. Those things in the ceiling are *smoke detectors*. Inside them are very small sources of ionizing radiation which are used to detect smoke from a fire. Because they can do this very quickly, they are really essential in tall buildings like this and thanks to them many lives have been saved. In a big city there are, of course, lots of tall buildings – hotels, restaurants, offices, blocks of flats, etc. And many of them have got smoke detectors inside".

smoke detectors

"Shall we go on?" asked Uncle Arnold, after they had looked around the place. None of the people working there could see them and this was what Angela enjoyed most of all. "The exit signs above the doors in many buidings are another example of how radioactive substances are used," explained Uncle Arnold. "And what about luggage checks at the airport? The security people can see what is in your suitcase without opening it!"

After they had boarded the machine again they headed for a factory. When they had landed Paul immediately realised this was an aircraft factory. In one of the sheds he saw a wing and a tail section. In another workshop people were busy assembling a plane. Everywhere people in overalls were walking about.



Sources of ionizing radiation used in different applications.
A. smoke detector
B. to check high voltage cables
C. to check wallthickness

"They use radioactivity here, too", Uncle Arnold told them. "For example, they use radioactive sources and industrial X-ray machines, like the ones used in medicine, to look for cracks in welds. You can imagine how important that is for an aeroplane. As a matter of fact, radioactive sources are used a lot in factories like this to measure and check things".
"That's really interesting", said Angela, who had almost got used to the fact that people could not see her, even when she went right past them. Again they boarded the tispama and were soon flying over another factory. "What kind of factory is that?" asked Paul. "It's a factory where they make high voltage cables", replied Uncle Arnold. "I had planned to pay a little visit to this factory as well, but it's getting late now. In any case, they use ionizing radiation here in much the same way as in the aircraft factory".
While they were talking like this, they flew over some open countryside. Uncle Arnold pointed at the ground beneath them. "In places like this, they can use sources of ionizing radiation to measure the density and humidity of the soil or to find out whether there are any heavy metals or poisonous materials in the ground".
"That's enough, Uncle Arnold," said Paul, "my head is spinning". "That's what I hoped, Paul," said Uncle Arnold with a smile, "shall we go now?"
As they were flying home, Uncle Arnold pointed out of the window and asked: "Do you know what that is down there?" The children looked down and saw a number of large buildings. In the centre there was a gigantic chimney and around it was something that looked like a lake. "I haven't got the foggiest idea," answered Paul. "Actually", said Uncle Arnold, "that is a nuclear power station. But we'll go into that another time. Now we have to get home".

Nuclear power station

KEY POINTS

Sources of ionizing radiation are widely used in industry, science and technology. For example, they are used in various devices such as smoke detectors or as a kind of tool, to check welds in planes and high-voltage cables, for example.

QUESTIONS

1a Reread the story. Together with Paul and Angela you have learned about several uses of sources of ionizing radiation. List these uses.

1b Which uses of ionizing radiation did you already know about? Or: what uses were you aware of, and which ones didn't you know about?

2 Bearing in mind that ionizing radiation involves risks, have another good look at the applications mentioned in the key-points section and decide which ones you think are necessary and which are not. Make two separate lists.

What do you think of nuclear power?

AIMS

At the end of the lesson the pupil:
• can identify the advantages and disadvantages of nuclear power
• can express his/her views about nuclear power.

PROPOSED MINIMUM TIME

50 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 2: The structure of the atom
Chapter 6: Protection against ionizing radiation

TEACHING SUGGESTIONS

This final lesson looks at the use of nuclear energy as a means of generating electricity. To begin with, you can write the words 'nuclear power' on the blackboard just like the teacher in the story. Write down the pupil's reactions. Tell them that this lesson is about nuclear power. Ask them to read the story. You can end the lesson with a discussion and explain more about the detailed workings of a nuclear power plant. For example, you can show that it does not burn coal, gas or oil and consequently does not consume oxygen or produce carbon dioxide (CO_2). You can also ask them to suggest and discuss alternative ways of generating electricity. To guide these discussions, you could invite experts and specialists in the field to talk about the subject.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Find out which countries of the European Community have nuclear power stations. Indicate them on a map.

2 Which people in Angela's and Paul's class did you agree with? Also write down why you are for or against nuclear power.

3 How much carbon dioxide (CO_2) is produced by a nuclear power station?
None.

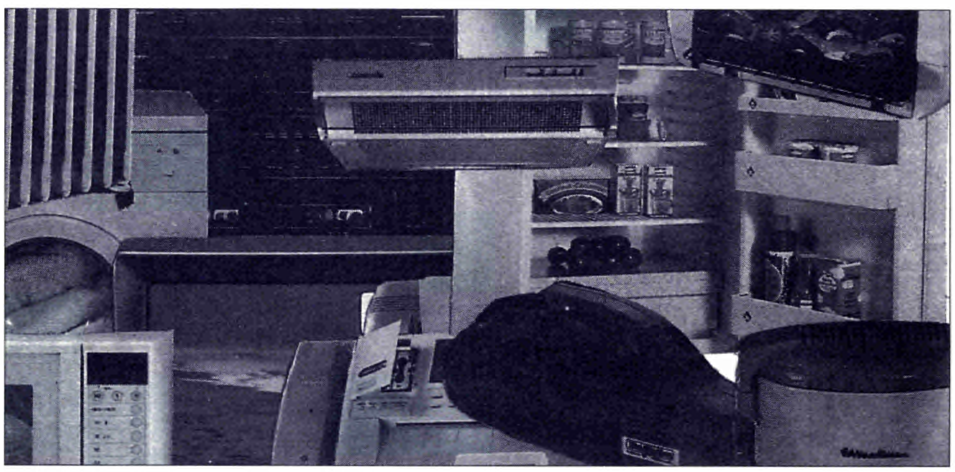
Paul and Angela were in their physics class. The teacher wanted to discuss nuclear power. In this lesson you will read about the pros and cons of nuclear power.

What do you think of nuclear power?

It was time again for physics in Angela's and Paul's class. There was uproar in the class. It was caused by two words written in large letters on the blackboard: NUCLEAR POWER. Everybody was trying to voice his or her own opinion at the same time.

A boy called Steven shouted: "Nuclear power stations are downright dangerous. If one explodes, half of Europe will be blown to bits!" Somebody else said in a slightly quieter voice: "That's rubbish! They work perfectly these days; nothing can go wrong with them". Wendy, who was sitting beside Paul, said: "Yes, that's what they thought in Chernobyl". A girl behind Wendy yelled: "I'm against them, too". The boy who was sitting next to her roared at the top of his voice "I'm all for them".

At that moment the teacher came in and gradually the noise dropped. He said: "I thought I heard somebody whispering about nuclear power just now. Before we get into an argument, let's look at some facts on nuclear power".



We use a lot of electricity these days

He sat down and, when everyone was quiet, began to explain. "We need a lot of electricity these days. Just think how many electrical appliances you have at home and in factories they often need even more electricity, so we really couldn't do without it. But who knows where it comes from?"
A girl with a ponytail put her hand up. "Yes, Janet?" said the teacher. "It comes from *a power station*", she said confidently. "That's right", said the teacher. "At one time all power stations used coal, gas or oil as fuel. The fuel heated some water which became steam, the steam was used to drive turbines, which in turn moved a large generator (rather like a dynamo) and this produced electricity. Nowadays", he continued, "we need so much electricity that the supplies of coal, oil and natural gas are being used up very quickly. If we go on using them at the current rate, these natural sources will soon run out".

a power station

The teacher paused. Nobody asked any questions, so he went on. "There is another problem and that's to do with the burning of oil and coal. You may have heard of the *greenhouse effect*, which might have serious consequences for the earth's climate. This is caused by the increasing amounts of carbon dioxide that are building up in the atmosphere as a result of activities such as the burning of coal and oil. Well, some scientists found out that they could split atoms of uranium and that this produced lots of energy and heat. So they decided to use this energy to make electricity and that's why we have nuclear power stations. For the time being, I won't go into the processes involved. Those of you who would really like to know how it is done can find out for yourselves. I suggest you use your encyclopaedias".

greenhouse effect

The teacher looked round the class to see how it was reacting. He had rarely seen such an attentive class. "There was a problem, though," he went on. "After the uranium atoms were split – that's something we call *fission* and it

fission

Nuclear reactor where nuclear energy is generated

takes place in the reactor at the power station – there was some waste left. And not just any waste. This waste was radioactive. It emits ionizing radiation and this can be harmful to human beings. It has now become a serious problem".
Angela raised her hand. "Yes, Angela?" said the teacher. "Isn't it true", asked Angela, "that radioactivity gradually dies away by itself?" "Yes, it does," said the teacher," but it takes a long time to disappear completely and where do we keep the waste in the meantime? It must be stored as safely as possible so that

Radioactive waste disposal

human beings can't come into contact with it for thousands of years. At first, some of the waste was put in metal or concrete drums which were dumped into the sea. Scientists now have other ways of preventing nuclear waste from getting into the environment".

Chernobyl

He paused for a moment and then went on. "Nuclear power stations are operated very carefully but something may still go wrong. In 1986 there was a steam explosion in a nuclear power station in *Chernobyl* (in the Ukraine) and the upper part of the reactor was destroyed. Two people were killed by the explosion and 29 died shortly afterwards from massive exposure to the ionizing radiation that was released. So there were 31 deaths directly related to the accident. The wind carried radioactive substances in many directions and a lot of countries, including some in the European Community, were contaminated. So you can see that there are some risks in using nuclear power".

The teacher sat down on the corner of his desk. "Now you know a bit more about nuclear power, perhaps you would like to carry on with your discussion. Any volunteers?"

KEY POINTS

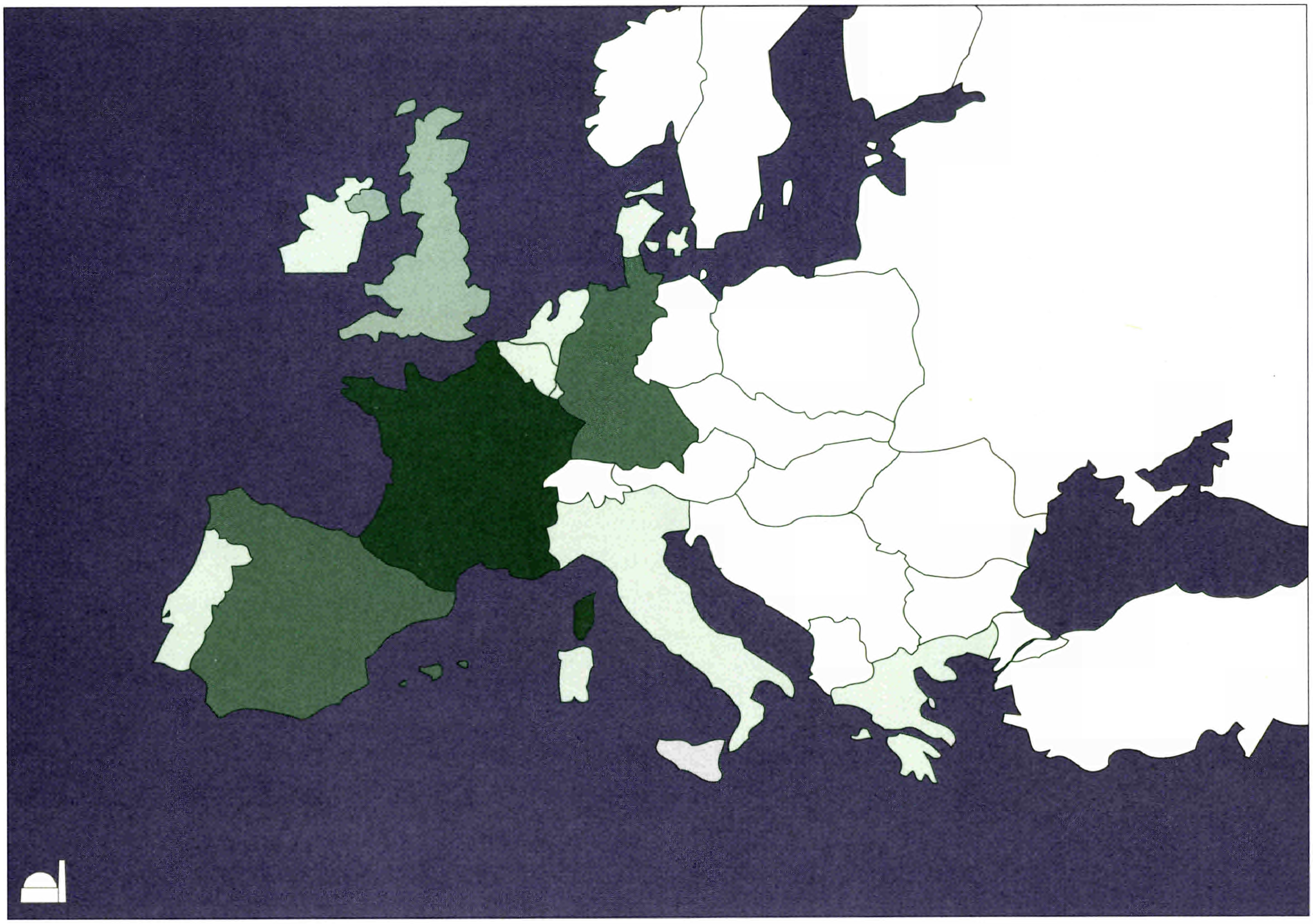
Nuclear power stations are used to generate electricity. In many countries they are used on a large scale. Nuclear power has advantages and disadvantages.

QUESTIONS

1 Find out which countries of the European Community have nuclear power stations. Indicate them on a map on the next page.

2 Which people in Angela's and Paul's class did you agree with? Also write down why you are for or against nuclear power.

3 How much carbon dioxide (CO_2) is produced by a nuclear power station?



12-14 YEARS

The lessons at this level are intended for secondary school pupils.

INFORMATION

If you wish, you can also use lessons from the previous levels.
This level deals with the various topics in greater detail than earlier levels. As before, Paul and Angela are the main characters guiding pupils through the lessons.

The topics for the 12-14 age group are:

CONTENTS

- sources of radiation
- types of radiation
- atoms and ionizing radiation
- detection of ionizing radiation
- effects of ionizing radiation on the body
- the various applications of ionizing radiation
- nuclear power stations

LESSONS LEVEL IV

EVALUATION

When you have completed all the lessons at this level you can test what the pupils have learned with the following assignment.
Pupils should gather information from newspapers, magazines, etc. on all the aspects of radiation which they have studied in the course. They should then write an essay covering all the aspects dealt with.

Radiation is everywhere

AIMS

At the end of the lesson the pupil:

- is able to list sources of radiation
- is able to differentiate between sources of non-ionizing and ionizing radiation
- is able to differentiate between natural sources and man-made sources of radiation.

PROPOSED MINIMUM TIME

45 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

For more detailed information on the history and applications of radiation and radiation protection, consult:
Chapter 1: Historical introduction
Chapter 3: Non-ionizing radiation
Chapter 7: Applications of ionizing radiation and radioactivity
Chapter 8: Doses from ionizing radiation

TEACHING SUGGESTIONS

This first lesson is concerned with examples of radiation sources taken from daily life and the children's own environment. These sources can be classified according to their nature (natural or man-made) and to the type of radiation they emit (ionizing and non-ionizing radiation).
Ask the pupils to read the story.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Ask the pupils to complete a table classifying the sources of radiation mentioned in the text.

Model:

Sources	Ionizing radiation	Non-ionizing radiation
Natural	radon gas	
	soil	sun
	building materials	
	sun, human body	
Man-made	X-ray machines (medical)	radar installations
	X-ray machines (luggage)	microwave ovens
	nuclear power stations	light bulbs
	luminous dials	radiant heaters

You must have heard or read – perhaps in the news media – about radiation. Radiation is a fact of life which you come across everyday no matter where you are. It comes from many sources and has different applications. In this lesson about Paul, his family and Angela, you learn about different sources and some applications of various types of radiation.

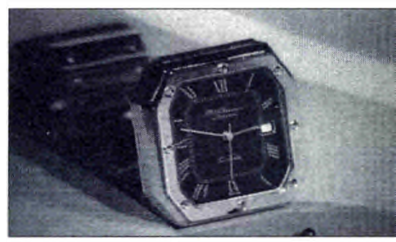
LESSON

Radiation is everywhere

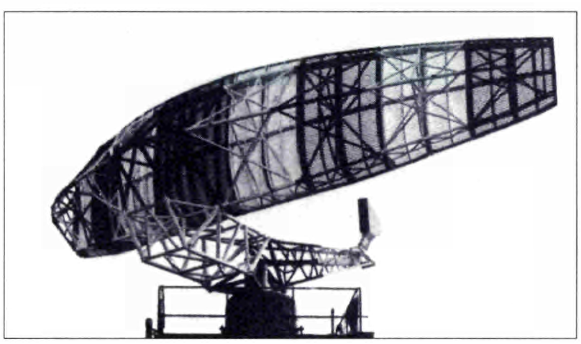
Paul's holiday in the south of Spain was nearly over. "It has been a great holiday, dad", he said just before taking a shower before going to bed. "What time do we leave tomorrow?" Paul asked. "Seven-thirty" replied his father. When Paul looked in the mirror in the bathroom he saw his skin was still sunburnt. "Strange", he thought, "the sun didn't feel too strong today. Anyhow, I'll put on some after-sun lotion before I go to bed". The moment Paul's head touched his pillow he fell asleep.

"Rrrring, rrring." Next morning the alarm-clock went off. Paul woke up, looked at the luminous dial and saw it was time to get up. He switched on the radio and looked out of the window. The sky was bright and clear and Paul hoped it would be just as clear during the flight home. Over breakfast, Paul asked his father whether he could have a window seat on the plane. "Yes, of course", his father said. "Yippee!", Paul exclaimed enthusiastically.

When the family arrived at the airport Paul's friend Angela, who was accompanying them on their holiday, asked Paul's father: "What is that peculiar thing turning round on the top of that building?"



Luminous dial



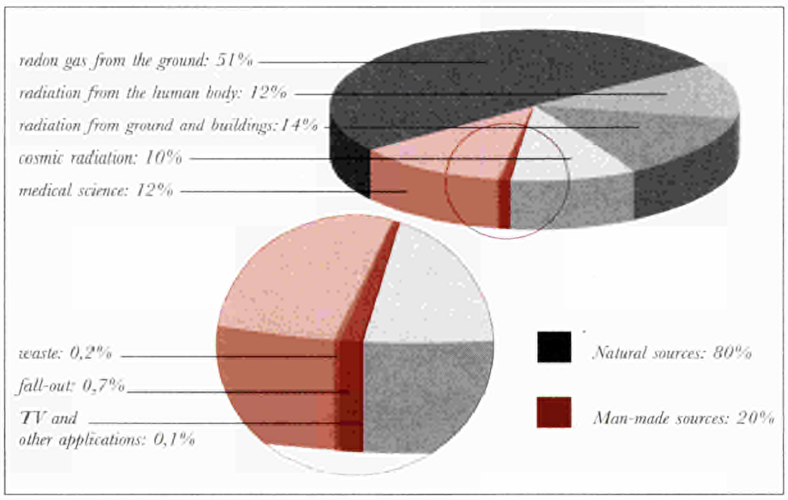
Radar installation

"Well, Angela, " he said, "it is a radar scanner. As it turns the people who control air traffic can see all the incoming and outgoing aircraft on a screen. All aircraft have to wait for permission to take off or land. It is for safety reasons." "So it is a kind of an electronic traffic light?" Angela asked. Paul's father smiled. "Yes, you could call it that", he answered.

"Leave it, mum, I'll do it.", Paul said to his mother. She was not able to carry any luggage because she had had a little accident during the holiday. She had fallen down while she was climbing some rocks at the beach and had broken two fingers. At the hospital they had taken an X-ray to see if anything was broken, and now her two fingers were kept in place by a supportive bandage. After they had checked in they went to the departure gate. At the customs control everybody had to put their hand luggage through a big box-like machine. "What is that for?", Angela asked. "It is a security check" said Paul's father. "The man over there can look inside bags and cases without opening them. On his screen he can also see what we are carrying inside our hand luggage. So he can see whether passengers are taking dangerous things like weapons with them into the aeroplane. Why don't you go over and look at the screen – it's not every day you can look inside a case without opening it". Angela went over and was amazed to see everything showing up clearly on the screen.

Luggage scanner

During the flight Paul was enjoying the marvellous view from his window seat. His father, who was reading a newspaper, turned to his wife. "Valerie", he said, "I am reading an article in this newspaper about ionizing radiation. Did you know that the sun is a source of cosmic radiation and dose rates increase at high altitude as we lose the shielding effect of the earth's atmosphere? It also says there are other natural sources of ionizing radiation: radiation from the soil and building materials, radiation in the human body and radon gas from the ground. Over 80% of the annual radiation doses we receive comes from natural sources and under 20% from artificial (man-made) sources."



The distribution of the average radiation doses received in Europe

Paul's father paused. "Now, that's something I didn't know", he said, folding the newspaper. "I thought that most of the ionizing radiation we receive comes from X-rays, like the ones they took of your fingers. Did you know that, Valerie?" he asked his wife. "Yes, I did" she answered. "You did?" her husband exclaimed. "Yes, does that surprise you, darling? There are *two kinds of radiation*: ionizing and non-ionizing radiation. You mentioned a few *sources of ionizing radiation*. They were all natural sources except for X-rays from an X-ray machine, which is a man-made source. Another example of a man-made source of ionizing radiation is the luggage scanning machine you see at airports".

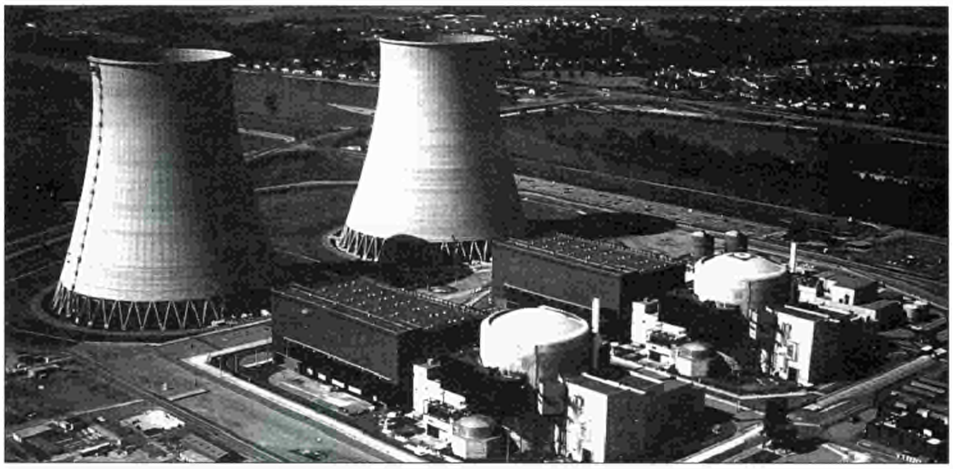
two kinds of radiation

sources of ionizing radiation

"And what about non-ionizing radiation?" her husband asked.
"Well, we all know about light from light bulbs or heat from a radiant heater. Then there are the radar installations at airports, which emit radio waves. All of these are examples of man-made sources of non-ionizing radiation. The sun, on the other hand, is an example of a natural source of both ionizing and non-ionizing radiation".
"You really amaze me, Valerie," her husband said, "but can you also explain what the difference is between ionizing and non-ionizing radiation?"
"Well, that's very difficult to explain", she said, "but as far as I understand ionizing radiation causes 'ionization' in the materials or tissues which it passes through. *Ionization* is a complex electrical change in the material or tissue, which can be damaged by this change".

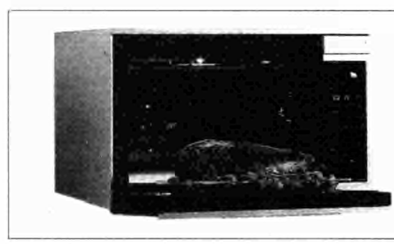
Ionization

"And non-ionizing radiation can't cause this change, I presume?"
"Exactly, darling. you're very quick on the uptake," she replied with a smile.
Later on in the flight, Paul's father pointed out of the window and asked the children: "Do you see that down there? What do you think it is?" The children looked down and saw a number of large buildings beside a river. In the centre there was a big chimney. "It could be a factory", suggested Angela.
"Well," said Paul's father, "you're quite close. In fact, it's a nuclear power station. It uses nuclear energy to produce electricity".



Nuclear power station

When the family finally got home everybody was hungry. "Is there anything to eat?", Paul asked his mother. "Don't be silly, Paul", she said. "We have only just got back from our holiday. I haven't done any shopping yet! But, wait a minute. There are some frozen meals in the freezer. I can prepare a quick meal in the microwave".
After dinner Paul went to bed, tired but satisfied.
"It has been an exciting day", said Paul to himself and fell asleep.



Microwave oven

KEY POINTS

Radiation is a fact of life and is everywhere.
We make a distinction between sources of ionizing radiation and sources of non-ionizing radiation.
We also distinguish between man-made and natural sources of radiation.

QUESTIONS

1 Read the story carefully once more. Try to find all the examples of sources of radiation mentioned in the story and list them in the correct places in the following table

SOURCES	IONIZING RADIATION	NON-IONIZING RADIATION
Natural		
Man-made		

What is ionizing radiation?

AIMS

At the end of the lesson the pupil:
- is able to explain that all matter is composed of elements which consist of characteristic atoms
- can explain that unstable atoms emit ionizing radiation
- is able to name three types of ionizing radiation and their characteristics.

PROPOSED MINIMUM TIME

45 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 2: The structure of the atom
Chapter 4: Radioactivity and ionizing radiation

TEACHING SUGGESTIONS

This lesson deals with the nature of ionizing radiation and starts by explaining the nature of atoms. Begin this lesson by asking pupils what they know about atoms. Depending on how much the pupils know, you may expand the lesson by using additional material.
You can then ask the pupils to read the story.
After the pupils have read the story, you can discuss its contents with them and use the blackboard for illustrations (structure of an atom, types of radiation, penetration properties, etc.).
At the end of the lesson, the pupils can tackle the following questions/assignments.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Describe in your own words what theory Democritus had about the composition of materials. If you can, make a drawing showing how he pictured the atom.

He was the first to suggest that all matter consists of atoms and that an atom is the tiniest particle of matter. In fact he could not prove this and his definition of the atom is no longer accepted.

2 In the story you read that there are about 100 basic types of atoms. How do they differ from each other?

They differ in the number of protons and neutrons in the nucleus; for instance, carbon has 6 protons and 6 neutrons and uranium has 92 protons and over 100 neutrons.

3 What do we mean by "radio-active"? What is a radioactive substance? How is it created?

When there are more neutrons than protons, the nucleus of the atom becomes unstable; to regain its stability, the nucleus emits particles and/or ionizing radiation in the form of waves and this makes the substance radioactive.

4 Draw a picture showing the different penetration properties of alpha, beta and gamma radiationm, and X-rays.

What types of radiation do you know about? In the first lesson we learned that radiation can be either ionizing or non-ionizing. Ionizing radiation cannot be seen, smelt, heard or felt. If we cannot see, smell, hear or feel ionizing radiation, how do we know it is there? What is ionizing radiation? In this lesson you learn some of the answers.

LESSON 5

What is ionizing radiation?

Outside the house it was raining cats and dogs but inside it was nice and warm. Paul and his parents were sitting in the living room. Paul had just finished the book "From the Earth to the Moon" (De la terre à la lune) written by Jules Vernes in 1865. "That was really exciting!", Paul exclaimed. "What did you say, Paul?", his father asked. "I have just finished a fantastic story by Jules Verne about three men going to the moon.", Paul answered. "Just imagine, he wrote this in 1865. It was science fiction then. He couldn't have known that men would actually go to the moon in 1969, a hundred years later!" His father agreed that Jules Verne had a brilliant imagination. "Well, I am going to bed now", Paul said, "I have to get up early tomorrow." He went upstairs.

But Paul just could not get to sleep that night. He could not get the story by Jules Verne out of his head and kept tossing and turning in his bed. "I know !" he suddenly whispered, "I'll pretend that I'm going on a journey". And Paul imagined he was one of the three men who went to the Moon, and ... off he went. The adventure had started. Paul dreamed he was on his way to the Moon.

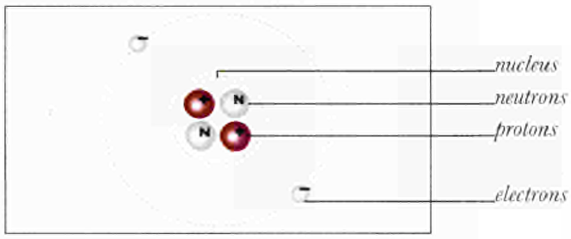
"Wow!", he exclaimed. "I have never seen anything like that before" He was looking at the earth, which he had just left.

It was like a coloured ball which became smaller and smaller. It was so far away. The sun and the Moon and all the other planets looked different. He had never seen the planets from this angle before. They seemed to be much closer than usual and, for the very first time, he saw the solar system with the sun in the middle and the planets moving around it. He stared in amazement. "Enjoying the view?" said a deep voice from somewhere in the dark. Paul was frightened and looked around anxiously. He saw an old man dressed in a white gown slowly coming in his direction. "I am Democritus", the man said kindly. Democritus, Paul thought, isn't that the man who lived in Ancient Greece? What is he doing here in space? Paul remembered the story of Democritus and his birthday cake which his father had once told him. While

Democritus was cutting up his birthday cake, it occurred to him that if you took a piece of cake and cut it into smaller and smaller bits, you eventually would end up with a tiny piece of cake which was indivisible. He called the indivisible pieces of matter "atoms". He was the first to suggest that everything consists of atoms and that all substances are made up of basic atoms or combinations of these atoms.
"What is your name?" Democritus asked. After Paul had told him, he explained why he had decided to speak.

"I saw how fascinated you were by the view of the solar system with the sun and the different planets going around it," he said. "Well, Paul, an atom is very much like the solar system. Everything surrounding us is composed of atoms. The word "*atom*" comes from Old Greek and means "indivisible", because we Ancient Greeks thought that atoms were the smallest particles that existed. Later on, though, people discovered that an atom is made up of even smaller particles called electrons, protons and neutrons. This drawing should make it clear:

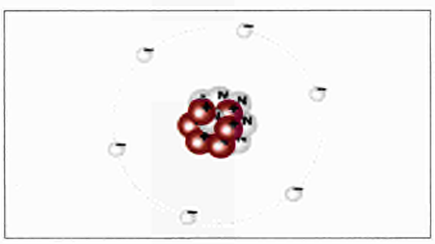
atom



Structure of an atom (nucleus, protons, neutrons, electrons)

"As I said", Democritus continued, "an atom can be thought of as a tiny solar system: a central sun or nucleus with electrons "orbiting" around it. The *nucleus* itself is made up of protons and neutrons, while lighter particles, called *electrons*, circle around the nucleus at a great speed. An atom is electrically neutral if the number of protons in its nucleus is the same as the number of electrons orbiting around the nucleus. The picture of the hydrogen atom I have drawn for you shows the most simple atom we know. It has a nucleus made up of one proton and one electron is travelling around it. On the other hand, a carbon atom has six protons and six neutrons in its nucleus and six electrons circling around it. This is what a carbon atom looks like:

nucleus
electrons



Carbon atom

"*Uranium*", Democritus went on, " is the heaviest natural atom. It has 92 protons and more than 100 neutrons. There are about 100 types of atoms, such as hydrogen, carbon, iron and uranium for example. Normally, Paul, the number of protons and neutrons are roughly equal, but if there are more neutrons than protons, the nucleus is out of balance and it has to change. It will try to become stable again by emitting particles or waves transporting energy, both of which we call ionizing radiation. This process of change in the atom's nucleus is called *radioactivity*. We can usually measure how quickly this process is taking place and express it using a special unit called the *becquerel*,

uranium

radioactivity
becquerel

which is one change per second. It was named after Henri Becquerel." (Becquerel? That was a name Paul thought he had come across before somewhere.)

ionizing radiation

"The *ionizing radiation* emitted by unstable atoms is called ionizing because when it passes by an atom it can tear electrons away from it. This means the atom is no longer electrically neutral and becomes an ion. In other words, the atom has been ionized."

types of ionizing radiation

"We know that there are various *types of ionizing radiation*:

- Alpha radiation

These are small particles, each consisting of two protons and two neutrons. Like a blunt needle, alpha radiation can barely penetrate the skin on your hands.

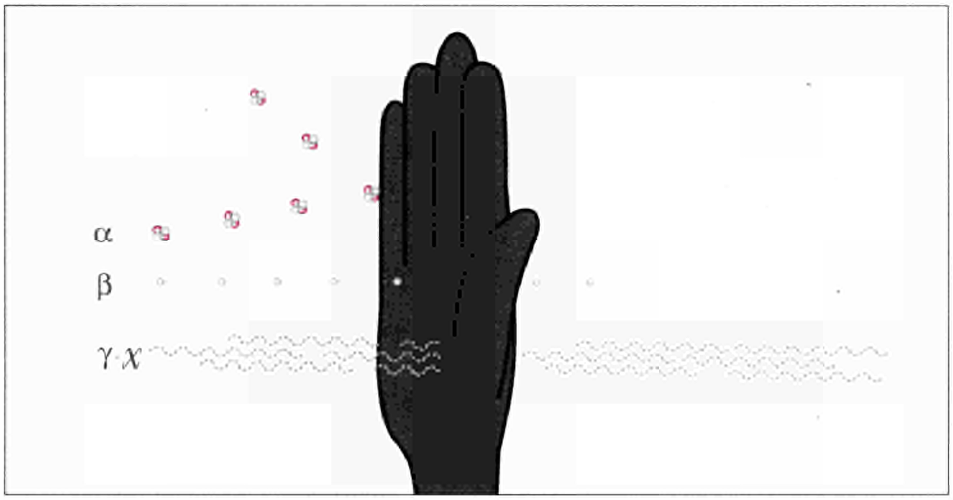
- Beta-radiation

These are small particles of free electrons. Like a sharp needle, beta radiation can penetrate some way into your hand.

- Gamma radiation

This is similar to X-rays, but more penetrating. It can be thought of as energetic waves. Gamma and X-rays go right through the hand. This may seem a bit strange, but it is like a strong light shining through your hand.

This drawing should make it clearer:



Penetration power of the different types of ionizing radiation

Paul had listened to Democritus very carefully."That's fascinating but it's rather complicated.", Paul said. "Yes", agreed Democritus, "it is, but later on you will understand it more. The important thing at the moment is that you find it interesting. Anyway, I must go now, Paul. I hope we meet again one day". As quickly as he had come, Democritus disappeared into the darkness.

Paul woke up. The dream was over. He looked at the ceiling and the wall of his room. He realised he was home again. "What a wonderful dream", he thought, and looked at the title of the book on the floor next to his bed: "From the Earth to the Moon (De la terre à la lune)", written by Jules Verne in 1865...

KEY POINTS

- ***Unstable atoms disintegrate and emit ionizing radiation.***
- ***The unit of activity, equal to one change per second, is called the becquerel.***
- ***The main types of ionizing radiation emitted from atoms are alpha, beta and gamma radiation. These types of radiation differ in how far they penetrate through the body.***

QUESTIONS

1 Describe in your own words what theory Democritus had. If you can, make a drawing showing how he pictured the atom.

2 In the story you read that there are 100 basic types of atoms. How do they differ from each other?

3 What do we mean by "radio-active"? What is a radioactive substance? How is it created?

4 Draw a picture showing the different penetration properties of alpha, beta and gamma radiation.

How do you detect ionizing radiation?

AIMS

At the end of the lesson the pupil:
- can explain that we need instruments to detect ionizing radiation
- is able to name at least two methods of detecting ionizing radiation
- can name the three quantities (activity of a radioactive substance, absorbed dose and effective dose) and the units used to describe them (becquerel, gray and sievert).

PROPOSED MINIMUM TIME

45 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 4: Radioactivity and ionizing radiation

TEACHING SUGGESTIONS

The lesson deals with the instruments used to detect ionizing radiation and gives the units in which the amount of activity and the dose are expressed.
You can begin the lesson by talking to the pupils about how weight and length are expressed (refer to kilograms, grams and milligrams, or to kilometres, metres and millimetres).
Then read the introduction to the lesson and tell the pupils that they are going to learn about the units used to measure activity and ionizing radiation. Explain what radioactivity is, asking the pupils to say in their own words what they learned in the previous lesson. Ask the pupils to read the text and answer the questions. End the lesson by letting the pupils use softballs to represent units of measurement such as the becquerel, the gray and the sievert, as shown in the drawing accompanying the text (page 10).

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 What do we need to detect ionizing radiation?

Instruments such as a Geiger-Müller counter.

2 Name the units used to measure activity and doses of radiation. Describe in your own words what they mean. Illustrate them with a drawing if you wish.

The becquerel (Bq): the unit of activity, expressing the number of changes occurring per second in a radioactive substance.

The gray (Gy): used to express the absorbed dose to the tissue.

The sievert (Sv): used to express the effective dose to the tissue).

You learned about ionizing radiation in the previous lesson. We cannot see, smell, hear or feel it. But how do we know it is there? In this lesson we will show you ways of detecting ionizing radiation.

LESSON 9

12-14 YEARS

How do you detect ionizing radiation?

DETECTION

ionization chamber

Our senses cannot tell us if there is any ionizing radiation about and we need instruments to detect and measure it for us. To do so we use the capacity of ionizing radiation to ionize the atoms which it passes through. One of the instruments we use to detect ionizing radiation is called an *ionization chamber*. It contains a gas which is ionized by the ionizing radiation.

Geiger-Müller

A very similar device was developed from an advanced version of an ionization chamber by Geiger in 1928 and is called the *Geiger-Müller counter*. This counter can be used to detect radioactive contamination and to estimate its activity.

Geiger-Müller counter

badge

Another method which can be used in the detection of exposure to ionizing radiation, often used for workers in the nuclear industry, is the wearing of a *badge* containing sensitive film. Ionizing radiation, like ordinary light, blackens photographic films and the blackening of the film is a measure of the level of the total dose of ionizing radiation received by the worker.

UNITS

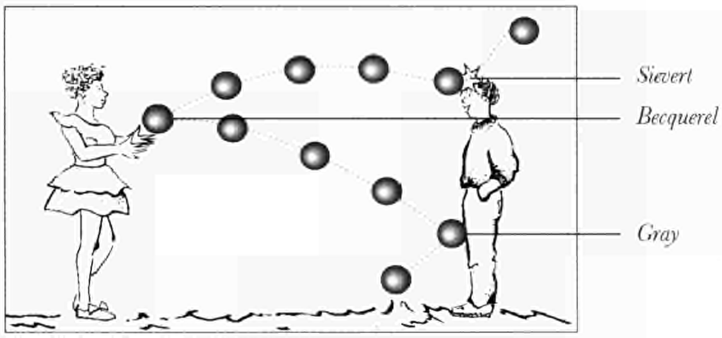
In our everyday lives, we like to measure things. For example, we like to know how much our body weighs and express it in kilograms, or we want to know how tall we are and express it in centimetres. In the same way we sometimes want to know the number of changes in an unstable radioactive substance and the level of absorbed dose in our body. For this purpose we use special quantities and units. In the second lesson of this level, you saw that the amount of activity of an unstable substance is expressed in *becquerel* (symbol Bq), one becquerel corresponding to one distintegration (change) per second. If we want to express the amount of ionizing radiation absorbed by body tissue, we use the unit *gray* (symbol Gy). If we also want to take into account the type of ionizing radiation involved (alpha, beta or gamma radiation or X-rays) and its biological effects, we use the unit *sievert* (symbol Sv). One sievert is a large amount and so we also use millisieverts (symbol mSv) and microsieverts (symbol µSv).

becquerel

gray

sievert

We can demonstrate the relationship between the three units by using the following analogy involving Paul and Angela:



This figure shows the relationship between the three units that measure radioactivity and doses of ionizing radiation in a simplified way (becquerel, gray, sievert)

Angela, acting like a disintegrating atom, throws softballs dipped in chalk at Paul. The rate at which the balls are thrown is measured in becquerels. The number of balls which hit him is the dose of radiation absorbed, and is measured in grays. Finally, the number of chalk particles on Paul's skin shows the effect produced and is measured in sieverts.

KEY POINTS

We need special instruments in order to detect the presence of ionizing radiation. The Geiger-Müller counter is a very sensitive instrument for detecting ionizing radiation.
The amount of a radioactive substance and doses of ionizing radiation are measured in three different units:
- ***the unit of activity (the number of changes occurring within the radioactive substance in one second) is called the becquerel (Bq) ;***
- ***the unit of absorbed dose is called the gray (Gy);***
- ***the unit of effective dose is called the sievert (Sv).***

QUESTIONS

1 What do we need to detect ionizing radiation?

2 Name the units used to measure activity and doses of radiation. Describe in your own words what they mean. Illustrate them with a drawing if you wish.

How does radiation affect your body?

AIMS

At the end of the lesson the pupil:
- is able to say how radiation can affect the body
- is able to name two early and two late effects of ionizing radiation
- can draw the international symbol for radioactivity
- can name three ways of providing protection against external ionizing radiation.

PROPOSED MINIMUM TIME

50 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

For more detailed information on the biological effects of ionizing radiation and how to protect yourself against it, consult:
Chapter 5: The biological effects of radiation
Chapter 6: Protection against ionizing radiation

TEACHING SUGGESTIONS

The fourth lesson focuses on the effects of ionizing radiation on the human body and on methods of protection.
You can start the lesson by illustrating with an electric torch the importance of three factors in exposure to radiation:
1. Time/duration (of exposure).
2. Distance from the source of radiation.
3. Shielding against radiation in order to protect the hands and eyes.

Compare ways of protecting the body against ultraviolet radiation with ways of protecting the body against ionizing radiation.
- time: long or short exposure time
- distance (e.g. the distance to a sun-lamp).
- shielding: the use or non-use of suntan oil; use a suntan oil with the right shielding factor.

After you have done this let the pupils read the text and tackle the questions and assignments.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Write down the three basic methods of protection against (ionizing) radiation coming from an external source.
1. Control of exposure time. 2. Control of distance from source. 3. Use of shielding.

2 What is the difference between the early and late effects of exposure to ionizing radiation? Give examples.
Late effects include cancer and hereditary effects, early effects include falling ill shortly after the exposure, hair loss and skin burns. Early effects are caused by very large exposures.

3 Why can radiation from an alpha source be dangerous even though it cannot penetrate your skin?
If the source enters your body through inhalation or swallowing, the radiation may have a direct effect on your organs.

4 Is ultraviolet radiation a type of ionizing radiation? If not, why not?
No, because it is too weak to affect the electrons of the atoms which it passes through and so cannot cause ionization.

As you probably know already, too much sun is harmful for your skin. Ionizing radiation can affect the human body too. We are now going to take a closer look at how these effects occur.

LESSON

How does radiation affect your body?

We can feel the sun's rays that reach the earth because they bring warmth, and we can see them because they bring light. This means that the rays that come from the sun are of various kinds.

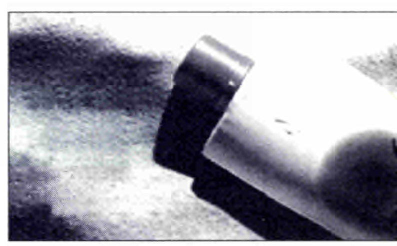
ultraviolet rays

But there are other rays from the sun which we cannot see or feel and these are called *ultraviolet rays* (UV rays). When we lie in the sun these rays make our skins produce pigment which gives the skin a suntanned look. Many people like a suntanned skin and to get one they often sunbathe for a long time.

However, we know that too much sunshine is dangerous for the skin. The ultraviolet radiation in the sunlight causes permanent changes in the skin tissue and this can lead to skin cancer. The greatest damage to the skin is caused when it is sunburnt. Sunburn can be prevented if the skin is gradually accustomed to the sun's rays, so it is safer to sunbathe 15 minutes a day for three weeks instead of sunbathing for 5 hours in one day. This means we should limit both how long and how often we are exposed to the sun. People with a pale skin and light-coloured eyes are more susceptible to sunburn than dark-eyed people with a tinted skin and dark hair. Suntan oil gives good protection against UV rays.

UV rays can reach you even you are in the shade. This can happen, for example, when you are near some water because a lot of these rays, which are invisible, are reflected by water. As the damaging effect of sunlight is greatest at an early age, it is very important to protect children.

Fortunately the atmosphere, especially the ozone layer, absorbs most of the UV rays, which could otherwise cause skin cancer. That is why the ozone layer must be kept as intact as possible because it offers protection against ultraviolet radiation.



A way to protect your skin against the rays of the sun

UV radiation, by the way, is not a type of ionizing radiation. This is because it is too weak to affect electrons in atoms.

Ionizing radiation's penetration properties and how they affect the human body

Possible damage to the human body by ionizing radiation depends on a number of factors. These include:

- the kind of ionizing radiation which the body is exposed to (alpha, beta, gamma, X-rays);
- whether the radiation source is inside or outside the body;
- assuming the radiation source is inside the body, in what part of the body the source is located, how long it stays there and the type of organ which absorbs the radiation.

alpha radiation

Alpha radiation has very little penetrating power. Materials that emit alpha radiation outside the body are harmless, since they are already stopped by the skin. But when these materials enter the body through inhalation or swallowing, they may be harmful.

beta radiation

Beta radiation is able to penetrate further, through up to 1 or 2 cm of tissue. Outside the body materials that emit beta radiation may be harmful to the surface tissue of the body; when such materials enter the body, they may harm the organs in which they are present.

gamma radiation

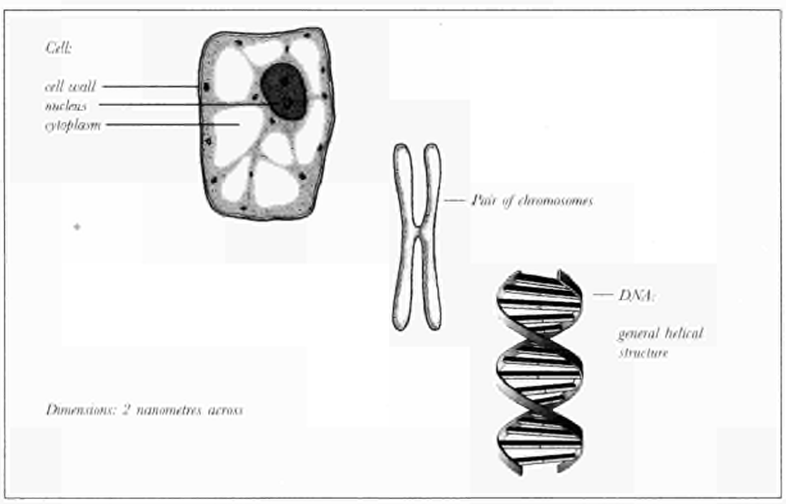
x-rays

Gamma radiation penetrates even further and is able to go straight through the body. This may harm the organs in the body.
X-rays are of the same nature as gamma rays and can also affect the organs in the body.

Effects of ionizing radiation on the human body

The human body is composed of cells which can reproduce themselves.This is a continuous process in every living creature. Ionizing radiation penetrating a cell can affect this reproduction process by causing abnormal chemical reactions. Some of these reactions can lead to the cell dying and some can lead to it surviving but in a changed form.

Structure of a human cell



EARLY EFFECTS

If the dose of ionizing radiation is very high and received over a short time, many cells at once can die off. This may result, for example, in hair loss or skin burns. We call these effects early effects. If early effects are widespread in one person, they may cause the death of that person.

DELAYED EFFECTS

If cells are not killed but modified, following for example a lower dose or a dose which was spread over a longer period of time, effects may appear many years later in the person who was irradiated (cancer) or in his/her offspring (hereditary effects). We call these effects delayed or late effects.

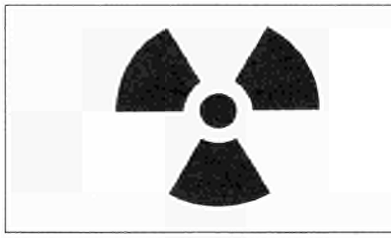
Practical examples of protection in the workplace

basic principle of protection

People who, because of their work or for other reasons, are more likely to be exposed to ionizing radiation have to be well protected against its effects. The *basic principle of protection* against ionizing radiation is to avoid exposure. When exposure cannot be avoided the quantity received from external sources should be limited by observing the following rules:

- Limit the duration of the exposure as much as possible (control of exposure time).
- Ensure that the distance to the ionizing radiation source is as great as possible (control of distance to the source).
- Make use of a screen which stops or reduces ionizing radiation (use of shielding).

Radioactive sources and X-ray machines must be clearly marked by appropriate labels carrying the international (trefoil) symbol for radioactivity.



The international trefoil symbol

KEY POINTS

- ***Too much sunshine is dangerous to the skin.***
- ***Ionizing radiation affects the human body.***
- ***We distinguish between early and late effects.***
- ***Control of exposure time, control of distance to the source and the use of shielding are important ways of protecting people against external sources of ionizing radiation.***

QUESTIONS

1 Write down the three basic methods of protection against (ionizing) radiation coming from external sources.

2 What is the difference between the early and delayed effects of exposure to ionizing radiation? Give examples.

3 Why can radiation from an alpha source be dangerous even though it cannot penetrate the skin?

4 Is ultraviolet radiation a type of ionizing radiation? If not, why not?

Medical applications of radioactive substances

AIMS

At the end of the lesson the pupil:

- knows that, apart from X-rays, there are other medical applications of ionizing radiation sources
- knows that nuclear medicine is based on the principle of using radioactive tracers.

PROPOSED MINIMUM TIME

40 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 7: Applications of ionizing radiation and radioactivity

TEACHING SUGGESTIONS

This lesson deals with a specific medical application of ionizing radiation sources.
After the pupils have read the story and answered the questions, start a discussion about medical applications of ionizing radiation, bringing in the pupils' own experiences. You could ask the following questions:

- Have you ever had an X-ray?
- Do you have any relatives who have been examined using radioactive tracers?
- Do you know of anyone who has been treated with ionizing radiation? (deal carefully with this subject in case a pupil has lost a relative from cancer)
- You can also ask about the risks and advantages of using ionizing radiation and list them on the blackboard.

Ask the pupils about their own views.
You can also use information from the previous lessons.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Why did the landlady think George de Hevesy was using magic when he told her that she was serving him old food?
Because she could not see the ionizing radiation coming out of the food containing a radioactive tracer and therefore could not understand how he had found out.

2 How does the use of an X-ray machine differ from the use of a radioactive tracer?
An X-ray machine is a source outside the patient's body while a radioactive tracer is injected into the patient's body.

3 Why is a tracer emitting gamma rays preferable to a tracer emitting alpha or beta rays?
Because gamma rays easily penetrate the human tissues and come out of the patient's body so that they can be recorded by the camera. Alpha and beta rays will not – or only partially - come out of the body because they are stopped by the tissue and it is therefore difficult to record them on a camera outside the body.

4 Why is it important to use a tracer with a short half-life?
Because then the exposure time and dose are kept to a minimum.

You have already been introduced to some of the applications of ionizing radiation in medicine and dentistry. All of them concern X-rays: X-rays used for diagnostic purposes to diagnose a bone fracture or a disease in a tooth, and X-rays used to treat cancer.

As you know, X-rays come from an X-ray machine which is outside the patient's body. In other words, it is an external source of ionizing radiation. In this lesson you will learn how sources of ionizing radiation are brought into the human body for diagnostic purposes. But to trace the origins of this technique, we have to go back to 1911 to a man called George de Hevesy.

LESSON

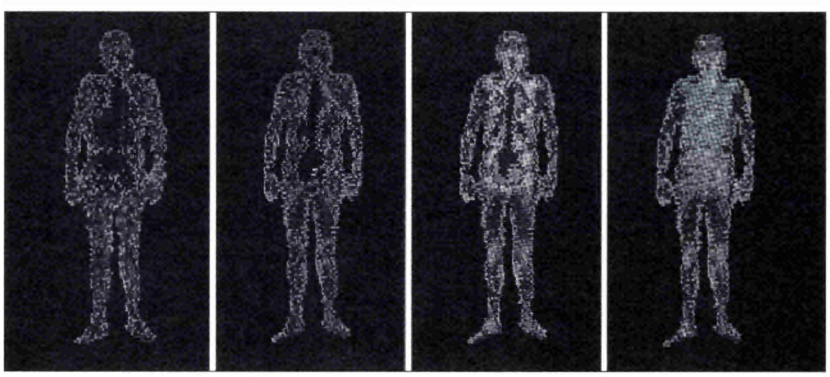
Medical applications of radioactive substances

George de Hevesy

In 1911 *George de Hevesy* was a young research assistant working in a Manchester laboratory on natural radioactivity. As a young assistant, he was badly paid and therefore had to live in modest accommodation. He rented a small furnished room in an old and musty house in a grey neighbourhood. His rent also covered breakfast and an evening meal. It struck George after a few weeks that the food which his landlady served him was often the same and tasted peculiar, as if it had been left over from earlier in the week. To be sure of this before accusing her of anything, he had the brilliant idea of putting a trace of radioactive material into the leftovers on his plate. Several days later, when the same dish appeared, he used his ionizing radiation detector – at that time a very new and impressive device – and found that the food was radioactive. It had been served before! Now he was sure of it. In his enthusiasm he immediately confronted the landlady but she thought he was using magic and told him to leave her house immediately. George de Hevesy was not so lucky in 1911 but in 1943 he won the Nobel Prize for developing the technique of using radioactive materials as tracers.

nuclear medicine

Nowadays, doctors use radioactive tracers in a branch of medicine called *nuclear medicine*. They inject a radioactive substance into the patient's bloodstream and, depending on the chemical properties of the substance, it will be concentrated in certain organs. Once the substance is present in the



Technetium-99m scan. Radioactive material with a half-life of 6 hours organ we can, with a special camera, easily detect the gamma rays it sends out through the patient's body. If there is a tumour present, the concentration of the radioactive tracer will be abnormal in the tumour cells and this will show up on the image produced by the camera.

half-life

To reduce doses received by the patient, it is important to use tracers with a short *half-life* (= the time needed for the activity of a radioactive substance to fall to half its original level). Often tracers with a half-life of about 6 hours are used.

KEY POINTS

- ***In nuclear medicine radioactive tracers are injected into the patient's bloodstream.***
- ***Tracers are used because they are concentrated in specific organs.***

QUESTIONS

1. Why did the landlady think that George de Hevesy was using magic when he told her that she was serving him old food?
2. How does the use of an X-ray machine differ from the use of a radioactive tracer?
3. Why is a tracer emitting gamma rays preferable to a tracer emitting alpha or beta rays?
4. Why is it important to use a tracer with a short half-life?

Applications of nuclear energy

AIMS

At the end of the lesson the pupil:

- is able to name two applications of nuclear energy other than nuclear power stations
- is able to explain in a simplified way how a nuclear power reactor works.

PROPOSED MINIMUM TIME

45 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 2: The structure of the atom
Chapter 7: Applications of ionizing radiation and radioactivity

TEACHING SUGGESTIONS

Read the story and let the pupils answer the questions/assignments. Start a discussion based on articles collected from magazines and newspapers on accidents involving submarines or satellites.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Explain how a nuclear power reactor works.
Chain reaction, nucleus of uranium is bombarded with neutrons, splitting of nucleus, controlled by moderators, releases energy and heat which is transformed into steam, steam generates electricity via a turbine.

2 Why was the Nautilus the first submarine able to pass under the polar ice-cap?
Because the Nautilus did not rely on an external fuel supply and it did not require oxygen for combustion. It was therefore able to stay under the water for a very long time.

3 Why do you think people have launched satellites powered by nuclear reactors if they knew there was a risk of them falling back to earth and contaminating large areas with radioactive material?
Half-open question: one reason could be that nuclear power reactors are relatively cheap and easy to install and are reliable. The chance of a satellite falling onto populated areas is relatively small.

4 Collect information on accidents involving nuclear-powered vessels and satellites. Discuss this information in class.

In this lesson you will learn that there are other applications of nuclear energy apart from nuclear power stations.

Applications of nuclear energy

chain reaction
nuclear power reactor
fission reaction

As discussed during an earlier lesson in Level III, the most important use of nuclear energy is the operation of nuclear power stations for producing the huge quantities of electricity needed in our modern society. However, apart from this well-known application of nuclear energy, there are other applications of this energy source. All these applications, however, are based on the same principle: a *chain reaction* is triggered in a *nuclear power reactor* by bombarding a heavy uranium nucleus with neutrons so that it is split up into two smaller nuclei and several "free" neutrons which then split other uranium atoms, and so on. This *fission reaction* ("fission" means "splitting up") is

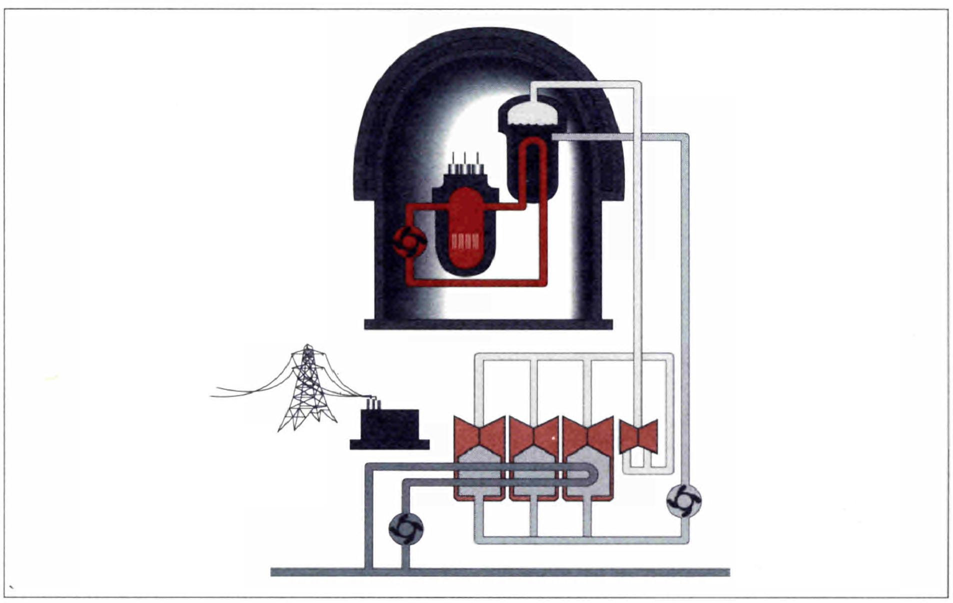


Diagram of a nuclear power reactor

controlled by putting a sort of brake on the free neutrons, so that not too many uranium atoms are split at the same time. The energy produced by the splitting of each uranium atom is released as heat. This heat makes water boil and the steam produced by this process is used to drive a turbine which is linked to a generator that produces electricity. This process does not involve combustion in the traditional sense and therefore does not produce carbon dioxide (CO_2).

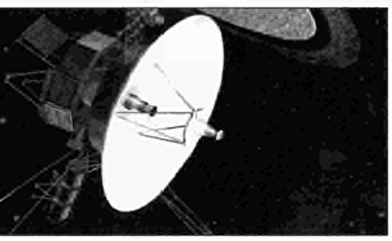
nuclear energy

This means that *nuclear energy* has to be converted into a useful form of energy such as steam or electricity in order to be used in applications. It soon dawned on scientists that nuclear energy could have other applications apart from the production of huge quantities of electricity for consumption. In 1954, an American submarine called the Nautilus was built using a small nuclear power

Nautilus, the first american submarine with a nuclear power reactor as energy source

reactor as an energy source. It was the first nuclear-powered vessel to be launched. It became famous on 3 August 1958 when it completed a remarkable voyage. It had passed under the massive ice floes in the Arctic Ocean and reached the North Pole before returning safely to its home port. This was only possible because the Nautilus did not have to rely on external energy sources such as oil or other types of fuel and needed no oxygen for their combustion.

Nowadays, many military and civilian vessels are powered by small nuclear reactors. This can cause problems if one of these vessels sinks. People are afraid that the radioactive material in the vessel might eventually escape from the reactor and pollute the sea.



Nuclear reactors are used for power supply in satellites

Nuclear reactors are also used as a power source in satellites launched for communication or observation purposes. Since 1978, when a satellite known as Cosmos 954 fell to earth in the plains of Canada due to navigation problems and contaminated parts of a large area with highly radioactive materials, alternative energy sources, in particular solar energy, have been used more and more to power these satellites.

KEY POINTS

Nuclear power reactors have other applications apart from the generation of electricity for general consumption. They are used, for example, to power ships (including submarines) and satellites.

QUESTIONS

1. Explain how a nuclear power reactor works.

2. Why was the Nautilus the first submarine able to pass under the polar ice-cap?

3. Why do you think people have launched satellites powered by nuclear reactors if they knew there was a risk of them falling back to earth and contaminating large areas with radio-active material?

4. Collect information on accidents involving nuclear-powered vessels and satellites. Discuss this information in class.

14-16 YEARS

There are eight lessons for students in the 14-16 age group.

INFORMATION

They contain increasing amounts of technical information on the structure of the atom, the applications of ionizing radiation, the effects of ionizing radiation on the body, and nuclear power stations.

The topics for the 14-16 age group are:

CONTENTS

- sources of ionizing radiation
- atoms and ionizing radiation
- effects on the body
- radiation from natural sources
- medical and other applications
- nuclear power

Background information and further information can be found in the Technical Supplement. At the beginning of each lesson, there will be a reference to the chapter or chapters which give the most detailed information.

LESSONS LEVEL V

V

EVALUATION

When you have given all the lessons at this level, you can test what the pupils have learned with the following assignment. Ask them to write an essay about one of the subjects in the lessons. To do this, they may have to do some background reading or interview someone who knows about the subject.

Pupils must make sure:

- the facts are right

- their own opinion is clear.

References to videotapes and books which can be used will be made in the lessons at this level. These books and videotapes are also listed in the bibliography at the end of this course together with the addresses where they can be ordered.

Radioactivity and other sources of ionizing radiation

AIMS

At the end of the lesson the pupil:

- is aware that some materials are radioactive and emit ionizing radiation
- knows the difference between the ionizing radiation doses coming from natural sources and those from man-made sources
- knows the percentage of the average annual ionizing radiation dose which is due to natural and man-made sources of radiation
- is able to give some examples of ionizing radiation from natural and man-made sources.

PROPOSED MINIMUM TIME

50 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 1: Historical introduction
Chapter 3: Non-ionizing radiation
Chapter 8: Doses from ionizing radiation

TEACHING SUGGESTIONS

0) Preparing for this lesson:

- in addition to the Technical Supplement, read the EC publication, "Radiation and You" by Peter Saunders.
- obtain and view video material including "Radiation – origins and control" by Trevor Moseley, CEC, 201/8.

1) Give a short introduction based on the first paragraph of the text in Lesson 1. Test the knowledge of the class by asking for examples of natural and man-made sources of ionizing radiation, distinguishing between those which are internal and those which are external to our bodies.
2) Show the video "Radiation – origins and control".
3) Give the class an opportunity to ask questions.
4) Divide the class into small groups and ask them to read the text. If time is short, they can skip the first section. At the end, the pupils should prepare a table by writing down examples of natural and man-made sources of ionizing radiation. They may consult each other. Do not tell them what layout the table should have (see first assignment below).
5) Groups which work quickly can tackle one or more of the other three assignments.
6) Evaluate the results in a class discussion. Refer to the key points.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Prepare a table summarising the main points in the text.

Natural	Man-made
External (the radiation comes from outside our bodies)	
The sun and outer space	Medical X-rays
The earth (gamma activity)	Nuclear power stations
Building materials	
Internal (the radiation comes from inside our bodies)	
Radon and thoron	Nuclear medicine
Radioactivity of food	Fall-out
	Nuclear power stations
	Industry

2 Draw a pie chart showing the average percentage of the annual radiation dose using the information in Figure 1. Add up the total percentage of our radiation doses from natural sources and from man-made sources and write them down next to the pie chart.
See pie chart.

3 Make a list of sources of radiation which are used in everyday life. Are you surprised about the number? What did you expect?
See Lessons 4, 5 and 6 for natural and man-made sources.

4 Collect newspaper and magazine reports which mention radiation and radioactivity. What percentage of the reports give a favourable view of the application of radiation and radioactivity which they report? Do you agree?

Ionizing radiation and radioactive materials are a source of worry to many people who are particularly concerned about nuclear reactors and the radioactive waste which they produce. These lessons are intended to help you to judge for yourself about nuclear power and many other man-made applications of ionizing radiation and radioactive material.

LESSON 1

14-16 YEARS

Radioactivity and other sources of ionizing radiation

THE HISTORY OF RADIATION

Man has been exposed to radiation from the beginning of time. For example, he has been exposed to sunlight, the visible light from the sun which is accompanied by invisible radiation known as ultraviolet and infrared radiation. He has also been exposed to other forms of invisible radiation coming from outer space and the sun which are known as *cosmic radiation*. This is a very energetic type of radiation which can penetrate deeply through thick layers of rock. There is nowhere on earth where a person can escape exposure to cosmic radiation. This energetic radiation can cause electrical changes in anything through which it passes and so we call it *ionizing radiation*. There are other types of ionizing radiation which come from the earth and the source of this radiation is radioactive material. This name was coined by Marie Curie, who discovered radium in 1898. *Radioactivity* is a natural property of some of the atoms from which the earth is made.

cosmic radiation

ionizing radiation

Radioactivity

The first type of ionizing radiation to be discovered was made by Wilhelm Roentgen in 1895. He used an apparatus in which electrons at high voltage were fired at a metal plate inside a glass tube. Roentgen named these *X-rays*. He showed that they could penetrate human tissue and with the aid of a photographic plate he was able to develop a shadow picture of the bones. Following Roentgen's discovery of X-rays they were quickly applied for medical purposes but, sadly, many of the doctors and radiologists became ill. The dangerous effects of excessive exposure to ionizing radiation were then recognised.

X-rays

We now know that these effects are due to chemical reactions caused by the electrical changes which ionizing radiation produces in matter. In 1928 the *International Commission on Radiological Protection* (ICRP) was founded by radiologists to tackle the problem. The ICRP have found ways of expressing the radiation dose and have recommended maximum doses for particular

International Commission on Radiological Protection

applications of ionizing radiation so that the benefits can be enjoyed without undue risk.

Ionizing radiation played an important part in the study of the atom and this led to the discovery of fission by Otto Hahn and Freidrich Strassmann in 1938. The explosion of the first atomic bombs over Japan in 1945 created a new group of people who had received large doses of ionizing radiation, and spread radioactive fall-out around the world. More fall-out was produced by atmospheric tests of atomic bombs, which continued until 1980.

The first nuclear reactor was operated by Enrico Fermi in 1942 and the first electricity to be generated from fission was made in 1951 by an experimental reactor in the USA. Nuclear power developed very quickly and Euratom was founded in 1957. As a result of the 1986 disaster at the Chernobyl nuclear power station in the Ukraine, a number of people received large doses of ionizing radiation. More radioactive material was dispersed around the world, reviving the earlier fears of ionizing radiation.

MAN'S RADIATION DOSE

Ionizing radiation is a normal part of our surroundings and we can determine the dose from any source of ionizing radiation by estimating the energy which is absorbed from the radiation. Most of our radiation dose comes from natural sources, which include cosmic radiation from the sun and outer space as well as radiation emitted from radioactive atoms in the earth and from radioactive material in all creatures on earth.

RADON

The most important radioactive atom or radionuclide is radon gas, which escapes into the air from natural uranium deposits in the ground and collects in buildings where we inhale it. This radioactive material inside our bodies is an internal source. Radon gives us the single most important radiation dose and is especially high in places such as Cornwall, where the rock is very radioactive.

POTASSIUM

Our bodies contain naturally radioactive potassium, which we consume in our food. This radioactive material inside our bodies is also an internal source but the dose is usually less than that from radon.

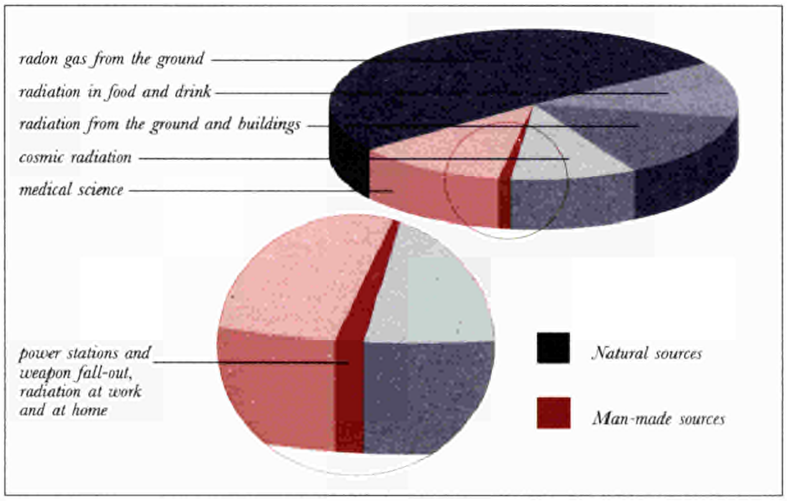
COSMIC RADIATION

When we fly in an aeroplane at a high altitude we have increased exposure to cosmic rays and, since the source is external, the dose we receive depends on the length of the flight.

X-RAYS

Radiation from medical X-rays gives us a significant radiation dose although in this case the radiation comes from the X-ray machine which is external to our bodies, so the dose is no longer received when the machine is switched off.

The application of radioactive materials by man is responsible for some additional radioactive material in our bodies. The most important is the medical use of radioactive materials. A much smaller dose still comes from radioactive fall-out due to atmospheric atom bomb tests. The Chernobyl reactor accident added more fall-out in 1986. There is a very small dose each year from the normal operation of nuclear power stations. To summarise we can say that ionizing radiation doses can come from natural or man-made radioactive material and the source may be internal or external to our bodies. The table below shows the percentage of average annual radiation doses which people receive in Europe.



The distribution of the average radiation doses received in Europe

SOURCE	%
Inhaled radon gas from the ground (internal)	51
Gamma rays from ground and buildings (external)	14
Radioactive material in food and drink (internal)	12
Cosmic rays (external)	10
Medical science	12
Power stations and weapon fall-out, radiation doses at work and at home	1

KEY POINTS

- ***Man has been exposed to radiation from the beginning of time.***
- ***Ionizing radiation causes electrical changes in anything through which it passes.***
- ***Ionizing radiation comes from two main sources, natural and man-made and the dose can be received from sources which are internal (inside the body) or external (outside the body).***
- ***Radioactivity is a natural property of some atoms.***
- ***About 87% of the dose we receive comes from natural sources and only 13% from man-made sources.***
- ***Röntgen's X-rays were quickly applied for medical purposes.***

QUESTIONS

1 Prepare a table summarising the main points in the text.

2 Draw a pie chart showing the average percentage of the annual radiation dose using the information in pie diagram on page 3. Add up the total percentage of our radiation doses from natural sources and man-made sources and write them down next to the pie chart.

3 Make a list of sources of radiation which are used in everyday life. Are you surprised about the number? What did you expect?

4 Collect newspaper and magazine reports which mention ionizing radiation and radioactive material. What percentage of the reports give a favourable view of the application of ionizing radiation and radioactive material which they report? Do you agree?

Ionizing radiation and its biological effects

AIMS

At the end of the lesson the pupil:
- is able to name four types of ionizing radiation
- is able to explain half-life using a simple example
- is able to draw the structure of a cell and name the main parts
- is able to state the difference between early and delayed effects of ionizing radiation on man.

PROPOSED MINIMUM TIME

60 minutes (or 2 x 30 minutes)

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 4: Radioactive material and ionizing radiation
Chapter 5: The biological effects of radiation

TEACHING SUGGESTIONS

0) Preparation
- It is important to use audiovisual material and radioactive material demonstration kits for this section since the concepts are complex. If a Geiger-Müller counter with an end window is available, the penetration of ionizing radiation through air, aluminium and lead can be demonstrated. A gas mantle can be used in the absence of an approved radioactive source. Use this material with care.
- Watch the video tape "Radiation: types and effects" by Donald Hughes, CEC NO 201/7, 1989, before the lesson. This video tape can also be used in Lesson 3.

1) Give a short introduction based on the first section of the text "Ionizing radiation and its biological effects".

2) Show the video tape "Radiation: types and effects".

3) Answer any questions which the pupils may ask.

4) Divide the text into 2 parts: types of radiation, ionization and radioactive material on the one hand and human biology on the other. Ask each pupil to read one of these parts and tackle the relevant questions/assignments.

Text part 1: page	Questions/ass.: 1, 2
Text part 2: page	Questions/ass.: 3, 4, 5, 6

5) Pupils exchange information on the following: types of radiation emitted, their capacity to penetrate (as demonstrated with the Geiger-Müller counter), the concept of 'half-life', some biological effects of ionizing radiation, the dose of radiation expressed in gray and sievert. Your help may be needed, e.g. in the case of the 'half-life' concept. The concept of half-life applies when the rate of change of a quantity is proportional to the quantity present. This may be demonstrated by the following:
(a) The rate of leakage of water out of a hole in the bottom of a bottle diminishes as the water level drops. The time to fall to half the level is the same at all levels in the bottle.
(b) Throw one hundred dice once and discard every dice which falls on 6 (this has decayed or disintegrated), record the number remaining and throw the remainder of the dice, record this number and continue until less than 5 dice remain. Plot a graph to show the way that the number of dice diminishes with the number of throws. The half-life is the number of throws needed to reduce the dice remaining to half of the start number.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Make a list of three types of ionizing radiation, putting the most penetrating first and so on. If possible, test this by using a radioactive material kit.
Gamma ray, beta ray, alpha ray (some neutrons are very penetrating).

2 One hundred atoms of the radionuclide, radon-222, are collected in a sealed bottle. How many radon atoms will be left after one half-life of 3.82 days? And how many will remain after another 3.82 days?
About 50, about 25.

3 Draw a diagram of a cell and name the parts.

4 How can early effects of ionizing radiation exposure be avoided?
Keep doses below threshold of 0.1 gray (about 0.1 Sv or 100 mSv), spread exposure over time.

5 What delayed effects may result from ionizing radiation exposure and how can they be reduced?
The effects include cancer and hereditary consequences and these are reduced by reducing the dose.

6 The unit of absorbed dose is the gray, defined as 1 joule per kilogram. What energy is absorbed by a person weighing 70 kilograms if a whole-body absorbed dose of 3 gray is received? What would be the effect?
Energy is 70 x 3 = 210 joules. The effect might be fatal.

The types of radiation emitted from a radioactive source are the consequence of a disintegration or transformation of the nucleus and we will learn more about this is Chapter 7. We shall also learn that the atom has a nucleus of protons and neutrons surrounded by shells of electrons which take part in all chemical reactions. We give each atom its proper chemical name, and a number indicating the size of its nucleus. This is important because there is a tendency for the heavier nucleus to disintegrate or transform.

LESSON

Ionizing radiation and its biological effects

radium

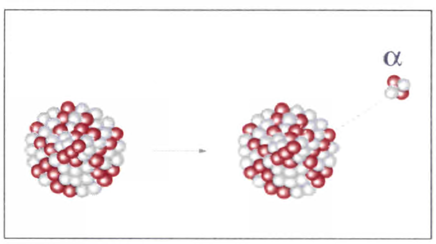
The famous element discovered by Madame Curie has the chemical name *radium* and is a brilliant white metal. The nucleus of radium with a size of 226 is labelled radium-226 and is most important because it is radioactive and transforms to a radioactive gas, radon.

TYPES OF IONIZING RADIATION

Radium-226 emits the:

- alpha particle :

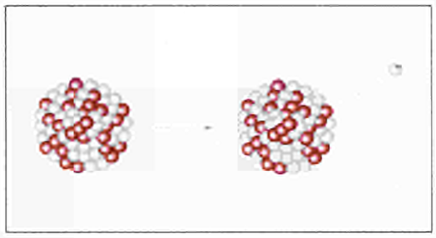
a big piece of the nucleus consisting of two neutrons and two protons.



The emission of an alpha particle

1 *Radium-226* → *Radon-222* + *α particle*

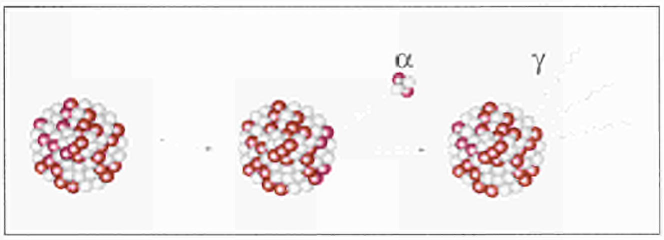
Lead-210, a relative of radium-226, emits the:
- beta particle :
  a negatively-charged electron coming from the nucleus.



The emission of a beta particle

2 *Lead-210* → *Bismuth-210*, β *particle*

But radium-226 also emits:
- gamma radiation.
  This is electromagnetic radiation, a packet or photon of the excess energy of the nucleus.



The emission of a gamma photon

3 *Radium-226* → *Radon-222*, γ *photon*
└→ α *particle*

To complete the list of types of radiation we must add X-rays and neutrons.

X-rays

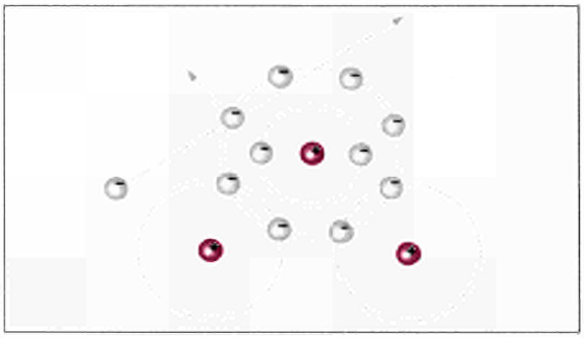
- *X-rays* are man-made electromagnetic radiation produced by the action of electrons on a metal target. These electrons react with the electrons in the shell of the atom and make them change energy and emit the X-ray.

neutrons

- *Neutrons* are emitted when a heavy nucleus disintegrates by splitting into two parts. This is the fission process discovered by Otto Hahn and Friedrich Strassmann in 1938 which we will describe in Lesson 7.

IONIZATION

When a particle or a gamma photon hits another atom it is most likely to react with the outer shell of electrons. If an electron is expelled the atom will loose a negative charge and becomes positively charged. The charged atom is called an ion and the atom is said to be ionized. The gap in the outer shell of the atom makes it chemically reactive. If the chemical reaction occurs in a living cell it is likely to damage the cell and so cause undesirable biological effects. This ability to cause ionization and the biological effects that it produces is the reason for the precautions which we have to take when using any type of ionizing radiation.

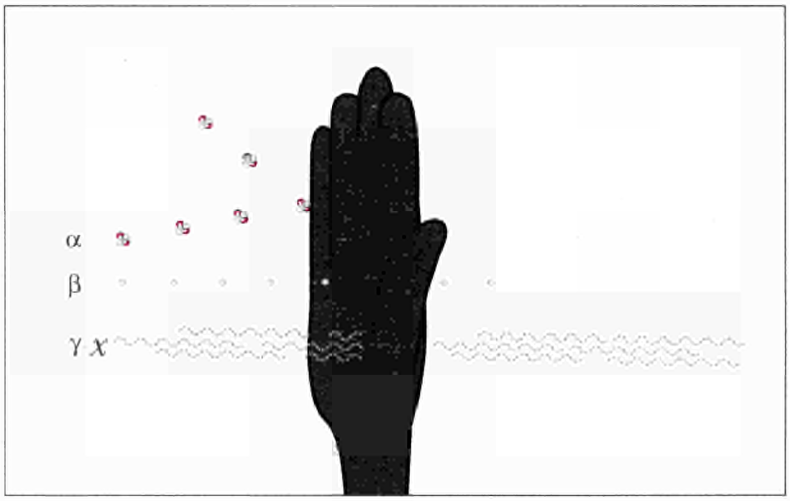


The ionization of a water molecule

penetration distances

We know that ionizing radiation is penetrating; in some cases it can pass through solid objects such as metal.
Typical *penetration distances* are shown below.

Alpha particle	• up to 5 centimetres of air. Produces very heavy ionization.
Beta radiation	• up to 1 centimetre of aluminium. Penetrates the skin and produces burns.
Gamma radiation	• up to several metres of concrete. Affects all parts of the body.



The penetrating properties of different types of ionizing radiation

radionuclides

RADIOACTIVE MATERIAL

Atoms which have an unstable nucleus are *radionuclides*. They disintegrate and transform to another nuclide which is usually of a different element with different chemical properties. Those radionuclides which are very unstable have a rapid rate of disintegration and the more stable have a slow *rate of disintegration*. We can use this rate, called the activity, to represent the quantity of the radionuclide. This works very well because we can easily detect the rays that are emitted when a transformation occurs. This may seem odd because it is a little like estimating the number of children in a class by listening to the noise that they make! The unit of activity is the *becquerel*, symbol Bq, which is equal to one transformation per second.

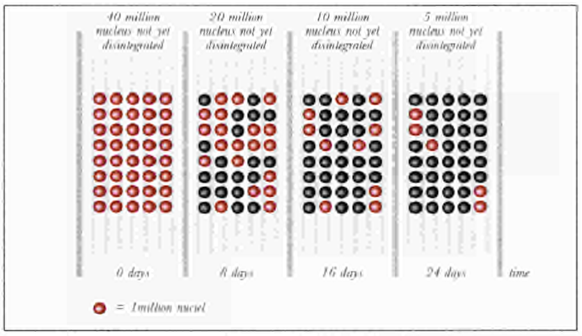
rate of disintegration

becquerel

half-life

The *half-life* is the time needed for half of the radionuclides to disintegrate; the more stable radionuclides have a long half-life. The half-life cannot be altered by heat or chemical reactions with the radionuclide. Here are a few half-life values:

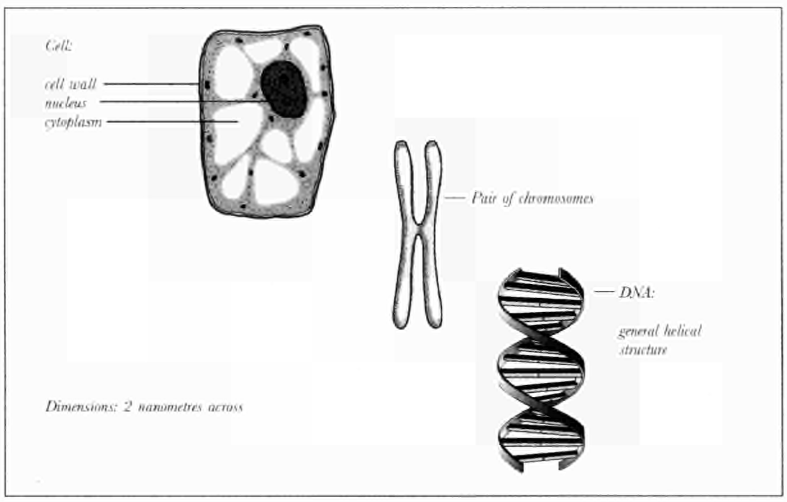
technetium – 99m	6 hours
radon – 222	3.82 days
iodine – 131	8 days
cobalt – 60	5.2 years
lead – 210	22.3 years
radium – 226	1600 years
carbon – 14	5739 years
uranium – 235	700,000,000 years



The decay of a radionuclide with an 8-day half- life

HUMAN BIOLOGY

The effect of ionizing radiation exposure on the human body depends on which of the organs is exposed. It is the reaction of the tissues of the irradiated organ and their cells to the ionizing radiation which determines the biological effect of the radiation. A typical cell is illustrated below showing the cell wall or membrane, the cytoplasm and the nucleus. The nucleus of the cell carries the genetic components, the chromosomes, which are DNA molecules. These molecules are the messengers with which the cell transmits biological instructions which control the daughter cells. If the DNA molecules are damaged by ionizing radiation the daughter cell is likely to be hopelessly confused and will be killed or damaged. In some cases of damage to the cell, cancer may eventually develop. The damage to the DNA in a germ cell may be transmitted to future generations.



The structure of a human cell

EARLY EFFECTS OF IONIZING RADIATION EXPOSURE

gray

deterministic effects

The early damage to tissue caused by ionizing radiation is proportional to the amount of radiation energy absorbed above a certain limit. The energy absorbed is the absorbed dose, which is measured in units of *gray*. The amount of damage depends also on the type of radiation and on the tissue exposed. At absorbed doses of above 0.5 gray, received in a short time, certain consequences known as early effects will occur within two or three months of exposure. These are usually the result of the killing of cells and are *deterministic effects* (N.B.: Not all deterministic effects are early effects). These include damage to the digestive system of the person exposed, who will suffer vomiting in a few hours. In addition the blood may be affected and reddening of the skin may be seen. The skin reaction was used by early radiologists to estimate the amount of radiation exposure. There will be other serious effects and doses of about 3 to 5 gray could be fatal to about 50% of people exposed. These early effects are avoided by keeping the dose below 0.1 gray, which is well below the threshold dose, or by spreading the dose over weeks or months to give time for the cells to recover.

DELAYED EFFECTS OF IONIZING RADIATION EXPOSURE

stochastic effect

If early effects are avoided it is possible that the tissues of the exposed person may have received enough damage to produce, loosely termed, "delayed effects" which will occur many years after exposure. The process is random and so this has been named the *stochastic effect.* This effect of ionizing radiation exposure is predicted to be a small increase in existing diseases; it is therefore impossible to recognise the effects of low doses. Damage to the DNA in the chromosomes may transmit hereditary effects to future generations.

The stochastic effect has been found in the survivors of the atom bombing of the Japanese who received, in a very short time, ionizing radiation doses of about 1 gray. The most serious delayed effect is cancer since this is an existing disease which is frequently fatal. The increase in the chance of a person exposed to a dose of 1 gray getting a cancer such as leukaemia is low and there is a delay of about 7 years after ionizing radiation exposure before the disease is discovered. Radiation protection professionals assume that all ionizing radiation doses, however small, give a proportional chance of such a disease. Thus the ionizing radiation received by large numbers of people, for example from environmental releases of radioactive material, is kept very low to keep the predicted total of the ionizing radiation doses as low as possible.

The same precautions are taken to reduce the possible hereditary effect on future generations. In fact there is no record of this effect occurring in humans. On the other hand the foetus in the womb is known to be easily damaged by ionizing radiation and the risk is very high at certain stages of the pregnancy. For this reason great care is taken to avoid radiation exposure of the foetus.

IONIZING RADIATION DOSE

The deterministic effects of ionizing radiation exposure can be prevented if the amount of radiation absorbed is below a certain value. The absorbed dose is used to express the amount of radiation energy which has been absorbed. In order to predict stochastic effects of radiation exposure we also need to know the type of radiation and the organ exposed.

- The strongly absorbed alpha ray will produce concentrated ionization in tissue and so the effect is roughly 20 times more severe than the same dose from a gamma ray which spreads ionization lightly over the tissue.

- Exposure of the lung to ionizing radiation is 10 times more damaging to the exposed person than the same dose to the skin.

We allow for this by multiplying the doses by weighting factors which are proportional to the effect. When these corrected doses are added together the quantity calculated is appropriately called the effective dose. This quantity has a new unit called the *sievert*, symbol Sv. Most exposures are a small fraction of the sievert and so we use the millisievert, 1/1000 sievert, symbol mSv, or the microsievert, 1/1,000,000 sievert, symbol μSv, to express these quantities.

sievert

EXTERNAL AND INTERNAL DOSES

We have already discovered that some ionizing radiation doses are due to radioactive sources external to the body such as cosmic rays from the sun. Other doses come from radioactive sources internal to the body such as the radioactive material which gets into our lungs when we inhale radon gas. Internal sources are carried around in the body and can arise from an intake due to eating, drinking or inhaling radioactive material. The dose we receive from all of these very different sources is expressed in the same unit, the sievert, but we have to protect ourselves from them in different ways.

KEY POINTS

- ***Radioactive decay is a transformation taking place in the nucleus.***
- ***Four types of radiation may be emitted.***
- ***This radiation is energetic and is capable of removing electrons from atoms and so it is called ionizing radiation.***
- ***An atom with a very unstable nucleus has a short half-life.***
- ***Ionizing radiation can cause biological damage in cells and organs. This may cause deterministic effects or stochastic effects on exposed people.***
- ***The dose of radiation is expressed as absorbed dose, in gray, or as effective dose, in sievert.***

QUESTIONS

1 Make a list of three types of ionizing radiation, putting the most penetrating first and so on. If possible, test this by using a radioactive material kit.

2 One hundred atoms of the radionuclide, radon-222, are collected in a sealed bottle. How many radon atoms will be left after one half-life of 3.82 days? And how many will remain after another 3.82 days?

3 Draw a diagram of a cell and name the parts.

4 How can early effects of ionizing radiation exposure be avoided?

5 What delayed effects may result from ionizing radiation exposure and how can they be reduced?

6 The unit of absorbed dose is the gray, defined as 1 joule per kilogram. What energy is absorbed by a person weighing 70 kilograms if a whole-body absorbed dose of 3 gray is received? What would be the effect?

Radiation protection

AIMS

At the end of the lesson the pupil:
- is able to compare the risks of an ionizing radiation dose to other risks at home or in industry
- is able to describe some methods of protection against ionizing radiation from both internal and external sources.

PROPOSED MINIMUM TIME

60 minutes (or 2 x 30 minutes)

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 6: Ionizing radiation protection

TEACHING SUGGESTIONS

0) Preparation:
- you can view the same video tape as in Lesson 2 (Radiation – Types and effects)

1) Give a short introductory talk on the need for radiation protection. Find out what the pupils already know about this subject.
2) You can show the video "Radiation – Types and effects" again. ICRP have now proposed higher risks from radiation exposure than those quoted in the video. Stress that the risks of radiation exposure can be estimated because the effective dose unit, the sievert, is based on risk comparisons. This does not mean that ionizing radiation is the only risk we have to face!
3) Give pupils an opportunity to ask questions.
4) Ask the pupils to read the text "Radiation protection". Get them to read assignments 1 and 2 first so that they can make appropriate notes.
5) Ask the pupils to do the assignments.
6) Discuss the results.

7) Stress the application of the different penetrating properties of ionizing radiation to the protection of people. Discuss the use of radiation absorbers to reduce exposure, e.g. the use of shields on a reactor, the wearing of lead rubber aprons and gloves by a radiologist.
8) Describe the reduction of the radiation dose by 4 when the distance from a small source is doubled (the inverse square law).

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 List the dose limits recommended for various groups. Would you expect these to be different for different types of ionizing radiation? Can you list any other industry in which the risk taken by the workers has to be limited in some way?

No, because the sievert unit applies to all ionizing radiation. All industries control risks to workers.

2 List three ways to protect a person from external sources of ionizing radiation and three ways to protect a person from unsealed radioactive material.

Reduce external dose by reducing exposure time, increasing shielding and increasing distance; reduce internal dose by reducing radioactive contamination on surfaces and in the air, and by using respirators and protective clothing.

3 Compare the methods of protection of a person from ultraviolet light with the protection from external ionizing radiation.

Answer: The table below makes the comparisons

Method of protection	Application to ionizing radiation	Application to ultraviolet radiation
Limit dose received	Work within dose limits and avoid deterministic effects (burns)	Sunbathe gradually and take great care to avoid getting sunburn
Control exposure distance	Use remote handling tongs, protective barriers	Correct positioning of the sun lamp
Limit duration of exposure	Limit working hours	Limit the time in the sun or the time that the sun lamp is switched on
Absorb the radiation	Lead aprons and screens used for protection of radiographers using X-ray equipment	Stay in the shade, use sunglasses and suntanning oils

Because of its biological effects radiation exposure can be harmful. The risks of radiation exposure, wich have been estimated by the International Commission on Radiological Protection (ICRP), are discussed in this lesson. Protective measures against radiation exposure are given special emphasis.

LESSON

Radiation protection

IONIZING RADIATION RISKS

The current official estimates of the ICRP suggest that a person receiving a dose of 1 sievert, similar to that received by the Japanese survivors of the atom bomb, will have an increased chance of eventually dying of cancer from about 25% (the "natural" cancer rate) to about 30%. This is the stochastic or probabilistic risk of a person dying from cancer and the extra risk is about 5% due to a dose of one sievert. At much higher doses received in a short time other effects called deterministic effects will be observed in a short time, a matter of days or weeks. At doses below 1 Sv the main effect is extra cancers which are greatly delayed and in fact would not appear until the exposed person was very old. This would be observed as an average shortening of life by one year, about the same as that caused by smoking 10 cigarettes a day for 30 years. In addition to this life shortening effect we must also take account of other types of delayed cancers which are not fatal as well as the hereditary effects delayed to the next generation and passed on to our children. ICRP state that an adult radiation worker, who by law must not be younger than 18 or older than 65 years, has a risk of fatal cancer of 4 % per sievert, lower than the population as a whole. Each of the other two factors carries an extra risk of around 0.8% for a dose of 1 sievert and so the total detrimental effect is 4 + 0.8 + 0.8 = 5.6% per sievert.

On the other hand, a member of the public can be any age and some will therefore be more sensitive to cancer than the typical worker which is why the risk of fatal cancer is 5%. ICRP believe that the other factors are also higher and these are 1% for non-fatal cancer plus a further 1.3 % for hereditary effects, making a total of 5 + 1 + 1.3 = 7.3% per sievert.

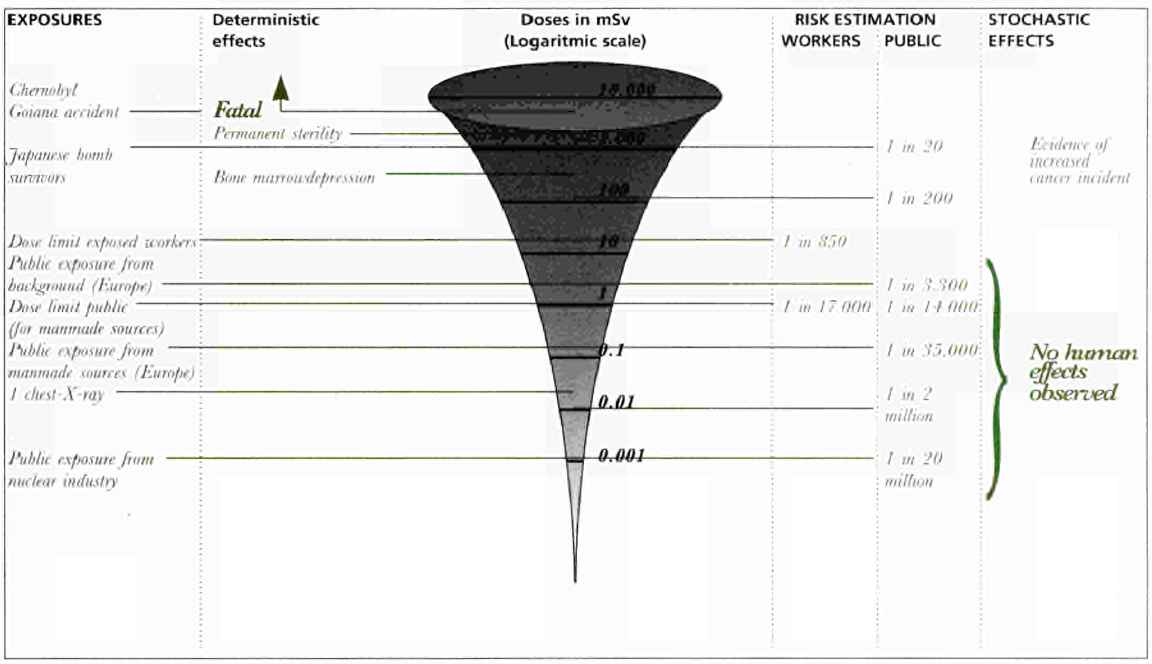
Let us examine an actual case of radiation exposure. Take, for example a worker who receives a dose of 1 mSv every year. In this case the risk to this worker of dying from cancer (at some future date) is increased by 0.004% each year. This represents an extra risk of 1 in 25,000, which is a very small increase in the chance of dying from cancer. At the same annual dose there is also a risk of 0.0008% or 1 in 125,000 of getting a non-fatal cancer and the same increase in the risk of an hereditary effect. All of these chances are small compared to other risks. For example, the additional genetic risk caused by 1 mSv is less than 0.002% of the natural hereditary effects. Putting all these factors together for a dose of 1 mSv, the radiation worker would have an overall risk of 1 in 17,000. This means that in a group of 17,000 workers each receiving 1 mSv, one person might be affected by the radiation.

The higher risk for members of the public means that the same dose gives an overall risk of 1 in 14,000.

These figures can be applied to actual situations such as our exposure to natural and man-made radiation. In Lesson 4 you will see that the typical annual dose in Europe is about 4.2 mSv per year from natural sources of radiation and 0.4 mSv per year from man-made sources. On average this will give a member of the public an increased risk of 1 in 3300 for natural radiation and 1 in 35,000 for man-made; combined together, the overall risk is 1 in 3000 per year.

annual limit of dose

The *annual limit of dose* for a radiation worker is now 20 mSv per year and this brings a risk of 1 in 850 per year, similar to the annual risk of a fatal accident for an offshore fisherman. This is about the same risk per year (of death in that year) from natural causes at age 40. These radiation risks, although they are theoretical and the consequences are long delayed, are considered to be high. Radiation workers are therefore encouraged to keep their annual doses low. We now find that the average dose is about 2 mSv per year and the risks per year have fallen to a more tolerable level of 1 in 8,500.



Comparison of risks from radiation

three principles to protect people from ionizing radiation

RADIATION PROTECTION

The International Commission on Radiological Protection has recommended *three principles* which may be applied *to protect people from ionizing radiation*. These are:

1. Any practice involving radiation exposure must be justified by showing that the benefits received outweigh the damage caused.

2. For any source of ionizing radiation used in a practice the exposures must be kept "As Low As Reasonably Achievable", social and economic factors being taken into account. This is called the ALARA principle.

3. In normal circumstances individual exposures are subject to dose limits so that no individual is exposed to unacceptable risks.

We cannot feel, see, hear or touch ionizing radiation and so all sources of ionizing radiation including radioactive sources and X-ray machines and all places where ionizing radiation is used are marked with warning signs using the international three-bladed symbol.

The international trefoil symbol

IONIZING RADIATION DETECTION

film badge

We use special devices to detect ionizing radiation. Using the principle originally applied by Roentgen, we can detect ionizing radiation on a photographic film. For this purpose we use a *film badge*. This is a special film in a paper cover to keep out light similar to the film used by dentists. This film is carried in a special badge, the film badge. The developed film shows a blackening proportional to the dose.

Geiger-Müller

We can also use the *Geiger-Müller tube*, a device invented by Geiger in 1928. This device consists of a glass or metal tube containing a gas at low pressure and two electrodes. Ionizing radiation releases electrical charges in the gas, producing an electrical pulse. A meter or speaker connected through an amplifier will register a "count" or an audible click. The number of pulses or clicks records the dose while the rate of pulses or clicks gives the dose rate. Part of the tube is very thin to allow beta radiation to enter.

Radiation detectors

IONIZING RADIATION PROTECTION RULES

Special rules

Special rules are used to protect both workers and the public:

- Entry to places where ionizing radiation can be present is prevented unless the person is appointed as a radiation worker or has special authority.
- The radiation worker must have regular health checks and must carry a radiation measuring device so that the total exposure can be recorded and compared with the legal limit. This limit, based on the Recommendations of the ICRP, is 50 mSv in one year, but in view of the risk factors mentioned above the ICRP propose that the total should not exceed 100 mSv in five years. Most workers receive much lower doses.

- Members of the public would not normally enter these controlled places but some ionizing radiation exposure will occur when they are near to radioactive sources during a visit to a factory or to a hospital. They also must not exceed radiation dose limits. These are set at 1 mSv per year, which is lower than those for radiation workers. However, the ionizing radiation received by a person who is a patient in hospital is not controlled in this way since it is an inevitable part of that person's treatment.

The method of protection depends on the nature of the radioactive source. It may be sealed and produce an external dose, or it may be unsealed and can get into the body and produce an internal dose.

PROTECTION FROM SEALED SOURCES

Sealed ionizing radiation sources can be used safely if these methods of protection are used:

1. Exposure time
   The radiation exposure stops when the source is removed and so by limiting the time spent near to the source the dose can be kept low. The dose received is calculated by multiplying the time that the person is exposed by the dose rate (quantity of dose received in unit time). A short exposure will help to keep the dose low.

2. Distance from the source
   If the dose rate near to the source is too high the person using the source must move away. The dose rate drops as the distance from the source is increased. This is because the ionizing radiation from a small point has to spread over an area which is four times greater when the distance from the point is doubled.

3. Shielding the radiation
   Some kinds of ionizing radiation, like beta radiation and alpha radiation, are very easily absorbed in thin pieces of paper or plastic. Gamma radiation and neutrons are very penetrating and a nuclear reactor will need a concrete wall several metres thick to absorb the radiation coming from the core.

PROTECTION FROM UNSEALED SOURCES

Unsealed sources of radioactive material are difficult to use because the radioactive material may be ingested or inhaled by the user and become an internal source of ionizing radiation exposure. The following methods of protection are used:

Wherever possible unsealed radioactive sources are kept and used in containers which prevent the radioactive material from escaping. If the source cannot be contained the person working with it must be protected against the following:

- inhalation of the radioactive material
- ingestion of the radioactive material
- absorption of the radioactive material through the skin

Radiation workers wear protective clothing and breathing masks which keep out the radioactive material. The working area must be specially equipped with means of measuring the unsealed radioactive material. It must also be clean and have strict rules to prohibit eating, drinking and smoking in the area. People and equipment leaving the area must be checked for radioactive material and a special way of crossing the barrier has been evolved. In addition, special medical checks are made to ensure that radioactive material has not been taken into the body of any worker.

PROTECTION FROM ULTRAVIOLET LIGHT (COMPARISON OF METHODS OF PROTECTION)

The methods of protection used against ultraviolet light are similar to those used for ionizing radiation and are set out here so that a comparison may be made.

Exposure of the skin to ultraviolet light from the sun can produce both early and delayed effects and protection is necessary to avoid injury. If we expose our skin for several hours to strong sunlight, the skin will become red and burns and blisters may appear in a few hours. Increase in the exposure of the skin therefore produces early effects which increase in severity if the sun is stronger. If a burn is produced there is also an increase in the probability of skin cancer, a disease which is sometimes fatal. The same amount of exposure spread over several days does not usually cause early effects because the skin cells can recover. In addition to the reduction of the duration of exposure we can protect ourselves by staying in the shade, by covering our skin with clothing and by using suntanning oils. We can protect our eyes with hats and sunglasses. Artificial sources of ultraviolet light such as sun lamps are often very small in physical size and the intensity of the light increases very rapidly close to the lamp. The distance of the skin from the lamp must be carefully controlled, the duration of the exposure limited, and it is very important to prevent eye exposure with the use of goggles.

KEY POINTS

- ***The risks of ionizing radiation exposure have been estimated and are not detectable in the population.***
- ***The annual risks for radiation workers could be as high as those of an offshore fisherman but ionizing radiation doses are kept very low in practice.***
- ***Ionizing radiation detectors and warning signs are important for safety.***
- ***There are practical methods for working safely with both sealed and unsealed sources of radioactive material.***

QUESTIONS

1 List the dose limits recommended for various groups. Would you expect these to be different for different types of ionizing radiation? Can you list any other industry in which the risk taken by the workers has to be limited in some way?

2 List three ways to protect a person from external sources of ionizing radiation and three ways to protect a person from unsealed radioactive material.

3 Compare the methods of protection of a person from ultraviolet light with the protection from external ionizing radiation.

Everyday ionizing radiation

AIMS

At the end of the lesson the pupil:

- knows that the earth has always been radioactive and that natural ionizing radiation is all around us
- knows that the annual average effective dose to the population of Europe is mainly from natural sources of ionizing radiation (over 80%) and the remainder is from man-made ionizing radiation
- is able to name some sources of natural and man-made radiation
- knows how to reduce the effective dose from radon.

PROPOSED MINIMUM TIME

60 minutes (or 2 x 30 minutes)

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 8: Doses from ionizing radiation

TEACHING SUGGESTIONS

0) Preparation:

- find a map of the natural ionizing radiation dose rates in your country
- obtain some biographical data about the Nobel Prize winner George de Hevesy. In short the story is as follows:
  George de Hevesy was a young research assistant working in Manchester on natural radioactive material in 1911. He lived in modest accommodation and took his meals with his landlady. The food was often the same and he suspected that certain dishes which appeared regularly were left over from earlier in the week. He put a trace of radioactive material into the leftovers on his plate. Several days later when the same dish appeared he used his ionizing radiation detector and found that the food was radioactive. It had been served before! His landlady thought he was using magic and told him to leave. He was the first to use radioactive tracers in biology research and was awarded the Nobel Prize in 1943.

1) Introduce the subject by showing the country map of natural radiation. Ask the pupils how the dose rate of an individual may be changed by moving house to a different part of the country.

2) Divide the class into small groups and ask each group to tackle one of the four assignments/questions. Each group must read the text carefully to find the right answer.

3) Discuss what the pupils have found out. Ask them to exchange the information gathered from the text. Taking the last table in the lesson as a starting point, discuss the points covered in assignment 1.

4) In connection with the last assignment you can tell the story of George de Hevesy.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 What is the difference between natural and man-made ionizing radiation?

In most cases the types of radionuclides are different, but the range of dose rates is similar. The effects on living creatures are the same. Radiation protection standards are different because natural radiation was already there before radiation protection was considered but man-made radiation is created deliberately and so radiation protection can be arranged before it is used.

2 Name the three most important sources of natural ionizing radiation. Suggest a way to reduce the annual dose from these sources.

Radon-222, radiation from the ground and cosmic radiation. The radon-222 dose can be reduced by ventilation; the dose from the ground is highest on granite so you could move away from such areas; and cosmic radiation is reduced if you move house to lower altitudes.

3 What is the annual radiation dose received by a member of an aircrew who makes 100 flights of 5000 km each per year?

3 mSv.

4 If the aircraft quoted in this lesson flies at 650 km per hour, what is the dose rate in the aircraft?

0.004 mSv per hour.

5 Using the information about potassium-40, calculate the amount of potassium in milk and in peanuts. (This is the same method as is used with radioactive tracers to estimate concentrations of other elements).

The potassium content of milk is 1.45 grams per litre and the potassium content of peanuts is 5.8 grams per kilogram.

You have already learned that more than 80% of the annual effective dose to the population of Europe comes from natural sources of ionizing radiation. To describe this radiation exposure we have to talk about small quantities of effective dose and we will use one thousandth of a sievert, which is 1 millisievert (symbol mSv), and one millionth of a sievert, the microsievert (symbol µSv). In this lesson we will use the word "dose" to mean effective dose.

LESSON 4

Everyday ionizing radiation

annual dose

The *annual dose*, which is a dose rate, is usually expressed in mSv per year. The unit of activity is the becquerel (symbol Bq) and we will use Bq per cubic metre and Bq per kilogram to express the concentration of radionuclides in materials.

The table at the end of this lesson is a summary of the annual doses which we receive from natural and man-made ionizing radiation.

Natural ionizing radiation

COSMIC RADIATION

The dose rates from cosmic radiation increase as we climb to high altitudes because we lose the shielding effect of the earth's atmosphere. The passengers and crew of an aeroplane will receive a dose of 0.03 mSv during a 5000 kilometre jet flight, about 10% of this dose being due to neutrons. The dose rate to persons living above sea level increases by 0.03 mSv per year for each 1000 m increase in altitude.

Persons living further north receive more cosmic radiation than those in the south. For example, a person living in Scotland has a 20% higher dose rate from cosmic radiation than a person living in Greece.

GROUND RADIATION

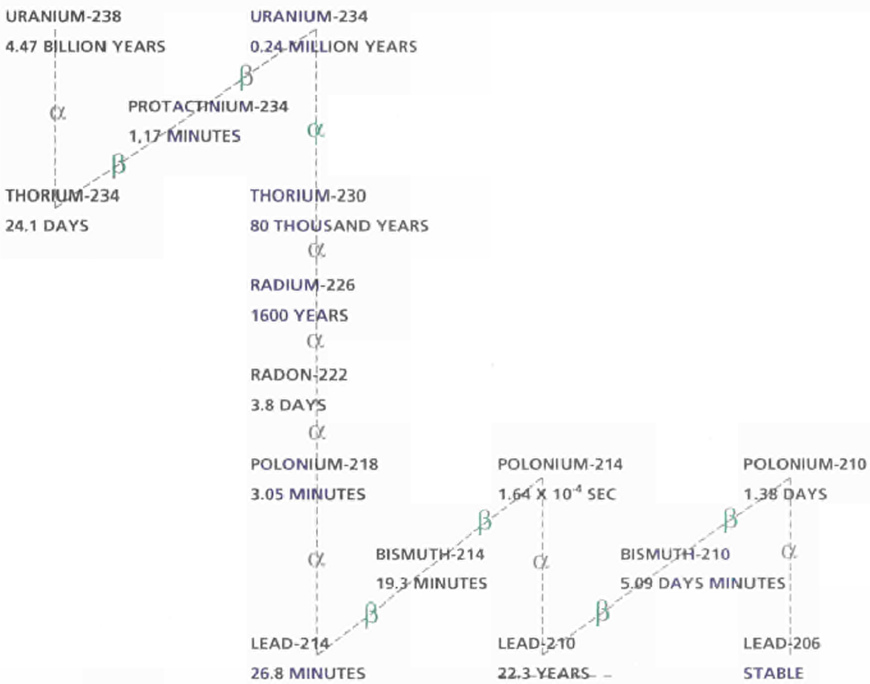
The gamma radiation coming from the rocks below the surface of the earth gives a person living on that part of the earth a dose rate which can be as high as 10 mSv/year. The dose rate is at its highest over igneous rocks and is least over sedimentary rocks. In addition, granite buildings give higher doses to the occupants than wood buildings.

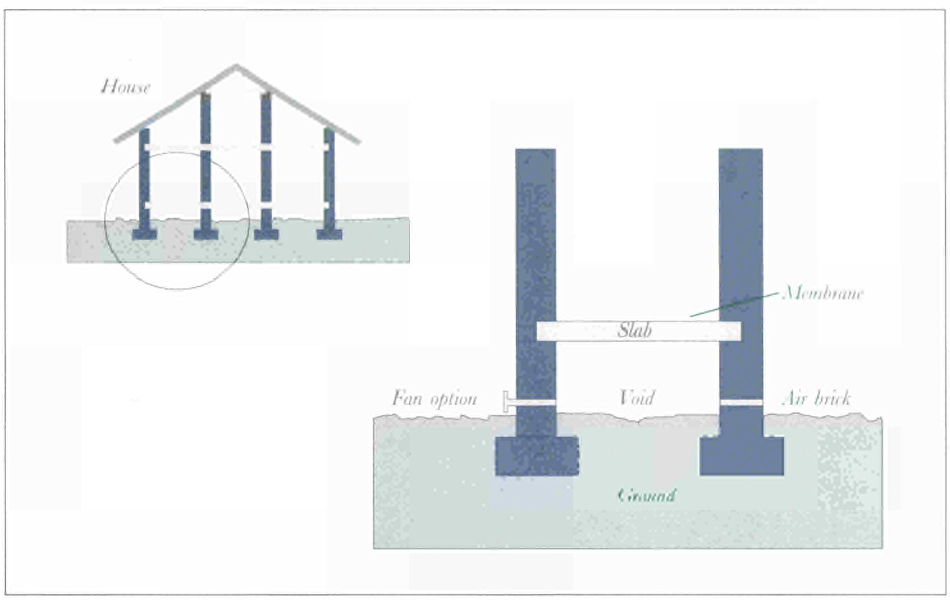
RADON

The radioactive gas, radon-222, is responsible for the most important fraction of our dose rate. The concentration of the radon in indoor air is between 20 and 400 Bq per cubic metre and the dose rate due to breathing this air is about 1 to 20 mSv per year.

The radon-222 gas enters our houses from the ground below and, as shown in Figure 13, decays to radioactive daughters which are short half-life radionuclides emitting alpha radiation. Our lungs retain some of these radionuclides and we receive a radiation dose as they decay in our lungs. Radon-222 concentrations vary throughout the day and are at their lowest when doors and windows are open so that the house is well ventilated. Thus we can reduce the radon concentration in our houses by increasing the ventilation rate. Houses which have concentrations of radon-222 exceeding 400 Bq per cubic metre should be protected against radon entry by sealing the floor or by extracting air from below the floor, as shown in the following scheme. Some types of air cleaners will remove the radioactive daughters.

The radon family tree





A house protected against radon

INTERNAL SOURCES OF IONIZING RADIATION

Practically all food contains potassium and part of this is naturally radioactive due to the presence of the natural radionuclide potassium-40. There is about 50 Bq of potassium-40 in a litre of milk and 200 Bq in a kilogram of peanuts. We are what we eat and so every adult contains about 145 grams of potassium, which includes 5000 Bq of potassium-40. This is an internal source of natural ionizing radiation which we cannot escape since potassium is an essential element in our food. However, we retain no more potassium than we need.

Uranium and its family, including the important radionuclide radium, is found in most rocks and soils and in sea water. Some natural water supplies contain radium at an activity concentration of 10 Bq per litre and some nuts have over 100 Bq per kilogram.

The atmosphere contains the natural radionuclide carbon-14, which is produced by the action of cosmic radiation on the atmosphere, and there is about 200 Bq per kilogram in all carbon. This gives an average dose of 12μSv per year.

MAN-MADE IONIZING RADIATION

We shall hear about the medical uses of ionizing radiation in the next lesson but you will see that the dose from this is included in the table at the end of this lesson. The table gives the range of dose rates received in Europe from X-rays and other man-made sources of ionizing radiation. Medical X-rays are the second highest contributor.

Some small doses are of interest because they are a part of environmental pollution. Atmospheric tests of atom bombs stopped in 1980 and so the annual dose rate from fall-out is now fairly low. Discharges of radioactive waste arising from nuclear power are responsible for about 0.001 mSv per year and the radioactive material released by coal burning contributes about 0.2 μSv per year.

Several household appliances emit ionizing radiation. For example, a smoke detector in your room will give you a dose rate of 0.01 μSv per year. Television sets emit a small amount of X-rays and the average dose rate we receive is about 0.004 μSv per year.

TYPICAL ANNUAL DOSE TO INDIVIDUALS IN EUROPE

The information used in this table is taken from "Radiation Atlas: Natural Sources of Ionizing Radiation in Europe" (EUR 14490) by B M R Green, J S Hughes and P R Lomas NRPB Chilton, Didcot, Oxon, prepared for the Directorate-General for the Environment, Nuclear Safety and Civil Protection, Commission of the European Communities, Luxembourg.

human exposure

The atlas shows that *human exposure* is variable and is strongly affected by radon concentrations. Annual doses and their percentage contribution are estimated for two cases:
(a) individual in a low radon area, typical of the UK (this dose pattern is similar to the world average), and (b) an individual living in a higher radon area in Europe (this dose pattern is similar to the European average).

Table of annual doses

TYPE	NATURE	EXTERNAL	INTERNAL	(A) LOW RADON AREA mSv/Y	%	(B) AVERAGE RADON AREA mSv/Y	%
				DOSES IN mSv PER YEAR			
NATURAL	RADON (1 – 400 Bq/m^3)		1 to 20	1	38	3	65
	THORON (fairly constant)		0.15	0.15	6	0.15	3
	FOOD (fairly constant)		0.35	0.35	13	0.35	8
	GAMMA (indoors and outdoors)	0.18 to 0.5		0.4	16	0.4	9
	COSMIC (changes with altitude)	0.26 to 0.32		0.29	11	0.29	6
	TOTAL NATURAL			2.2	84	4.2	91
MAN-MADE	MEDICAL (mainly X-rays, nuclear medicine)	0.33	0.03	0.36	15	0.36	8
	MISCELLANEOUS Discharges: nuclear- 0.001 coal- 0.0002 Air travel, TV etc: 0.01 Fall- out from bomb tests: 0.01 Work exposure: 0.008	0.018	0.011	0.03	< 1	0.03	< 1
	TOTAL MAN- MADE			0.39	16	0.39	9
TOTAL				2.6	100	4.6	100

The radiation doses received by those who work with radiation are mostly from external sources. When calculated as an average over the whole population they are very small because the radiation workers are a small proportion of the population and their doses are strictly controlled.

KEY POINTS

At least 80% of the annual average dose of ionizing radiation to the population of Europe comes from natural sources.

The natural sources are radon (together with a fairly constant amount of thoron), natural radioactive material in our bodies including food, gamma radiation from buildings and the earth, cosmic radiation from the sun and outer space.

Man-made ionizing radiation includes medical radiation and the internal dose due to nuclear medicine. A very small but interesting radiation dose is due to fall-out from bomb tests, nuclear discharges and radioactive discharges from coal power stations, work exposure and various miscellaneous sources such as air travel and exposure to X-rays emitted from TV sets. The radiation doses from work exposures are mainly external and are very small when averaged over the whole population because radiation workers are a small proportion of the population.

QUESTIONS

1 What is the difference between natural and man-made ionizing radiation?

2 Name the three most important sources of natural ionizing radiation.
Suggest a way to reduce the annual dose from these sources.

3 What is the annual radiation dose received by a member of an aircrew who makes 100 flights of 5000 km each per year?

4 If the aircraft quoted in this lesson flies at 650 km per hour, what is the dose rate in the aircraft?

5 Using the information about potassium-40, calculate the amount of potassium in milk and in peanuts. (This is the same method as is used with radioactive tracers to estimate concentrations of other elements).

Medical and dental applications

AIMS

At the end of the lesson the pupil:
- is aware that radiation is used for the benefit of our health in medical diagnosis, in nuclear medicine and in radiotherapy
- is able to name two applications of ionizing radiation in medical diagnosis
- is able to name two applications of ionizing radiation in radiotherapy.

PROPOSED MINIMUM TIME

45 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 7: Applications of ionizing radiation and radioactivity.

TEACHING SUGGESTIONS

0) Preparation:
- obtain some audio-visual material, especially an X-ray photograph or a video of a nuclear medicine investigation.

1) Show an X-ray photograph (see also Figure 14) or a video of a nuclear medicine investigation. Encourage a discussion about the experience of the pupils or their families with the medical applications of ionizing radiation.

2) Give pupils the first assignment. Make it clear that they must set out the answers in two columns: diagnosis and radiotherapy (see the answers below). Pupils must look for the answers by reading the text.

3) Tackle assignments 2 and 3 in a class discussion.

4) It would be instructive if the class could make a visit to a hospital X-ray or nuclear medicine department. Prepare for the visit by, for example, collecting questions from the pupils about the medical applications of radiation.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Make a list of the sources of ionizing radiation used for diagnosis and another list of those used for radiotherapy.

Diagnosis	Radiotherapy
X-ray machine	X-ray machine
technetium-99m	cobalt-60
	radium-226
	iridium-192
	iodine-131

2 In radiotherapy ionizing radiation is used to cure cancer. How is it possible that more cancer is not caused by the ionizing radiation?

The tumour cells are killed and the dose to other organs is kept as low as possible by using shields to direct the beam of rays. The risk that the patient can develop another cancer is very small.

3 Why is it important to protect the doctor and the nurse when ionizing radiation is used for diagnosis or for treatment of a patient?

The doctor and nurse work with ionizing radiation every day and so must keep their own radiation exposure as low as possible to limit their annual dose rate.

Radiation has a number of useful applications. An important example is the use of radiation in medical diagnosis and treatment. The text tells you more about this type of application as used by doctors and dentists.

5 LESSON

Medical and dental applications

Roentgen

X-rays

Wilhelm *Roentgen* discovered X-rays in 1895 and he recognised their ability to penetrate the human body. The *X-rays* which he produced are strongly absorbed by the bones and so a photographic plate exposed to the emerging rays shows a shadow of the bones which gives a picture of their shape and position in the body. Since then better equipment has been invented which can show other organs of the body in great detail. Radioactive materials are now used to study the way in which our bodies work and ionizing radiation is used in radiotherapy to treat cancer. In summary, there are *two main applications of ionizing radiation* in medicine: diagnosis and radiotherapy.

two main applications of ionizing radiation

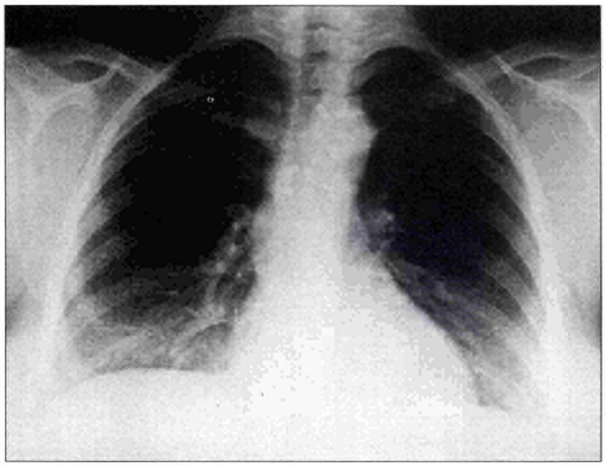
Diagnosis

X-RAYS

More than half of the X-rays taken are for dental purposes and are used to help the dentist to repair and improve our teeth and to examine abscesses or injuries. Each intra-oral dental X-ray gives the patient a dose of about 0.02 mSv. Most people have had a chest X-ray which enables the doctor to look for possible disease of the lungs and heart. The patient receives a dose of about 0.05 mSv for each chest X-ray and a similar dose is received for each X-ray of a limb. The X-ray machines have been specially designed to ensure that the radiation doses are as low as possible for these frequent examinations.

CONTRAST MEDIA

The stomach or intestine can be filled with a meal of material such as barium, which absorbs X-rays, and these organs can be examined by the doctor through a fluoroscopic screen. The dose to the patient is about 3 mSv.



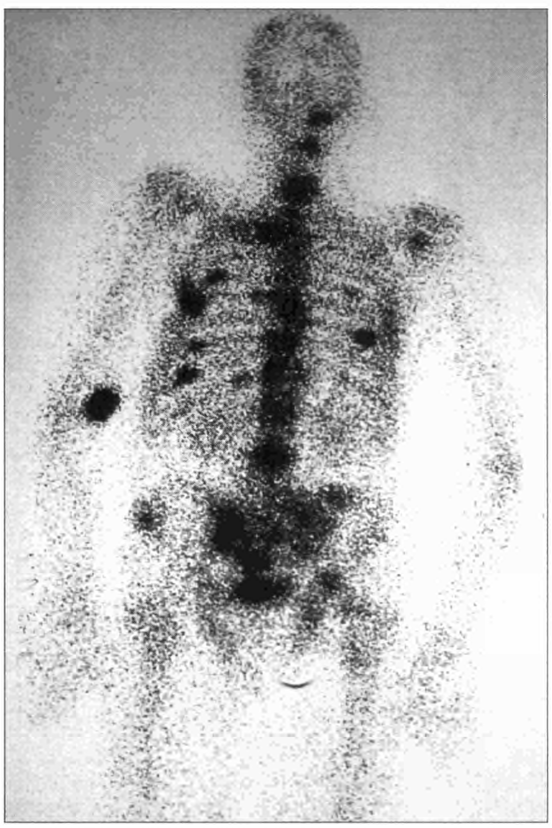
Chest X-ray picture

BODY SCANNER (COMPUTERISED TOMOGRAPHY)

New methods of diagnosis are now possible through the use of X-ray body scanners which record a cross-sectional view of the body, giving a very clear image of the organs and soft tissues. The radiation dose to the patient from this examination is about 3 mSv for a headscan. This method has saved many lives due to its use in investigating head injuries and in the diagnosis of cancer.

NUCLEAR MEDICINE

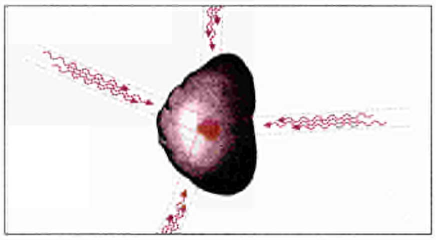
A radioactive substance is injected as a tracer and an image of the organ in which it concentrates can be produced by using ionizing radiation detectors; the movement of the material through the body can be followed and the position of tumours can be found. One of the most suitable materials is technetium-99m, which is used for brain, bone or liver examinations. Technetium-99m, for example, decays quickly with a half-life of 6 hours and the dose to the patient lies between 1 and 5 mSv.



Gamma scan

RADIOTHERAPY

Ionizing radiation is used to help a patient who has cancer by destroying the cancer tumour without undue risk to the patient. The tumour is exposed to large and concentrated doses from external and internal sources of radioactive material. The cells which form a tumour are abnormal and divide very rapidly. They are therefore very sensitive to chromosome damage and are more likely to be killed by ionizing radiation than normal cells. It is very important to give the tumour the correct amount of radiation dose, which will be about 50 gray, and to give surrounding tissue as little dose as possible. The ionizing radiation is delivered at a high dose rate, and if the source is external to the body the radiation is directed in a beam from different angles to reduce the damage to surrounding tissue.



Gamma radiotherapy

The following sources of ionizing radiation are used:

X-RAY MACHINES AND ACCELERATORS

The radiation from an X-ray tube may be produced at various energies so that the penetrating power of the ionizing radiation may be adjusted to the depth of the tumour. X-ray machines will work at up to 250,000 volts. Higher voltages have to be produced in a linear accelerator, which builds up the energy in stages and can reach energies of up to 20 million volts.

COBALT RADIOTHERAPY

This makes use of cobalt-60 in very compact sealed sources, about 1 cm wide, which contain sufficient radioactive material to give dose rates of 1 gray per minute at the tumour.

CURIE RADIOTHERAPY

This uses beta and gamma radiation from isotopes which can be inserted as internal sources and sometimes used as external sources. The aim is to put the source close to the tumour so that lower doses are received in the rest of the body. Originally, radium-226 was used in the form of leak-proof tubes or needles, sometimes sealed in gold, and these were inserted into the patient with special equipment which also provided protection for the operator. Radium has now been replaced by caesium-137. When protection is difficult, it is possible to use iridium-192, which emits a less energetic gamma ray and can be more readily shielded.

NUCLEAR MEDICINE THERAPY

Certain radioisotopes may be injected into the bloodstream of the patient and the treatment depends on the ability of the body to concentrate the isotope in the tumour. This works well for thyroid tumours into which iodine-131 is concentrated. Iodine-131 is a fission product which is produced in nuclear reactors.

KEY POINTS

- ***Ionizing radiation is used in medical diagnosis and radiotherapy.***
- ***Medical diagnosis uses X-rays with film, fluoroscopy or body scanners to examine internal organs. Some nuclear medicine examinations use radionuclides injected into the body.***
- ***In radiotherapy, tumours are destroyed by ionizing radiation from X-ray machines, accelerators or radionuclides.***

QUESTIONS

1 Make a list of the sources of ionizing radiation used for diagnosis and another list of those used for radiotherapy.

2 In radiotherapy ionizing radiation is used to cure cancer. How is it possible that more cancer is not caused by the ionizing radiation?

3 Why is it important to protect the doctor and the nurse when ionizing radiation is used for diagnosis or for treatment of a patient?

Other applications

AIMS

At the end of the lesson the pupil:
- is able to name three areas of application of ionizing radiation
- is able to name at least two applications in each area
- can make a model or a labelled sketch of an application
- can explain the reason for using radiation in an application.

PROPOSED MINIMUM TIME

50 minutes

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 7: Applications of ionizing radiation and radioactivity.

TEACHING SUGGESTIONS

0) Preparation:
- obtain a copy of a film about an application of radioisotopes or on radioactive waste disposal (available from nuclear power companies)

1) Refer to Lesson 5 and the medical applications of ionizing radiation. Ask the students if they also know some non-medical applications. Ask them to make a list of applications of radiation which they have seen or read about in newspapers and magazines.

2) Tell pupils to read the text and then make a display or design a leaflet about the applications of radiation.
The following headings could be used:
   1) Industrial
      a) power
      b) radiography
      c) testing
      d) activation analysis
      e) processing
      f) food irradiation

2) Research
   g) carbon dating
   h) tracers
3) Domestic
   i) smoke detectors
   j) luminous dials
4) Military
   k) atomic bombs

Also tell the pupils to write some keywords after each example.

3) Check the results and show the film.

4) Tackle the two assignments in a class discussion.

5) If possible, arrange a visit to an industrial or research laboratory which is using radionuclides.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Make a list of applications of ionizing radiation which you have seen or read about in newspapers and magazines. Discuss the advantages and disadvantages of these applications.

2 Make a display or design a leaflet about the applications of ionizing radiation.

3 Why does food not become radioactive when it is made safe for consumption by irradiation?
Food irradiation is carried out using gamma radiation which does not create radioactive material in the food.

4 Many people would object to the construction of a radioactive waste disposal facility near their homes. Discuss the reasons for this objection.

The main non-medical areas of the application of ionizing radiation and radioactive material are:

a) industrial, for electricity production and testing.
b) research, in universities and research centres.
c) domestic, for appliances.
d) military, for submarines and weapons.

In all of these applications the radioactive material has to be delivered and removed safely and, if it has not decayed already, it must eventually be sent for disposal as radioactive waste.

LESSON

Other applications

INDUSTRIAL

POWER

The nuclear fission process

The nuclear fission process is the source of the heat which is used to make steam in a nuclear power reactor. The steam is fed to a turbogenerator to make electricity just as in other types of power station. But the process in a nuclear power station is very different from combustion of fuel in a normal power station. Neutrons are essential to start the fission process in which uranium is consumed. More neutrons are released in the fission process and so more uranium can be consumed to keep the process going but the fission products are radioactive and become radioactive waste. On the other hand, this process does not burn coal or oil and consequently does not need an oxygen supply. Carbon dioxide is not released into the atmosphere. Nuclear power will be described in Lesson 7.

RADIOGRAPHY

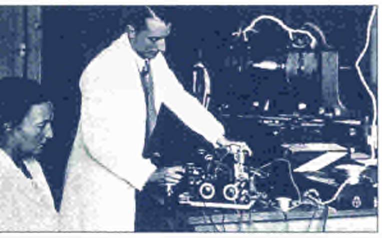
The use of radiation for radiography in industry is based on the same scientific principles as those used in medical X-rays. The engineer uses ionizing radiation to look for flaws in the pieces of metal used to build ships, bridges, aircraft and other structures where a break could be very dangerous. X-rays of the same kind as those used in medical diagnosis are suitable when the pieces are thin but higher energy X-rays can be produced by means of accelerators. Gamma sources similar to those used for radiotherapy are required when the metal is more than 50 centimetres thick.

TESTING

Gamma radiation from a radioactive source can be used by an engineer to "see" through the walls of pipes and containers to detect changes in thickness of the walls and changes in the fluid inside the walls. The amount of ionizing radiation passing through the wall or the tank indicates the thickness of the wall or the amount of fluid in the tank.

Joliot and Curie

ACTIVATION ANALYSIS



Juliot and Curie

In 1934 *Joliot and Curie* discovered that neutrons can make things radioactive. Engineers had to wait until nuclear reactors were perfected before a sufficient quantity of neutrons could be produced to make this a useful method of testing. As little as one part of iron in a million parts of sand can be detected by measuring the radioactive material induced in the iron after the mixture has been bombarded by neutrons.

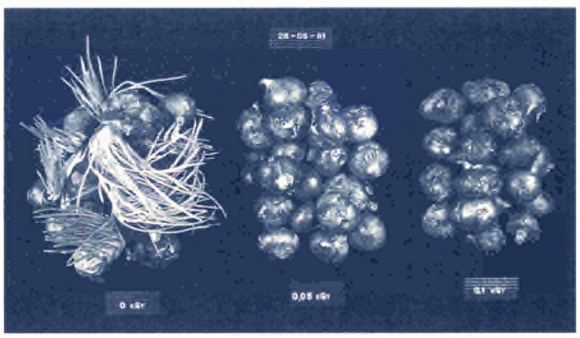
PROCESSING

Some chemicals, especially plastics, can be manufactured with the aid of gamma radiation. Very large cobalt-60 sources are needed for this process, in which the raw material is irradiated. Another example is the irradiation of medical supplies to make them sterile is designed to ensure that no more than 1 viable microorganism will survive in a million items of medical equipment and there will be no damage to the medical equipment, bandages and dressings. Microorganisms include bacteria, yeasts, moulds, spores and other related organisms. It is very likely that any visit you make to hospital for treatment will involve the use of radiation-sterilised dressings. You will see no damage to the dressing because ionizing radiation attacks only the living bacteria.

Gamma radiation

FOOD IRRADIATION

Gamma radiation is used to decontaminate food which does NOT become radioactive and the consumer is not exposed to any radiation. The food is made safe for consumption by the elimination of microorganisms such as salmonella, campylobacter, listeria etc. Irradiation also delays the sprouting of potatoes and other tubers like onions and garlic and is also used to extend the shelf life of other vegetables and fruits. However, people are wary of this use of ionizing radiation on food although it would help to avoid considerable waste, which is important for those people in the world who are short of food!



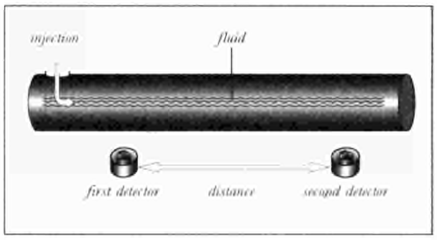
Food irradiation

TRACERS

Radioactive material is a property of the nucleus of an atom and chemical properties are only affected by the outer electrons. A radionuclide behaves just like a normal atom until the moment that it disintegrates and emits ionizing radiation. It can then be detected. This property is used to trace the movements of materials in extraordinary places such as the centre of a blast furnace, the rubber on a tyre of a car, the metal inside a bearing and the movement of oil in a pipeline buried underground.

Wall thickness inspection

If a pipeline should leak, a small quantity of radioactive tracer can be added to the oil and this will come out through the leak and remain in the ground. The ionizing radiation from this can be detected from above ground or even from inside the pipe itself.



Tracer method for flow measurement

RESEARCH

CARBON DATING

Very sensitive equipment can measure the amount of the naturally radioactive carbon-14 in organic material. When alive all animals and plants have the same concentration as in the air. When they die the carbon is not replaced from the air and so the level to which the carbon-14 content falls gives a good indication of the time since the organism died.

TRACERS

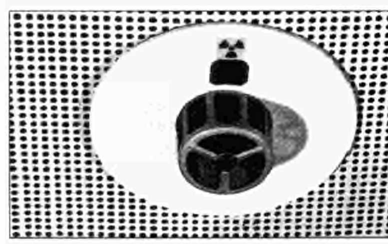
Much of our modern knowledge of biology is due to the use of "labels" of radioactive atoms which can be inserted in molecules such as DNA. The part that the molecule plays in life can be followed.

DOMESTIC

A number of domestic appliances and other items in the home contain radioactive material.

SMOKE DETECTORS

These are life-saving devices which use a radiation detector and a radioactive source, americium-241, which has a 432-year half-life. Smoke particles in the air interfere with the radiation detector and the smoke detector alarm is switched on.



Smoke detector

LUMINOUS DIALS

When radium was discovered the scientists were able to detect it because the ionizing radiation caused certain materials known as phosphors to emit a flash of light. This was applied in clocks and watches in which the hands were painted with radium mixed with the phosphor so that they glowed in the dark. Unfortunately too much radioactive material had to be used and the people who painted the dials ingested the radium and were poisoned. In its place we now use tritium which makes the phosphor glow; the *beta radiation* is easily shielded and so the tritium can be used safely.

beta radiation

MILITARY APPLICATIONS

ATOMIC BOMBS

Two atomic bombs have been used in war and they were detonated in 1945 over Hiroshima and Nagasaki. Tremendous damage to life and property was caused by the vast explosive power. Some of the survivors from the effects of the explosion received radiation doses of around 1 gray (approximately equal to 1 sievert) and 47 years later more than half of them are still alive. They have been found to have about a 10% higher cancer risk than other Japanese people.
Atomic bomb tests in the 1960's were carried out in remote places but they released fall-out around the world and in lesson 4 we saw that a small amount is still present.

Explosion atomic bomb

NUCLEAR SUBMARINES

These are propelled by the power produced in a nuclear reactor. This does not require a supply of air like oil or coal-fired engines and is usually of the pressurised water type similar to those used on land for electricity production.

SERVICES

TRANSPORT

The transport of radioactive materials is strictly controlled in accordance with regulations drawn up by the *International Atomic Energy Agency*. Special packages are used according to the type and quantity of radioactive material. The higher quantities carry the trefoil label. Spent uranium fuel on its way to reprocessing is carried in flasks on special vehicles. These flasks are of a type tested by dropping and by immersion in a fire to ensure that they remain sealed in case of an accident. IAEA rules also apply to the transport of other smaller sources for use in hospitals and industry.

International Atomic Energy Agency

WASTE DISPOSAL

The disposal of radioactive waste is also controlled by strict regulations. All radioactive material from hospitals, factories and even quantities of old luminous dial wrist watches must be disposed of safely. The fission products from nuclear fission represent the major part of the radioactive material for disposal.

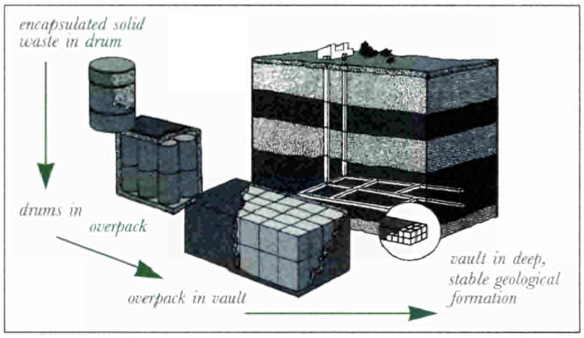
There are three *categories of radioactive waste*:

categories of radioactive waste

1. Low level waste is radioactive material with a short half-life which is produced in large volumes in the nuclear power programme and is buried in metal drums in approved places. About one third of the annual total is produced by hospitals and industry.

2. Intermediate level waste has to be sealed in concrete and stored.

3. High level waste will be converted to a glass for permanent disposal.



Multi-barrier protection of radioactive waste

KEY POINTS

- ***The main areas of application of ionizing radiation and radioactive material are medical, industrial, research, domestic and military.***
- ***Examples of applications are given for each area.***
- ***Food which has been made safe for consumption by irradiation with gamma radiation does not become radioactive and the consumer is not exposed to any ionizing radiation.***

QUESTIONS

1 Make a list of applications of ionizing radiation which you have seen or read about in newspapers and magazines, discuss the advantages and disadvantages of these applications.

2 Make a display or design a leaflet about the applications of radiation.

3 Many people would object to the construction of a radioactive waste disposal facility near their homes. Discuss the reasons for this objection.

The atom and nuclear power

AIMS

At the end of the lesson the pupil:

- is able to explain in a simplified way the structure of the atom
- is able to describe the fission process
- is able to name three types of nuclear power station
- is able to explain in a simplified way how a pressurised water reactor works.

PROPOSED MINIMUM TIME

60 minutes (or 2 x 30 minutes)

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 2: The structure of the atom

TEACHING SUGGESTIONS

0) Preparation:
- Try to get hold of some audiovisual material to show how a nuclear reactor works.

1) Start the lesson with a discussion on the importance of electricity in our lives. Ask the pupils to count the number of electric motors they have at home (e.g. fans, pumps etc). Question 3 could be tackled at this point.

2) Explain the structure of an atom on the basis of the first part of the text. Refer to Figures 19 and 20. Deal with question 1.

3) Ask the pupils to read the second part of the text (Uranium – the fuel for a nuclear power station).

4) Ask the pupils to write down or say in their own words how a pressurised water reactor works (see question 2).

5) Get the pupils to answer questions 4 and 5.

6) The government of a European country wants to build a new nuclear power station. The main problem is finding a suitable location. The site which the government has in mind is opposed by the local people. Arrange a role play in which the government and the local people are opponents: some pupils represent the government, others represent the local people. Give the pupils time to work out their arguments before they start. After the role play ask the rest of the class to decide which side has used the most convincing arguments.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Why is it that a radionuclide with an excess of neutrons in its nucleus emits a beta particle but no neutron?

When a beta particle is emitted the neutron is transformed into a proton, so there is no longer an excess of neutrons.

2 Explain how a pressurised water reactor works.

Why does it not emit carbon dioxide into the atmosphere?

Reactors do not burn coal or oil and so no oxygen is used and therefor CO_2 is not emitted. In some reactors CO_2 is used for cooling but it is not allowed to escape from the reactor.

3 Why not wait until all the coal and oil has been used before turning to nuclear power? Why do we not rely on renewable sources of energy? Discuss this.

4 Why cannot a nuclear power station explode like an atomic bomb?

The reactor carries only enough uranium to work with the moderator in place. This, together with the action of the control rods, sets a limit on the power that can be produced.

5 In Lesson 4 we saw that discharges of radioactive waste from nuclear power stations give a very small annual dose to people in Europe. How many kilometres would you have to fly each year to get the same annual dose?

The annual dose is 0.001 mSv, about 1/20 of the dose from a 5000 km flight, so the distance is 250 kilometres.

Electricity is essential for modern life because our homes use electricity for cooking and heating and for washing machines, television sets and so on. We are so dependent on electricity that a power cut disrupts our lives. We obtain electricity from central power stations, many of which burn coal, oil or gas. To satisfy the growing need for energy, many countries supplement their supplies by using nuclear power, which is discussed in the following text.

LESSON

The atom and nuclear power

NUCLEAR POWER

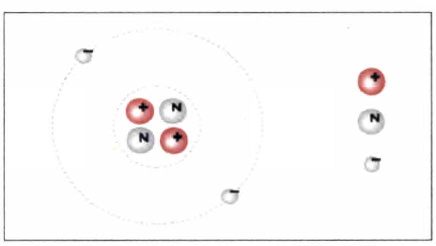
fission reaction

The power which is released when coal or oil is burned is the result of a chemical reaction affecting only the electron shells of the atoms involved. Nuclear power comes from the *fission reaction*, which releases enormous amounts of energy compared to chemical reactions but can only take place in a heavy nucleus such as that of the uranium atom. We must look more closely at the structure of the atom before this reaction can be explained.

THE STRUCTURE OF THE ATOM

atom

Everything around us consists of atoms, which are the building bricks of all material. The Greek perceived the *atom* to be the smallest piece of matter and gave it the name we use today. It means “a thing which cannot be divided”. This indivisible atom was accepted until 1897 when Sir Joseph Thompson discovered that it could be broken into smaller pieces. He thought of the atom as a “plum pudding” dotted with electrons. In 1913 Neils Bohr and Walter Bothe suggested that there was a nucleus containing protons and neutrons surrounded by electrons in orbits. We now think of these as shells, as illustrated in the atom pictures below.



The helium atom

electrons

This idea gives a very useful picture of the atom. Thus the *electrons* are little bits of electricity; each electron has a negative charge and can be removed from the atoms of some materials just by rubbing! In its normal state the atom is neutral and so its electrons must be balanced by the positive charge on the nucleus. This charge is provided by the *protons*, each exactly balancing one electron and holding it in its shell by the attraction between the electrical charges. The number of protons in the atom is the *atomic number*.

protons

atomic number

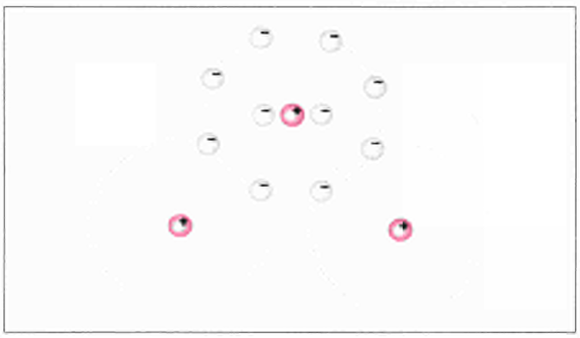
Protons and neutrons are nearly 200 times heavier than an electron and they make up the mass of the atom. The total number of protons and neutrons is the *atomic mass number*.

atomic mass number

To summarise we can say that :
the atomic mass number = the number of protons plus neutrons,
the atomic number = the number of protons.

Let us examine oxygen, which is a bigger atom than helium and has 8 protons and 8 neutrons in its nucleus. Of course, oxygen must have an atomic number of 8 because it has 8 protons which are balanced by 8 electrons to make the atom neutral. These 8 electrons must be in shells around the nucleus and we assume that these are in two different shells, 2 in an inner shell and 6 in the outer shell. The electrons in the outer shell are those which can be removed by ionization and are also responsible for the chemical properties of the element.

The water molecule



water

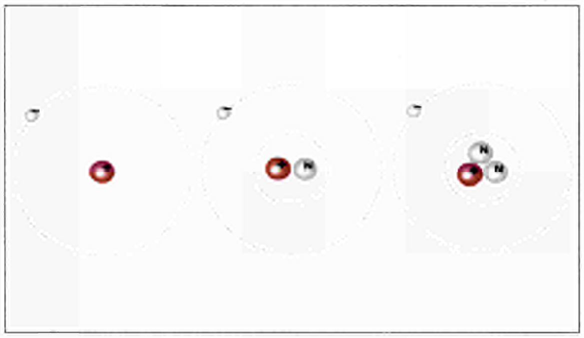
Water is a compound of hydrogen and oxygen and the two elements react together through the outer shell of electrons. Hydrogen has one proton in the nucleus and one electron in a shell, thus it has only one outer electron. The molecule of water has total of eight electrons in the outer shell, which we know to be a very strong chemical structure. The energy released in this reaction is the source of heat in the combustion of hydrogen.

nucleus

Let us return to the *nucleus*. How can it be stable? If the opposite charges of an electron and a proton attract each other we would expect the protons to repel each other. This is true but the nucleus nevertheless can stay intact because the neutrons act like an "atomic glue" sticking the nucleus together.

tritium

You would expect that the hydrogen nucleus would not require any neutron glue since it has one proton only. Nevertheless there are two other types of hydrogen atom which contain neutrons: hydrogen-2 with one neutron, which we call deuterium, and hydrogen-3 with two neutrons, called *tritium*. These three types of hydrogen are isotopes of hydrogen. We shall see later that the glue does not work very well in the tritium nucleus.



The three isotopes of hydrogen

The chemical properties of elements can be explained by the workings of the shells of electrons and the outer shell is the most important. We can find groups of elements which have similar chemical properties that change periodically as the atomic number is increased and there are also elements with similar outer shells. The elements can be arranged in a *periodic table*.

periodic table

periode \ groep	1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1,008																		2 He 4,003
2	3 Li 6,941	4 Be 9,012												5 B 10,81	6 C 12,01	7 N 14,01	8 O 16,00	9 F 19,00	10 Ne 20,18
3	11 Na 22,99	12 Mg 24,31												13 Al 26,98	14 Si 28,09	15 P 30,97	16 S 32,06	17 Cl 35,45	18 Ar 39,95
4	19 K 39,10	20 Ca 40,08	21 Sc 44,96		22 Ti 47,90	23 V 50,94	24 Cr 52,00	25 Mn 54,94	26 Fe 55,85	27 Co 58,93	28 Ni 58,71	29 Cu 63,55	30 Zn 65,38	31 Ga 69,72	32 Ge 72,59	33 As 74,92	34 Se 78,96	35 Br 79,90	36 Kr 83,80
5	37 Rb 85,47	38 Sr 87,62	39 Y 88,91		40 Zr 91,22	41 Nb 92,91	42 Mo 95,94	43 Tc 97	44 Ru 101,1	45 Rh 102,9	46 Pd 106,4	47 Ag 107,9	48 Cd 112,4	49 In 114,8	50 Sn 118,7	51 Sb 121,8	52 Te 127,6	53 I 126,9	54 Xe 131,3
6	55 Cs 132,9	56 Ba 137,3	57 La 138,9	►1	72 Hf 178,5	73 Ta 180,9	74 W 183,9	75 Re 186,2	76 Os 190,2	77 Ir 192,2	78 Pt 195,1	79 Au 197,0	80 Hg 200,6	81 Tl 204,4	82 Pb 207,2	83 Bi 209,0	84 Po 209	85 At 210	86 Rn 222
7	87 Fr 223	88 Ra 226	89 Ac 227	►2	104 Unq 259	105 Unp 262	106 Unh 263												

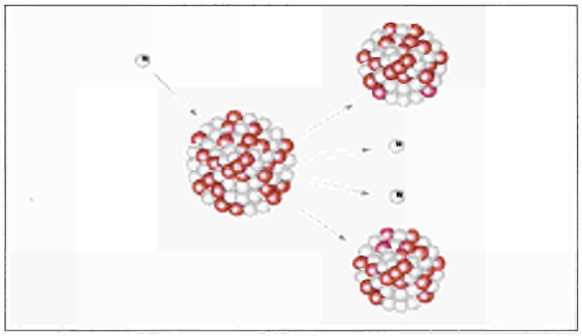
Part of the periodic table of elements

The idea that the neutron supplies "atomic glue" is a simplified way of explaining how the nucleus is held together. In fact there are many types of atom in which the nucleus is not at all well glued together and one of these is tritium. It seems that a good glue has to have the correct proportions of neutrons and protons and the proportion can be too high or too low for a particular atom. The ratio is too high in tritium and the nucleus has a tendency to disintegrate and rid itself of the excess neutron but, in fact, the tritium emits an electron from the nucleus. One of the two neutrons has become positive by losing an electron, so that it has become a proton. The tritium has transformed to helium, which has a different number of protons in the nucleus! The electron emitted by the neutron is named the "*beta particle*". A beta particle is emitted every time that the tritium disintegrates and transforms to the helium atom. This is one of the four main types of ionizing radiation which are emitted from a nucleus to make it more stable. The types of ionizing radiation emitted by a radionuclide have been described in Lesson 2.

beta particle

URANIUM – THE FUEL FOR A NUCLEAR POWER STATION

The idea that the nucleus of an atom is unstable if it has too many neutrons also applies to very big elements such as uranium. We have met the radionuclide uranium-238 but natural uranium also contains small amounts of uranium-235, which is unstable and is therefore radioactive and emits alpha particles. However, the discoveries made in 1939 showed that one more neutron added to the uranium-235 nucleus makes it extremely unstable and it disintegrates violently. This reaction, which is started by bombarding the uranium-235 with neutrons, is the famous fission reaction. We now know that this disintegration of uranium-235 is the splitting of the nucleus into two roughly equal fission products, each of which is a lighter element. A very large amount of energy is released in this reaction. A lot of heat can be produced in a very rapid burst of a large number of these reactions and this is the source of the energy of an atomic bomb.

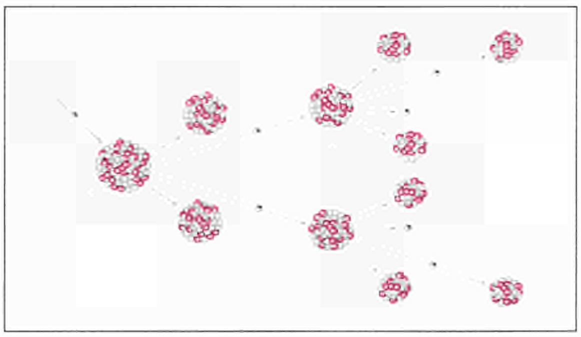


The fission process

You can see that several extra neutrons are produced in the reaction. If one of these neutrons is absorbed by another uranium-235 nucleus, the fission process can continue as a *chain reaction*. In this way one reaction leads to another and this steady fission process is the key to the operation of a nuclear reactor. Most of the products from the fission of uranium-235 are radioactive and are the waste products or ashes produced by consuming uranium in a reactor. We have seen in Lesson 4 that the radiation dose rate from this source is very small.

chain reaction

The first man-made nuclear reactor operated in 1942 but it was not the first on earth since it is believed that a fission chain reaction occurred spontaneously in an African uranium deposit about 1,700 million years ago.



The chain reaction

The neutrons released from the fission reaction are very energetic, so that they can easily escape from the uranium. They must be moderated in speed by the action of a layer of material, the moderator, which does not absorb too many neutrons around each piece of uranium. This was the brainwave of Enrico Fermi, who built the first reactor. We have seen it is essential for the total number of neutrons which return to the uranium to be controlled in a reactor to ensure that the reaction continues at a steady pace. This is achieved by using neutron absorbers or control rods which are inserted into the reactor to allow just enough neutrons to return to keep the chain reaction at the desired level.

The presence of the moderator and control rods is essential in a reactor and this is the reason why a reactor cannot explode or detonate like an atom bomb.

The heat generated in a reactor must be removed properly, not only to supply steam to the turbogenerators but also to keep the uranium at a satisfactory temperature. The uranium is cooled by placing it in a liquid which takes away the heat. This is the reactor coolant which is usually water but it may be a gas such as carbon dioxide, CO_2. This CO_2 is retained in the reactor. It is not released into the atmosphere like the CO_2 produced as waste from the burning of coal and oil in conventional power stations. When water is used it can perform both tasks and is a moderator and a coolant.

THE PRESSURISED WATER REACTOR

The uranium metal is made into a fuel for the reactor by the manufacture of pellets of oxide which are assembled in stainless steel tubes tightly sealed to retain the fission products. When the reactor is operating the coolant is also sealed inside a pressure vessel and the whole reactor operates inside a sealed building. This building is the containment and it is provided with equipment to reduce the spread of radioactive contamination if an accident occurs. Thus there are several barriers to prevent the escape of fission products.

NUCLEAR POWER IN EUROPE

The table below shows the use of nuclear power for electricity production in Europe. On the next page the table gives a summary of the types of reactor used.

ELECTRICITY FROM NUCLEAR POWER IN THE EC

COUNTRY	% OF ELECTRICITY PRODUCED BY NUCLEAR POWER
United Kingdom	19.7
France	74.5
Belgium	60.1
Germany	33.1
The Netherlands	4.9
Spain	35.9
Denmark	0
Eire	0
Italy	0
Greece	0
Portugal	0
Luxembourg	0
OVERALL IN EC	**34.8**

Nuclear electricity production in Europe in 1990

The following table lists the types of reactor which are used today for electricity production (figures published by Eurostat in 1991).

Types of reactor used for electricity production

TYPE	% OF REACTORS IN THE EC	COOLANT/ MODERATOR	URANIUM FUEL	COMMENT
PRESSURISED WATER REACTOR				
PWR:	80	Water/ water.	Enriched	A second water circuit is used to make steam.
BOILING WATER REACTOR				
BWR:	9	Water/ water	Enriched	The reactor coolant is allowed to boil and make steam.
NATURAL URANIUM-GAS GRAPHITE REACTOR				
UNGG:	4.5	CO_2 / graphite	Natural	The CO_2 gas heats a separate water circuit to make steam. Similar to UK Magnox reactor
ADVANCED GAS-COOLED REACTOR				
AGR:	6.2	CO_2 / graphite	Low enriched	The CO_2 gas heats a separate water circuit.
REACTOR BOLCHOIE MOLCHNASTIE KIPIACHIÉ				
RBMK:	0	Water/ graphite	Low enriched	Involved in the serious accident in the USSR in 1986.

KEY POINTS

- ***The atom can be described as outer shells of electrons and a nucleus in which there are various numbers of protons, neutrons and electrons.***
- ***The nuclear power reactor contains uranium fuel, a moderator and control rods and the heat is obtained from the fission process.***
- ***The most common type is the pressurised water reactor.***
- ***Nuclear power stations contribute about 34.8% of the electricity supply in the European Community in the year 1990.***

QUESTIONS

1 Why is it that a radionuclide with an excess of neutrons in its nucleus emits a beta particle but no neutron?

2 Explain how a pressurised water reactor works. Why does it not emit carbon dioxide into the atmosphere?

3 Why not wait until all the coal and oil has been used before turning to nuclear power? Why do we not rely on renewable sources of energy? Discuss this.

4 Why cannot a nuclear power station explode like an atomic bomb?

5 In Lesson 4 we saw that discharges of radioactive waste from nuclear power stations give a very small annual dose to people in Europe. How many kilometres would you have to fly each year to get the same annual dose?

Nuclear power and the environment

AIMS

At the end of the lesson the pupil:
- is able to describe the Chernobyl reactor accident
- is able to talk about the effect of releasing radioactive material into the environment
- knows that reactor incidents and accidents are reported on an 8-point scale.

PROPOSED MINIMUM TIME

60 minutes (or 2 x 30 minutes)

REFERENCES TO THE TECHNICAL SUPPLEMENT

Chapter 5: The biological effects of radiation
Chapter 6: Ionizing radiation protection
Chapter 7: Applications of ionizing radiation and radioactivity

TEACHING SUGGESTIONS

0) Preparation:
- find some audiovisual material to introduce the Chernobyl accident;
- find some newspaper cuttings to show conflicting reports about this or other accidents.

1) Ask the pupils if they can remember any accidents involving nuclear power stations. When is a nuclear accident a world-wide emergency? What do they remember about the Chernobyl accident in 1986? Use the International Nuclear Event Scale to show how the Chernobyl accident compares to other accidents.

2) Ask the pupils to read the text and tackle assignments 1 and 2.

3) Discuss the answers. You can give additional information about the differences between the Chernobyl station and the types designed in Europe. Also refer to Lesson 7.

4) Prepare an event scale for accidents and incidents at school.
Example:
Scale 3, Serious Incident, widespread disobedience in the science class, etc.

5) Give the pupils assignment 3.

Review the results of assignment 3 in Lesson 1 and repeat the initial knowledge test in Lesson 1. The review and the test can take place in this lesson, which is the last one in this course.

QUESTIONS/ASSIGNMENTS AND ANSWERS

1 Describe the cause of the Chernobyl accident on 26th April 1986.

2 Trace the release of radioactive material on the pathway picture.

3 Write a newspaper article about the experience in 1986 of a child on a farm near Pripyat.

The safety of workers and the public is important in every industry. Nuclear power stations are very large machines which have been designed with great care and must be operated under very strict rules. Any large radioactive source can cause a hazard if the radioactive material is accidentally released into the environment. Between 1945 and 1985 there were over 170 accidents worldwide involving large radioactive sources and 40% involved industrial gamma radiography units . In the same period there were three accidents involving nuclear reactors. The most serious accident happened in Chernobyl.

LESSON

Nuclear power and the environment

RESPONSE TO AN ACCIDENT

emergency plan

Despite of all the safety measures taken, the possibility of an accident occurring at a nuclear power station cannot be ruled out. The authorities therefore draw up an *emergency plan* for every reactor. The public is protected by series of interventions which will reduce the dose received as a result of the accident. These interventions include countermeasures such as evacuation which are applied if intervention levels, which are a level of radiation dose, are likely to be exceeded.

countermeasures

The *countermeasures* available are:-

a) sheltering indoors
b) distribution of stable iodine tablets
c) temporary evacuation and prohibition of entry to contaminated areas
d) relocation for a long period
e) ban on the consumption of contaminated food and drink.

What are the risks to the public from the operation of nuclear power stations? The average radiation dose to members of the public from the normal operation of a nuclear power station is 0.001 mSv per year. The risks from this ionizing radiation exposure to the individual are very small although it is possible to estimate a very tiny total risk due to the very large number of people exposed.

Chernobyl

THE CHERNOBYL REACTOR ACCIDENT

The world's worst accident to a nuclear power station occurred at *Chernobyl* in the former Soviet Union in 1986 when one of the four RBMK reactors on the site was destroyed as a result of flaws in the design and mistakes made by the operators.
The RBMK-1000 reactor was one of 14 reactors of this type and it was on a site on the Pripyat River 60 miles north of Kiev. It was developed from the

first power reactor in the world, which started generating electricity at Obninsk in June 1954. The fuel in the RBMK reactor was held in a series of tubes. The heat was removed by water, which turned to steam in the tubes. The steam entered two turbogenerators which produced an electrical output of 1020 MW.

The site of the Chernobyl power plant

The accident took place on 26th April 1986, when the reactor was being used to supply steam to a turbogenerator which was undergoing a test. The test involved the disconnection of a number of safety features and the reactor was running at a power level at which it was known to be unstable. When the test was started the reactor power jumped to 100 times full power. The cooling system was unable to cope and the resulting explosion lifted the 1000 tonne concrete roof, exposing the reactor to the air. The reactor contents were white hot and fire spread towards a second reactor in the same building. The plume of radioactive material lifted into the sky to a height of 1 kilometre and over the next ten days 70 PBq of caesium-137 (a mass of 22 kg) and 630 PBq of iodine-131 were released. About 1/3 of this fell on Europe with most of the remainder deposited in the USSR. The release of radioactive material ceased when the armed services used helicopters to drop lead and sand on the reactor, which was finally sealed in a concrete structure.

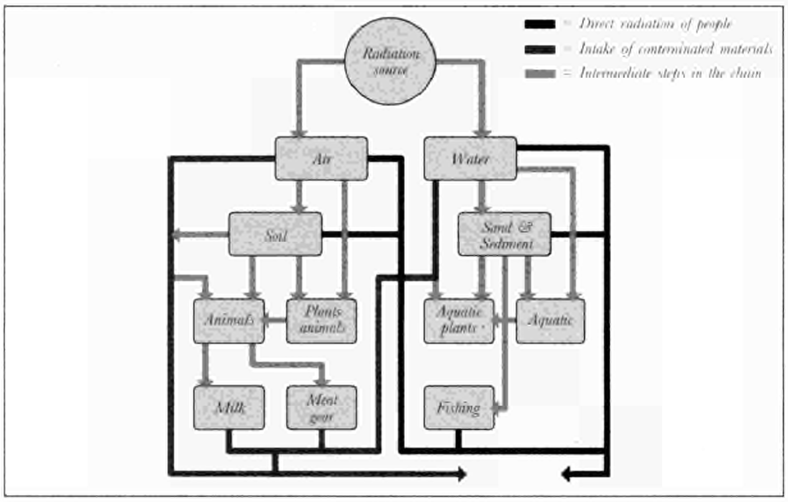
The accident caused 31 fatalities amongst the fire and recovery teams who saved the other reactors and put out the fire. Over 40,000 inhabitants of Pripyat were evacuated and many more people were affected by the radioactive debris which fell over large areas of the USSR. A total of 116,000 people were evacuated in the first year. Some of these were moved again and two further evacuations of 50,000 and 200,000 were announced in 1990.

The USSR authorities were strict in limiting ionizing radiation exposure to low levels but this has created great stress in some people who were not able to work on the land, children had to be kept indoors and many farmers were not allowed to eat or sell their own farm produce. As a result of more intensive medical examinations, many diseases were revealed but it is not clear how many, if any, of these diseases are attributable to exposure to radiation following the accident.

In the first year the maximum dose in Europe was 0.37 mSv in Greece, falling to about 6 µSv in Spain. These doses are small compared to the annual dose from the natural background. Restrictions on the sale and consumption of some foods were applied in Europe for some years after the accident. The most serious health effect of the accident seems likely to be due to the severe disruption of people's lives. The uncertainties arising from fear of ionizing radiation and the possibility of evacuation from their homes caused nervous ailments.

NUCLEAR POWER AND THE ENVIRONMENT

There are many pathways by which radioactive material can be returned to us in our food. These pathways are illustrated in the picture, which shows that radioactive materials may be carried by air or water. The radioactivite materials may be concentrated in some animals and plants, and are then processed into food.



Radioactive material pathways

The Chernobyl accident released radioactive material over a huge area and this might be thought to be a serious threat to the environment. However, the radioactive material released over many years of the atomic bomb tests carried out by the USA and the USSR was 17 times more than that released from Chernobyl but no health effects have been observed anywhere in the world.

International Nuclear Event Scale

SCALE OF REACTOR EVENTS

Reactor accidents are now classified on an *International Nuclear Event Scale*:

ACCIDENTS:

Level 7: An extremely large release of radioactive material causing widespread health and environmental effects. Described as a "major accident".

Level 6: A very large release of radioactive material (about 1/10 of level 7) likely to require the full use of planned countermeasures. Described as a "serious accident".

Level 5: A limited release of radioactive material (about 1/10 of level 6) likely to require partial use of planned countermeasures. This involves severe damage to the reactor. Described as an "accident with off-site risk".

Level 4: A minor release but public exposure near the prescribed limits and significant damage to the reactor (about 1 /10 of the damage in level 5). Described as an "accident without significant off-site risk".

INCIDENTS:

Level 3: A severe spread of radioactive contamination on-site but a very small release of radioactive material and very little exposure to the public. Described as a "serious incident".

Level 2: A significant spread of radioactive contamination on-site. Described as an "incident".

Level 1: An operating problem. Described as an "anomaly".

Level 0: An event of no safety significance. Described as "below scale".

The four lower-scale points are incidents which do not affect the environment and are reported to show how the plant is being run.

Conclusion

The Chernobyl accident caused worldwide alarm and has made some Governments change their policy on nuclear power. The RBMK reactors were not of a type which was acceptable to designers in the European Community and were operated only in the Soviet Union. Flaws in the design were discovered after the accident. Five years after the accident, delayed effects among the population have been assessed and are seen to have been overestimated.

KEY POINTS

- ***Arrangements are made to prevent the spread of radioactive material if a reactor accident occurs.***
- ***The Chernobyl accident was the world's worst nuclear accident.***
- ***The actions taken to deal with the widespread release of radioactive material affected the lives of Russian people.***
- ***The incidence of radiation disease has been less than expected.***
- ***The International Nuclear Event Scale puts the event in perspective.***

QUESTIONS

1. Describe the cause of the Chernobyl accident on 26th April 1986.
2. Trace the release of radioactive material on the pathway picture.
3. Write a newspaper article about the experience in 1986 of a child on a farm near Pripyat.

technical supplement

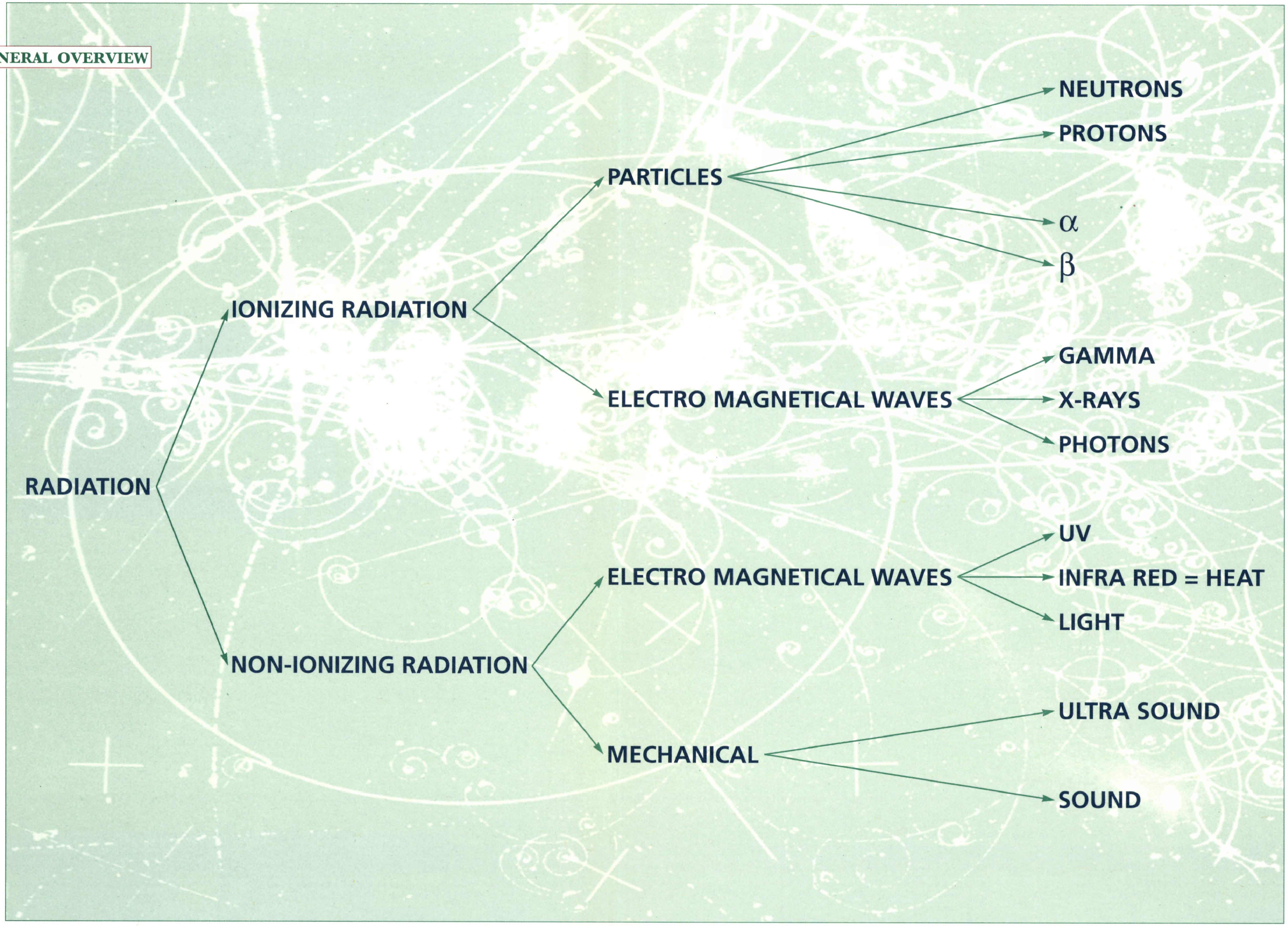
TS

GLOSSARY

BIBLIOGRAPHY

INFORMATION

A GENERAL OVERVIEW



HISTORICAL INTRODUCTION

Radiation

electromagnetic radiation
X-rays
electrons
ionizing radiation
ultraviolet
infrared
non-ionizing radiation
nucleus
atom

In 1831 Michael Faraday discovered the electrical forces of nature which surround an electrical charge and in 1873 James Maxwell used this concept to explain the properties of *electromagnetic radiation*. His theory holds good to this day and the *X-rays* created by Wilhelm Roentgen in 1895 were eventually recognised as electromagnetic radiation. Roentgen used an apparatus in which *electrons* at high voltage were made to strike a metallic target from which came the X-rays and he demonstrated that these could penetrate human tissue. With the aid of a photographic plate he was able to develop a shadow picture of the bones and this led to the medical application of X-rays. The effects on living tissue can be harmful and subsequent study revealed X-rays to be a form of *ionizing radiation*. However, sunlight, the visible light from the sun, and the invisible *ultraviolet* radiation and *infrared* radiation with which it is accompanied are also electromagnetic radiation. The familiar radio waves used for communications are electromagnetic and similar radiation is emitted from many items of household and industrial equipment. Clearly these are not harmful in the same manner as X-rays; in fact they do not cause ionization and are labelled *non-ionizing radiation*.

Other forms of invisible radiation called cosmic rays are emitted from the sun and outer space and we now know that these are made up of some very deeply penetrating types of ionizing radiation. Further studies have shown that ionizing radiation is also emitted from the earth itself; exposure to this type of radiation is therefore unavoidable. The emission of radiation from minerals was discovered by Henri Becquerel in 1896 and is now known to be a natural property of many of the atoms from which the earth and all creatures on earth are made. The earth sources are atoms which naturally disintegrate and are said to be radioactive; they emit radiation as they are transformed as a result of the disintegration of the *nucleus*. This radiation consists of three main types: alpha, beta and gamma radiation.

The study of radiation and radioactivity has played an important part in the evolution of our present knowledge about matter and the structure of the *atom*.

The table below links the work of the modern scientists to the discoverers of radiation and radioactivity.

The structure of matter

DATE	NAME	DISCOVERY
400 BC	DEMOCRITUS	The atom as the smallest part of an element.
1831	Michael FARADAY	The properties of electrical forces.
1873	James MAXWELL	Electromagnetic waves.
1895	Wilhelm ROENTGEN	X-rays.
1896	Henri BECQUEREL	The emission of radiation from a mineral.
1897	Sir Joseph THOMPSON Maurice de BROGLIE	The electron and the idea of the "plum pudding" atom.
1898	Pierre and Marie CURIE	The isolation of radium from pitchblende.
1900	Max PLANCK	The Quantum Theory and the idea of the photon as a burst of energy.
1903	Sir Ernest RUTHERFORD	The *alpha particle* and the idea of a decay series.
1905	Albert EINSTEIN	Mass and energy are equivalent.
1908	Hans GEIGER	The radiation detector.
1913	Niels BOHR Walter BOTHE	The nucleus of the atom and the orbital electrons.
1930	Ernest LAWRENCE	The cyclotron.
1931	Sir James CHADWICK	The nucleus containing *protons* and neutrons.
1934	Frédéric JOLIOT Irene CURIE	The neutron used to create artificial radioactivity.
1938	Otto HAHN and Friedrich STRASSMANN	The production of barium in uranium which has been bombarded by neutrons.
1938	Lise MEITNER Otto FRISCH	The idea of *nuclear fission*.
1939	Hans von HALBAN Frédéric JOLIOT Lew KOWARSKI	The release of neutrons in fission.
1942	Enrico FERMI	The first nuclear reactor started up in Stagg Field, Chicago, USA.

alpha particle

protons

nuclear fission

The history of radiation protection

Following Roentgen's discovery of X-rays they were quickly applied for medical purposes but, sadly, many of the doctors or radiologists became ill. The dangerous effects of excessive exposure to ionizing radiation were soon recognised. In 1928 the *International Commission on Radiological Protection (ICRP)* was founded by radiologists to tackle the problem.

International Commission on Radiological Protection (ICRP)

We have seen that the ionizing radiation which is emitted from the earth together with that arriving as cosmic rays is part of our natural environment. Radioactivity can also be created by man with the aid of neutrons which are generated in nuclear reactors and these will be described later. Visible light, infrared radiation and a number of other radiations both man-made and natural do not cause *ionization* but some can cause harmful effects in living tissues and so these must be controlled. Therefore the control of both ionizing and non-ionizing radiations from man-made and natural sources has become necessary for public health reasons.

ionization

dose
effective dose
millisievert

We can now estimate the "*dose*" of ionizing radiation received by a person who is exposed to a source such as an X-ray machine. The *effective dose,* which is expressed in standard units such as the *millisievert,* can be estimated by use of monitoring instruments and good methods of calculating the dose are available. The history below summarises the evolution of the radiation protection procedures used today.

1556	Agricola wrote about miners who died at an early age in the Joachimsthal mines.
1902	S. Rollins proposes an X-ray exposure limit equal to the amount of radiation required to darken a photographic plate, equivalent to roughly 100 mSv per day.
1914	The curie is adopted as a unit of activity.
1920	The British X-ray and Radium Committee proposes general recommendations for radiation protection.
1925	The first International Congress of Radiology (ICR) forms Committees and recognises the need to quantify radiation exposure. Authors such as Mutscheller propose 1/10 of the skin erythema dose as the annual exposure limit.
1928	The roentgen unit of radiation exposure is adopted.
1928	The International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) is formed by the International Congress of Radiology.
1951	The first dose limit recommendation, 3 mSv per week*, is made by ICRP.
1953	The rad and rem units of radiation dose are adopted.
1957	Euratom Treaty
1958	ICRP adopts the assumption that risk increases with the dose accumulated by the individual.
1959	ICRP recommends a dose limit of 30 mSv in 13 weeks.
1959	The Council of the European Communities issues the first directive on basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation.
1964	The Quality Factor (now replaced by radiation weighting factor) is adopted to reflect the ratio of the effect of different radiations.
1966	ICRP revises the dose limit for workers to 50 mSv per year.
1970	ICRP formulates the "ALARA – As Low As Reasonably Achievable" principle.

* The dose limits in this table are given in the 1992 units.

1977 The ICRP adopts the sievert as a unit for dose and introduces corrections for the sensitivity of different tissues (tissue weighting factor).

1979 The General Conference on Weights and Measures adopts the sievert (Sv) for equivalent dose, the *gray* (Gy) for absorbed dose and the *becquerel* (Bq) for activity as units of the Système International. **gray** **becquerel**

1980 The Council of the European Communities updates the Directive on basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation.

1984 Partial revision of Basic Safety Standards Directive and a specific Directive on the protection of the patient.

1991 ICRP make new recommendations and define the effective dose unit, the sievert (Sv), as the sum of the absorbed doses, in all the tissues and organs of the body, weighted for the type of radiation and the tissue. The proposed dose limit for workers is 100 mSv in 5 years with a limit of 50 mSv in any one year.

1992 *The International Commission on Non-Ionizing Radiation Protection* (ICNIRP) is inaugurated by the International Radiation Protection Association to take over the work of the former Committee founded in 1977. **The International Commission on Non-Ionizing Radiation Protection**

THE STRUCTURE OF THE ATOM

CHAPTER

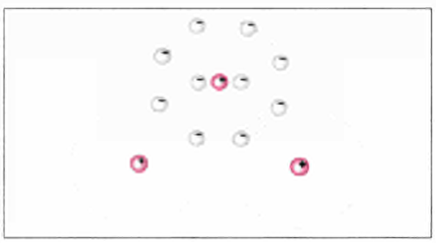
electrons

proton

We saw in Chapter 1 that most of our present knowledge of atomic structure was discovered in the first half of this century. The idea of the "plum pudding" atom, spotted with electrons, was conceived in 1897 by Sir Joseph Thompson. In 1913 Niels Bohr and Walter Bothe suggested that the electrons were in orbit around a nucleus but the *electrons* are now described as occupying a series of overlapping shells stepping upwards in a series of energy levels. The energies of these orbits or shells were found to relate to the energies at which X-rays were emitted. The idea of shells also helped to explain the chemical properties of an element, a particular type of atom. In 1931 the smallest nucleus, that of the lightest atom, hydrogen, was named the *proton*. It was recognised that matter does not normally show an electrical charge and so the atom must be electrically neutral. To achieve this balance of electrical charges the proton had to have a positive charge which was to be equal and opposite to the negative charge of the electron.

atomic number

The application of this idea made it possible to identify a particular atom from the number of electrons in its shells; this is the same as the number of its protons. This number of protons is the *atomic number* of the element, signified by the letter Z. For example, the nucleus of oxygen has 8 protons which is balanced by 8 electrons in its shells. This total is made up from 2 electrons in an inner shell and 6 in an outer shell which can hold 8 electrons. The hydrogen atom which has a proton in its nucleus has only one electron in the shell. Two atoms of hydrogen can therefore bring two shell electrons and if these combine with the 6 of oxygen the electrons complete a full shell of 8 which we know is stable. This is the explanation of the chemical reaction between 2 atoms of hydrogen and one atom of oxygen to produce the molecule of water. The chemical energy released in this reaction is the source of the heat released in the combustion of hydrogen in air.

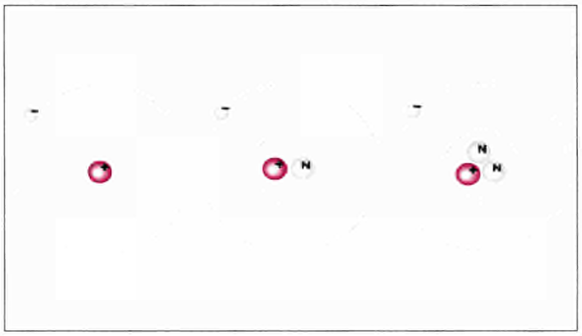


The water molecule

neutrons
mass number

isotope

The neutron, discovered by Sir James Chadwick in 1931, is now known to be part of the nucleus. It has the same mass as the proton but no charge and so the mass of a nucleus is determined by the total number of protons and *neutrons*. This is another important number, the *mass number* signified by the letter A. The neutrons and protons are the building bricks for all elements and using one of each, one neutron and one proton, we can construct the smallest nucleus which could contain both a neutron and a proton. This is the hydrogen nucleus of mass number 2 which is chemically identical with hydrogen. This type of nucleus is called an *isotope* and this particular isotope of hydrogen is deuterium. Water made from this type of hydrogen atom, double the mass of the smallest hydrogen atom, is heavy water, which actually has a higher density than ordinary water. We can construct a nucleus which is heavier still by adding one more neutron. This

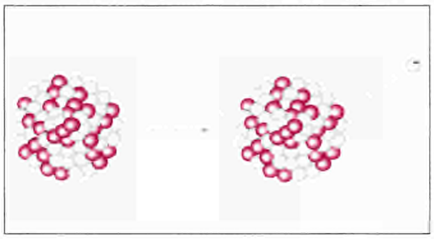


The three isotopes of hydrogen.

remains a hydrogen nucleus and becomes the third isotope, tritium. The various isotopes of an element are distinguished by their mass number and so we can refer to the three hydrogen isotopes as hydrogen-1, hydrogen-2 (deuterium) and hydrogen-3 (tritium).

In the case of hydrogen-3 the "atomic construction process" has gone too far and there are too many bricks in the structure; this isotope of hydrogen has too many neutrons and so it is unstable. This instability of the nucleus is the clue to radioactivity. The nucleus of the unstable tritium must change sooner or later and the most effective change occurs if one of the two neutrons emits an electron and is converted to a proton. The electron escapes from the nucleus at a high speed and can be detected as a *beta particle*.

beta particle



The emission of a beta particle.

This is the process which was discovered by Henri Becquerel in 1896 and is *radioactive decay*. The process liberates energy and so it may be accompanied by a burst of electromagnetic radiation and it also leaves behind a new element, in this case helium. The burst of energy is the *photon* or *gamma ray*, which is a penetrating form of electromagnetic radiation.

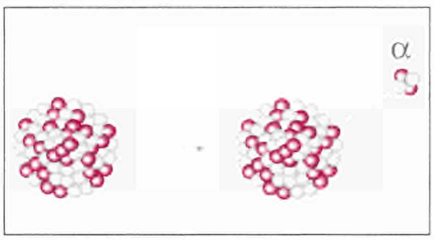
radioactive decay

photon

gamma ray

The idea that elements are unstable if they have too many neutrons applies to very big elements such as uranium. This is the *element* with Z = 92, and it has an isotope with 143 neutrons which is uranium-235. This is unstable but does not emit a beta particle since it can lose two neutrons by the emission of an alpha particle containing 2 neutrons and 2 protons. This is the nucleus of helium which will eventually gather the necessary electrons and become recognisable as an atom of helium, the isotope helium-4. The alpha particle is also emitted at speed and these two high speed particles are usually sufficiently energetic to become ionizing radiation.

elements



The disintegration of radium-226.

radium

In 1903 Sir Ernest Rutherford discovered the radioactive decay of uranium and found it to be the start of a series of radioactive elements which accounted for the radiation emitted from uranium ores such as pitchblende. *Radium,* which had already been separated in 1898 by Pierre Curie and Marie (Sklodowska) Curie, was found to be a member of this decay series. The whole series makes an important contribution to the natural radioactivity of the earth.

fission process

nuclides

chain reaction

In 1934 Frédéric Joliot and Irene Curie conducted experiments using a beam of neutrons and created artificial radioactivity. Aluminium was found to absorb a neutron and convert or transform to phosphorus-32. In 1939 the neutron beams were tried on uranium by Hans von Halban , Frédéric Joliot and Lew Kowarski and the nucleus disintegrated. Thus, the famous *fission process* was discovered. We now know that the neutron-assisted disintegration of uranium-235 is actually a splitting of the nucleus into two fragments each of which is a lighter element or nuclide, for example, krypton-89 and barium-144. The fission reaction starts with an element which has too many neutrons and it is no surprise to find that several neutrons are ejected in addition to the two *nuclides*. The enormous amount of energy or heat released in this reaction comes from the nucleus. If one of these neutrons is absorbed by another uranium-235 nucleus it is possible for the process to continue as a *chain reaction.* This is the key to the operation of a nuclear reactor. Most of these fission fragments are radioactive and are the waste products or ashes produced by consuming uranium in a reactor.

The first man-made nuclear reactor was operated by Enrico Fermi in 1942 but it was not the first on earth. The first nuclear reactor occurred spontaneously in an African uranium deposit about 1,700 million years ago; it is possible to show that the deposit now contains a lower fraction of uranium-235 than is normal on earth.

A nuclear reactor.

fusion

Another nuclear reaction which also produces a lot of energy can occur if two nuclides can be made to fuse together. This is a *fusion* reaction which is known to be the source of the energy liberated from the sun. It is very difficult to create the temperatures in the sun which are necessary for this process to start and so a commercial fusion reactor has not yet been developed. Both the fission and the fusion processes have been used in the atomic bomb. The detonations of these bombs spread radioactive debris around the world. The use of the fission process in a controlled nuclear reactor is responsible for very much smaller releases in the form of radioactive waste but there have been several accidental releases of radioactivity which are well-known events in nuclear energy history.

NON-IONIZING RADIATION

CHAPTER 3

Our human senses respond to heat, to light and to sound. Sound is transmitted through the air as a mechanical vibration but heat and visible light are conveyed to us as electromagnetic radiation. This is an oscillating wave which radiates energy and possesses both electric and magnetic fields. Energy is transmitted in packets called photons which carry an amount of energy linked to the frequency of the oscillation. For example, high frequency carries high energy packets. The photons of visible light do not possess sufficient energy to cause ionization because the frequency of visible light is too low. There are many other forms of radiant energy which do not cause ionization and with sensitive equipment it is even possible to detect the electromagnetic waves emitted from the human body. Most non-ionizing radiation is harmless although some is known to bring beneficial effects and some can be harmful. For example, the unpleasant and sometimes dangerous consequences of sunburn are well known. *The International Commission on Non-Ionizing Radiation Protection* (ICNIRP) provides guidelines for protection against the potentially harmful kinds of non-ionizing radiation. Recommendations have been made about static *electric* and *magnetic fields* and about mechanical radiation such as *ultrasound*.

The International Commission on Non-Ionizing Radiation Protection

electric

magnetic fields

ultrasound

Sources and properties of non-ionizing radiation

photobiological

(1) ULTRAVIOLET RADIATION (UV). This makes up about 5% of the solar radiation (sun's rays) which falls on the earth's atmosphere. It is invisible but it is essential for humans to receive some ultraviolet radiation in order to make vitamin `D' by means of a *photobiological* reaction. Over-exposure to ultraviolet radiation is the cause of sunburn and high exposures can cause skin cancer so protection is important. Malignant melanoma is a form of cancer which occurs infrequently but is very serious and there is some evidence that short-term intermittent exposure to high levels of UV, leading to severe sunburn, particularly at an early age, may be a factor. The UVB band, between 280 nm and 315 nm, is responsible for the more common non-melanoma skin cancers. Fortunately the atmosphere greatly reduces the ultraviolet radiation intensity but the protection depends on latitude, time of day, time of year, altitude, cloud cover and air pollution.

Some fluorescent lamps emit ultraviolet radiation and it is possible to receive dangerous amounts from excessive tanning on a sun bed and from welding arcs.

infrared radiation

(2) INFRARED RADIATION. About half of the solar radiation falling on earth is infrared and this too is reduced by the atmosphere. Although it is invisible we can readily feel the heat which it conveys to the skin. The feeling of warmth from a fire is also carried by *infrared radiation*. Over-exposure to infrared radiation is the cause of the burns which everyone has experienced by being too close to a fire. A piece of bread is an infrared radiation detector – the blackening of the toast is an indication of the absorbtion of radiation energy in the bread.

(3) VISIBLE LIGHT. This makes up 45% of the solar radiation falling on the earth's atmosphere. Visible light, especially blue, can cause dazzling when concentrated by the lens of the eye onto the retina. Fortunately the lens of the eye does not allow short wavelength ultraviolet and infrared radiation to reach the retina.

(4) RADIATION EMITTING LASERS. These are powerful sources of radiation which emit visible light and infrared radiation. The radiation can be very highly concentrated and cause damaging heating effects. Pulsed lasers are dangerous to the eye since they may flash too quickly for the eye to protect itself by blinking.

(5) RADIO WAVES. The wavelength is longer than infrared radiation. This is the radiation which transmits radio and television signals to household receiving sets. Microwaves, which are a type of radio wave, are capable of reacting with tissue to generate heat at depth. This property is used in the microwave cooker and has been used at low intensity to stimulate bone growth in a fracture. *Microwave* transmission links and radar use these same waves and all can burn human tissue if it is exposed to high intensities; a limit of about 0.4 watt per kilogram is recommended. Radio waves are also emitted from visual display units, cellular telephones and from all kinds of 50 or 60 Hz appliances such as power transmission lines as well as electric blankets. Static electric fields up to 20 kV per metre are generated in thunderstorms and electrical power transmission lines at 50 or 60 *hertz*, symbol Hz, can produce fields up to 10 kV per metre. This will produce an electrical current through the body which can be perceived by the person exposed.

microwave

hertz

(6) ULTRASOUND. This is a form of mechanical energy transmitted as waves through air, water or tissue. At certain frequencies and at high power, bubbles are released in liquids causing a biological effect which must be avoided in all human exposures to ultrasound. Ultrasound is used medically for making images of organs, for the detection of blood flow, and it is used in some treatments. It is widely applied for non-destructive testing in industry.

Protection against non-ionizing radiation

The methods of protecting people against the damaging effects of non-ionizing radiation offer examples which are useful as an introduction to radiation protection.

(1) ULTRAVIOLET RADIATION. Our eyes cannot detect ultraviolet radiation and so we may not be aware of dangerous exposure and have to rely on the accompanying visible light to warn us when to take precautions. Protection is achieved by taking shelter, by wearing protective clothing including broad brim hats, and by limiting the duration of exposure. We are advised to use sun tanning oils compounded to absorb a proportion of the ultraviolet radiation.

(2) INFRARED RADIATION. Our natural senses can detect an excess of infra-red. We can take shelter, or wear protective clothing and goggles. We can also move away from the heat source so that the intensity is reduced as the radiation spreads over a greater area.

(3) VISIBLE LIGHT. Our natural senses respond to visible light although unexpected lights can dazzle the eye. The blink reflex takes about 1/5 second to work.

(4) **LASER**, radio and microwave, ultrasound. Control is best achieved by careful design of the appliance, which must meet standards such as power limits, and by the use of special warning labels. The equipment must be properly used so operator training is essential.

The table below is a summary of the properties of non-ionizing radiations.

The properties of non-ionizing radiation compared to ionizing radiation.

CLASS	ELECTROMAGNETIC WAVELENGTH	BIOLOGICAL EFFECT
ELECTROMAGNETIC		
Ionizing	Less than 100 nm	Photons are energetic and cause ionization
Non-ionizing	More than 100 nm	
Ultraviolet (UV)	100 nm – 400 nm (UVA, 315 – 400 nm) (UVB, 280 – 315 nm) (UVC, 100 – 280 nm)	Photobiological effects include sunburn and skin cancer if badly burned.
Visible	400 nm – 800 nm	Dazzle.
Laser	0.2 µm – 20 µm	Heating and mechanical.
Infrared	0.78 µm – 1000 µm	Surface heating.
Microwave	1 mm – 1000 mm	Heating at depth.
Radiofrequency	1 m – 1000 m	None known.
Low and very low frequency	1 km – 1000 km	None known.
Extremely low frequency	1000 km – 10,000 km	Electric shock if badly-earthed metal is touched.
Static fields	Much greater than 10,000 km.	Burn due to skin currents.
MECHANICAL		
Ultrasound	Mechanical waves.	Heating, high power may cause dangerous bubbles (cavitation).

RADIOACTIVITY AND IONIZING RADIATION

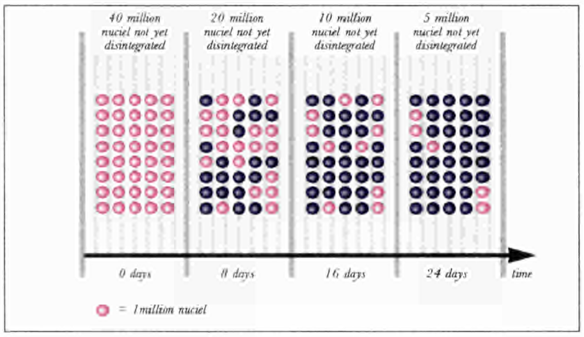
Radioactive decay

activity
becquerel

We can estimate or measure fairly accurately how many atoms of a radioactive substance have decayed in a period of time. This quantity is the *activity* of the particular radionuclide. The unit is the *becquerel*, one disintegration per second, symbol Bq.

half-life

The time taken for half of a large number of atoms of one particular radionuclide to decay is a property of the particular radionuclide and it does not change if the number of atoms of the nuclide is changed. It does not change if the temperature or the pressure of the atoms is changed and is not affected when the atoms are involved in chemical or biological reactions. An example of activity and *half-life* is shown below:



Decay of a radionuclide with 8-day half-life.

electron volts

A radionuclide may be identified by measuring the half-life or by measuring the nature of the radiation emitted, for example the energy of the photon. This energy is expressed in units of *electron volts*; one electron volt is equal to the energy of an electron energised by an applied voltage of 1 volt, the symbol being eV. The energies of photons emitted are usually expressed with the help of different prefixes, as shown below.

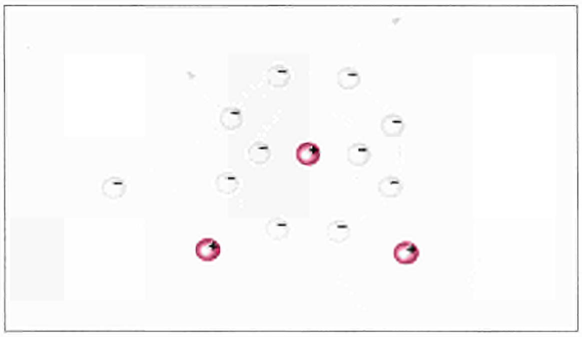
The use of prefixes to express energy in eV.

Energy in eV		energy in keV		energy in MeV
1000 eV	=	1 keV	=	0.001 MeV
1,000,000 eV	=	1,000 keV	=	1 MeV

Ionization

ion

The energy of the radiation emitted from a radionuclide is lost to the atomic electrons of the absorber and some of these electrons will be dislodged, leaving the atom with a positive electrical charge. The charged atom is known as an *ion* and one of its properties is the ability to react chemically with molecules nearby. Electromagnetic radiation can cause ionization if the wavelength is less than 100 nm, because the photon has sufficient energy to dislodge an electron.



The ionization of a water molecule.

When human tissue is exposed to ionizing radiation this chemical reaction will occur in living tissue, which may be damaging especially if the reaction takes place in the nucleus of a human cell. The purpose of radiation protection is to avoid this damage and so we must prevent or reduce the amount of radiation absorbed in tissue.

radiation detectors

We cannot measure this quantity in living tissue but we can make *radiation detectors* from materials similar to tissue and so predict the effect. Fortunately ionization in gases and some other materials is a relatively easy quantity to measure and so it may be used to detect radiation. The total amount of ionization indicates the total quantity of radiation which has been absorbed and gives us an indication of the total effect of the radiation.

There are three main types of ionizing radiation: alpha, beta and gamma radiation. The neutron is another type of radiation which is normally produced in a nuclear reactor. The neutron is the only radiation which induces radioactivity in the material in which it is absorbed.
X-rays produced by a machine have simular properties to gamma rays.

The following table is a summary of the properties of the most important ionizing radiations:

NAME	CHARGE	MASS	REACTION WITH MATTER.
ALPHA	+2	4	Heavy ionization over a short distance and then becomes an helium atom. Example: a 1 MeV particle is stopped by 1 mm of water.
BETA	-1	1/1840	Low ionization over a medium distance before attaching to an atom. Example: a 1 MeV electron is stopped by 400 mm of water.
GAMMA	0	0	Weakly ionizing over a long distance. Eventually becomes too weak to cause any further ionization. Example: a beam of 1 MeV gamma is reduced in intensity to 50% by 200 mm of water.
NEUTRON	0	1	Not directly ionizing. Penetrates over long distances and creates radioactivity when absorbed.

Radiation dose

Our natural senses do not respond to ionizing radiation and we are dependant on the use of instruments to warn us about its presence. With the aid of these instruments ionizing radiation has become one of the most readily detectable hazards in our environment. Detection is made possible because the ionization causes electrical and chemical changes in most materials, gases, liquids and solids. Neutrons produce some ionization indirectly and also react with the nucleus of an atom and produce effects which are detectable. Some of these effects can be made visible under a microscope. By using detectors which are sensitive to the ionizing effect of radiation we can estimate the amount of ionization in tissue exposed at the same place and for the same time and so deduce the biological effect. This task is simplified by expressing the effect on tissue in terms of the amount of radiation energy absorbed, referred to as the absorbed dose. The unit is the gray, 1 joule per kilogram, symbol Gy. This quantity is insufficient to specify the biological effect because the effect of a given *absorbed dose* of radiation will depend on the type of radiation and on the tissue exposed.

absorbed dose

The ICRP therefore introduced a system of weighting factors by which the absorbed dose is multiplied to give the Effective Dose and this is an indication of the biological effect. The unit is the sievert, symbol Sv. The weighting factors are selected in order that an *effective dose* of one sievert produced by the exposure of any tissue to any radiation will have the same biological effect on the person exposed. The sievert is a large quantity and so we use the millisievert, symbol mSv, or the microsievert, symbol 1 µSv. The quantity may be expressed using other prefixes as in the following examples.

effective dose

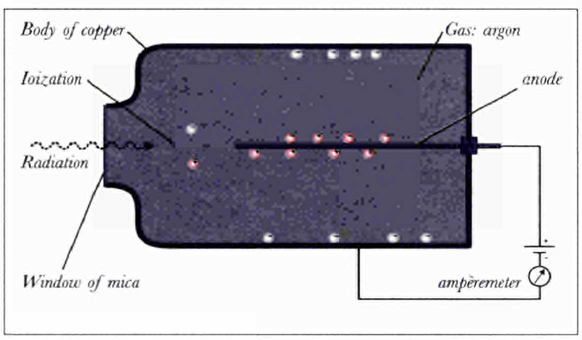
Use of prefixes to express effective dose.

Dose in sieverts		Dose in millisieverts		Dose in microsieverts
1 Sv	=	1000 mSv	=	1,000,000 µSv
0.001 Sv	=	1 mSv	=	1,000 µSv
0.000001 Sv	=	0.001 mSv	=	1 µSv

Detection of radiation

ionization chamber

The earliest radiation detectors contained a gas which became ionized when it absorbed the radiation. This device is an *ionization chamber* and the very small direct currents which pass through the chamber give a good indication of beta or gamma absorbed dose. Detectors based on this principle can be used to estimate the energy of the radiation and give a reading proportional to the effective dose.



The ionization chamber

Geiger-Mueller counters

Geiger-Mueller counters, invented in 1903, use a high voltage and a special gas filling which gives a strongly amplified burst of electric current for each ionizing particle detected.

Dosimeters used for radiation protection

Photographic film responds to ionizing radiation in the same way that it does to light and so an image is formed which can be developed and produces a blackening of the film. With the aid of filters built into a badge in which the film is carried the variation in the blackening of the film can be used to estimate the total radiation dose.

Pocket dosimeters can be made to carry a small ionization chamber or possibly a Geiger-Mueller counter and these can be installed in a case which contains the electrical circuits.

Survey meters may incorporate Geiger-Mueller counters and may be used to survey an area for beta, gamma and X-rays and some have detectors which respond to neutrons. When the detector is fitted with a "window" the meter can be used to record the amount of unsealed radioactivity, known as radioactive contamination, which is present on the surface.

THE BIOLOGICAL EFFECTS OF RADIATION

CHAPTER 5

Human biology

cytoplasm

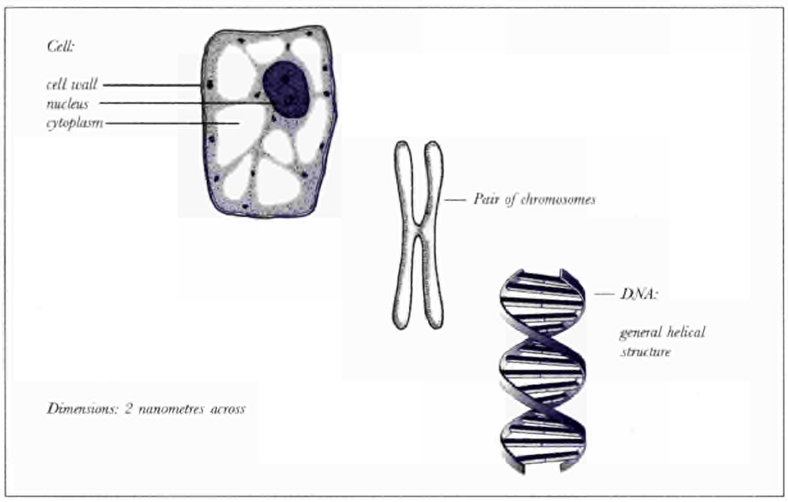
The effect of radiation exposure on the body depends on which of the organs is exposed. In each organ the properties of the cells determine the biological importance of the organ. A typical cell is illustrated below showing the cell wall or membrane, the *cytoplasm* and the cell nucleus. Some cells, known as germ cells, are responsible for our reproduction , the remainder are called somatic cells.

chromosomes
genes
DNA

The cell nucleus carries the *chromosomes* which contain the *genes* with which all types of cell transmit information to their daughter cells. The constituent from which the genes are made is *DNA* (deoxyribonucleic acid), which is the main target for radiation to produce biological damage. A cell possesses only a few, perhaps only two, copies of a gene, and there are tens of thousands of different types of genes in a cell, many of them vital for the reproduction and normal functioning of the cell.

If the DNA material is damaged to such an extent as to make a cell incapable of functioning and dividing normally, the cell will die either immediately or after one or several divisions. This will be most serious for the organism if radiation has destroyed a large proportion of the parent cells which provide daughter cells for vital tissues such as those in bone marrow, skin, intestine, testes etc. Genetic damage in a cell may not kill the cell but it can permanently alter its functions. Thus, a cell may be transformed in such a way that its descendants become cancer cells that cause cancer disease.

The germ cells may undergo a dominant or recessive mutation which in this case is transmitted to the descendants of the person affected.



The structure of a human cell

Deterministic effects of exposure to ionizing radiation

Damage to tissue caused by ionization is proportional to the amount of radiation energy absorbed, a quantity called the absorbed dose. We have seen that the damage depends on the type of radiation and on the tissue exposed. Following substantial exposure to radiation, so many cells may be damaged that the function of the tissue cannot be maintained. Therefore radiation acts like many other toxic agents and the consequences appear only when a certain threshold dose is exceeded. These early effects can be predicted in a given person when the radiation dose is known and so they are called *deterministic effects* (Not all deterministic effects are early effects). For example, exposure of the entire body to several Sv leads to radiation disease and potentially to death from failure of some of the blood-forming and immune functions; localized exposure to doses of tens of Sv causes damage to the affected tissues, for example to skin and underlying tissues. For most tissues the threshold for deterministic effects caused by a long-term exposure is an annual dose of about 0.5 gray.

deterministic effects

THE MOST SENSITIVE TISSUES ARE IN THE *TESTES*, THE LENS OF THE EYE AND THE BONE MARROW. The remainder of the body is less sensitive but exposure of the whole body to high doses produces a sequence of severe effects.

testes

THE TESTES. The male is rendered temporarily sterile with a dose of about 0.15 gray to the testes and a dose of 3.5 to 6 gray results in permanent sterility.

THE EYE. When the lens of the eye is exposed to X-ray or gamma radiation a single dose of about 2 to 10 gray given in a short time may cause opacities sufficient to cause impairment of vision (cataracts). Neutron radiation may cause the same damage at less than half of these doses.

THE BONE MARROW. The blood-forming process which takes place in the bone marrow is depressed if the whole red bone marrow receives a dose of more than 0.5 gray.

THE WHOLE BODY. Within a few hours the person exposed to doses exceeding 2 gray may suffer vomiting due to damage of the digestive system. Doses to the whole body of 3 to 5 gray may be fatal in 60 days unless very special medical care is available. At these doses there may be a reddening of the skin, an effect used by the early radiologists as a means of estimating the amount of radiation exposure. Above doses of 50 gray the person exposed may die in as little as two days.

Stochastic effects of exposure to ionizing radiation

If the radiation exposure is spread over weeks or months it is possible for the natural repair mechanism of our bodies to work so that the effect is reduced. Subsequently there may be other effects in the individual or in the person's descendants but these effects occur in a random way and are called *stochastic effects*. These are loosely termed "late effects".

stochastic effects

The annual dose which we receive from natural radiation, the most important source of our radiation exposure, is sufficient to release many millions of ion pairs in the DNA contained in our bodies. This type of damage to the DNA of a single cell could lead, after a long delay, to the development of a cancer of a type identical to those caused by other agents. In fact this development is completed very rarely, so the radiation exposure from natural radiation accounts for a small fraction of cancer deaths.

Damage to any one single cell in a given person is not predictable, which is why it is called stochastic. A probability can be estimated and the overall effect is usually assumed to be proportional to the absorbed dose. In fact risks are likely to be lower at lower doses and dose rates. Most of our knowledge comes from the study of the exposures at Hiroshima-Nagasaki, which were at high doses and high dose rates; little information is available on the effects on man of doses received at lower dose rates and practically none at doses lower than 0.2 Sv. Nuclear workers, who do receive doses at this level, appear to show a "healthy worker effect" with lower overall mortality and cancer risks than the population. A substantial proportion of the Hiroshima and Nagasaki groups and other exposed groups are still alive. Risk assessment requires extrapolation from the high doses experienced at Hiroshima and Nagasaki to the low doses and dose rates of normal experience. ICRP favour a "multiplicative risk model" which predicts a reduction in life span of about one year after exposure to one Sv. This is about the same life shortening as that from smoking half a packet of cigarettes daily for 30 years.

Genetic risks cannot be determined in human populations because of the high natural incidence of spontaneous mutations in germ cells.The genetic effect of radiation therefore has to be estimated from animal studies. It is now thought that the additional genetic risk caused by 1 Sv is about 1 to 2% of the risk of spontaneous genetic effects.

Radiation dose

radiation weighting factor
equivalent dose

The stochastic effects of radiation exposure depend on the type of radiation and the tissue involved as well as the absorbed dose. For example, the strongly ionizing alpha ray is 20 times more damaging than the gamma or beta ray. To allow for this we multiply the absorbed dose by a *radiation weighting factor* and the product is called the *equivalent dose*:

RADIATION	RADIATION WEIGHTING FACTOR
ALPHA PARTICLES and FISSION FRAGMENTS	20
NEUTRONS	5 to 20
GAMMA PHOTONS (all energies)	1
BETA PARTICLES	1
PROTONS	5

In addition we know that each of the organs in our bodies differs in sensitivity to radiation. The gonads, which have an early response to relatively low doses of radiation, also account for 1/5 or a fraction 0.20 of the stochastic effect. This fraction is the tissue weighting factor and the equivalent dose is multiplied by this factor to give the effective dose, which is also expressed in the sievert unit. Thus the effective dose may be calculated for any type of ionizing radiation and for the exposure of any part of the body to radiation.

ORGAN	TISSUE WEIGHTING FACTOR
Gonads	0.2
Red bone marrow, colon, lung, stomach	0.12
Bladder, breast, liver, oesophagus, thyroid	0.05
Skin, bone surface	0.01
Remainder taken together	0.05

The steps we have to take to calculate effective dose are :

ABSORBED DOSE	=	the energy imparted to tissue.
EQUIVALENT DOSE	=	ABSORBED DOSE multiplied by the radiation weighting factor.
EFFECTIVE DOSE	=	EQUIVALENT DOSE multiplied by the tissue weighting factor.

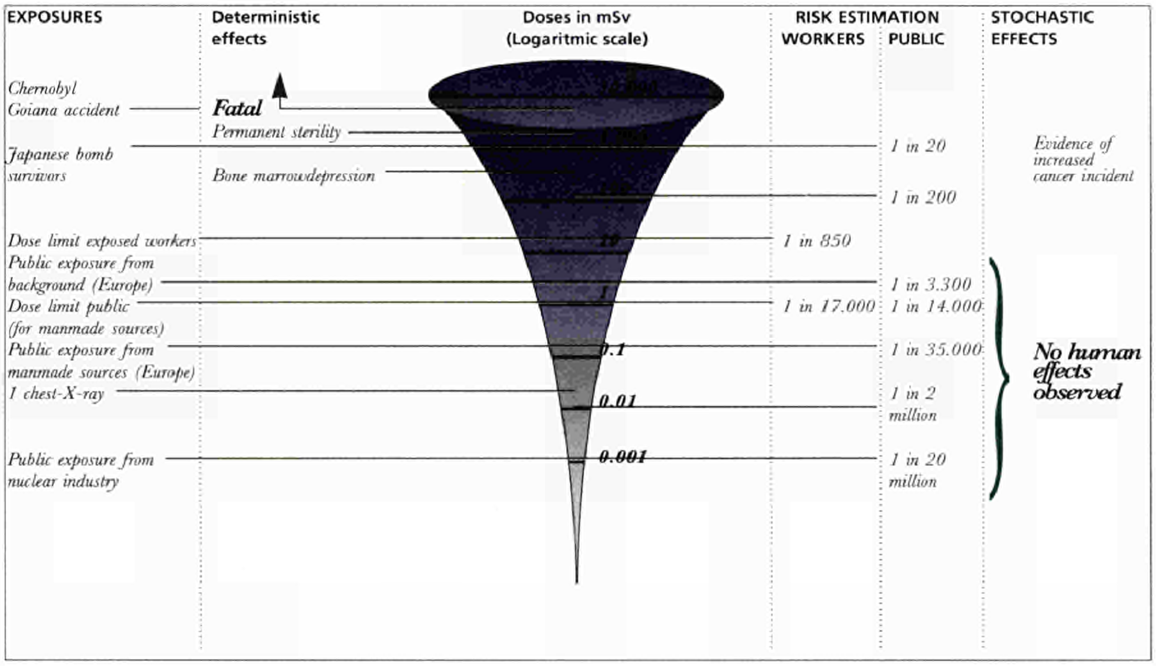
If many people are exposed to radiation, the total effect produced in that group of people is assumed to be proportional to the total dose. This "total dose" quantity is the collective effective dose and it is the product of the average effective dose and the number of people exposed.

Risks of radiation exposure.

The current official estimates of the ICRP suggest that a person receiving a dose of one sievert, similar to that received by the Japanese survivors of the atom bomb, will have an increased chance of eventually dying of cancer from about 25% (the "natural" cancer rate) to about 30%. This is the stochastic or probabilistic risk of a person dying from cancer and the extra risk is about 5% due to a dose of one sievert. At much higher doses received in a short time other effects called deterministic effects will be observed in a short time, a matter of days or weeks. At doses below one Sv the main effect is extra cancers which are greatly delayed and in fact would not appear until the exposed person was very old. This would be observed as an average shortening of life by one year, about the same as that caused by smoking 10 cigarettes a day for 30 years. In addition to this life shortening effect we must also take account of other types of delayed cancers which are not fatal as well as the hereditary effects delayed to the next generation and passed on to our children. ICRP state that an adult radiation worker who by law must not be younger than 18 or older than 65 years, has a risk of fatal cancer of 4 % per sievert, lower than the population as a whole. Each of the other two factors carries an extra risk of around 0.8% for a dose of 1 sievert and so the total detrimental effect is 4 + 0.8 + 0.8 = 5.6% per sievert.

Let us examine an actual case of radiation exposure. Take for example a worker who receives a dose of 1 mSv every year. In this case the risk to this worker of dying from cancer (at some future date) is increased by 0.004% each year. This represents an extra risk of 1 in 25,000, which is a very small increase in the chance of dying from cancer. At the same annual dose there is also a risk of 0.0008% or 1 in 125,000 of getting a non-fatal cancer and the same increase in the risk of an hereditary effect. All of these chances are small compared to other risks. For example, the additional genetic risk caused by 1 mSv is less than 0.002% of the natural hereditary effects. Putting all these factors together for a dose of 1 mSv, the radiation worker would have an overall risk of 1 in 17,000. This means that in a group of 17,000 workers each receiving 1 mSv, one person might be affected by the radiation.

The annual limits of dose for radiation workers is now 20 mSv per year and this brings a risk of 1 in 850 per year, similar to the annual risk of a fatal accident for an offshore fisherman. This is about the same risk per year (of death in that year) from natural causes at age 40. These radiation risks, although they are theoretical and the consequences are long delayed, are considered to be high. Radiation workers are therefore encouraged to keep their annual doses low. We now find that the average dose is about 2 mSv per year and the risks per year have fallen to a more tolerable level of 1 in 8,500.



Comparison of risks from radiation.

Public

A member of the public can be any age and some will therefore be more sensitive to cancer than the typical worker, which is why the risk of fatal cancer is 5%. ICRP believe that the other factors are also higher and these are 1% for non-fatal cancer plus a further 1.3 % for hereditary effects, making a total of 5 + 1 + 1.3 = 7.3% per sievert.

The same calculation as for workers applied to a dose of 1 mSv gives a risk of 1 in 14,000. This is mainly due to the higher sensitivity to radiation of children and women and especially the foetus. Special precautions are taken to avoid the radiation exposure of pregnant women in order to protect the foetus. This is particularly important during the most sensitive period, which lies between the 8th and 16th week of pregnancy. Children who were exposed to high radiation doses at this stage in the womb at Hiroshima or Nagasaki were found to have some mental retardation. Pregnant women are therefore not given X-ray exposures involving the abdomen during pregnancy unless there is an important medical reason.

These figures can be applied to actual situations such as our exposure to natural and man-made radiation. In Chapter 8 you will see that the typical annual dose in Europe is about 4.2 mSv per year from natural sources of radiation and 0.4 mSv per year from man-made. On average this will give a member of the public an increased risk of 1 in 3300 for natural radiation and 1 in 35,000 for man-made; combined together the overall risk is 1 in 3000 per year.

The table below summarises the radiation risks described above.

RISK	RADIATION WORKERS	GENERAL PUBLIC
Due to dose of 1 Sv:		
Fatal cancer	4%	5%
Non-fatal cancer	0.8%	1.0%
Severe hereditary effect	0.8%	1.3%
TOTAL	5.6%	7.3%
Due to dose of 1 mSv:		
All effects	0.0056%	0.0073%

IONIZING RADIATION PROTECTION

Dose control

practices
sources
dose limits

The protection of people from the harmful effects of ionizing radiation exposure is based on principles laid down by the International Commission on Radiological Protection (ICRP). This is an independent non-government organisation which provides recommendations for the protection of people against ionizing radiation. The ICRP's methods of protection against radiation make it possible to limit the harmful effects of radiation so that it can be used for the benefit of man in medical and industrial applications. Research on radiation biology has led the ICRP to recommend that the total exposure of individuals to radiation from all *practices* involving specific *sources* of radiation is subject to *dose limits*. The limits are set so as to ensure that no individual is exposed to radiation risks which are judged to be unacceptable in normal circumstances.

ALARA principle

The ICRP defines a practice as a situation in which radiation is used and recommends that the magnitude of the individual dose and the number of people exposed to the radiation should be kept "As Low As Reasonably Achievable", economic and social factors being taken into account. This is the *ALARA principle* which was introduced in 1970. This ensures that every exposure to radiation is carefully considered by the radiation protection specialists. Where required the conditions are adjusted or protective action is recommended to achieve the lowest possible exposure. As a consequence of this wise advice the actual exposures of most radiation workers are well below dose limits. ICRP dose limits are NOT the same for all practices involving radiation exposure because they are selected to be appropriate for the source of the radiation for which they will be applied. For example, the limits set for radiation workers (occupational exposure) are higher than those recommended for members of the public. In both cases the limit does not apply to exposure of the individual as a patient to medical sources of radiation.

intervention

Exposure due to natural radiation sources is usually excluded except where the exposure from natural radiation is high. In this case protective action known as *intervention* may be appropriate. ICRP recommend that a form of the ALARA principle should be applied and intervention should not take place if it is found that the social and other costs exceed the benefit.

Since 1959, ICRP recommendations have been taken in to account to make European community standards for the protection of workers and the general public against the harmful effects of ionizing radiation.

Three radiation protection principles are applied:

1. Radiation exposure must be justified by the advantages which it produces. This might involve a Government decision.
2. Radiation exposures, once justified, must be held as low as reasonably achievable (corresponding to as low as practicable).
3. Under normal conditions the radiation dose received by an individual worker, apprentice, student or member of the public must not exceed the dose limits published in the EC Council Directive. The dose limits based on those recommended by ICRP are selected to ensure that the risks of the radiation worker are not exceptionally high compared to

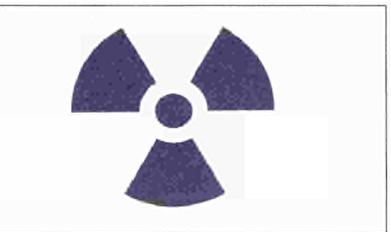
other workers. The exposure of patients for medical purposes is not limited by this principle.

Methods of personal protection

An annual dose limit is recommended for the whole body exposure of a worker, with lower values for women of reproductive capacity and pregnant women. Younger persons who must work with radiation, such as apprentices and students, are subject to lower limits. A personnel monitoring service using legally calibrated and approved radiation detection equipment is required to measure the dose received for entry in the legal records. Working areas may be designated for the application of special rules and are subject to routine and special surveys by qualified radiation protection personnel. Radioactive substances and apparatus emitting radiation are defined. Laboratories using unsealed radioactive sources are subject to limits on the quantities of radioactivity which may be used. The internal exposure of workers is controlled by the use of an *annual limit of intake* and this is calculated to ensure that the *internal dose* is below the limit. An important aim is to ensure that the contribution to the population dose of any work practice is kept to the minimum.

annual limit of intake
internal dose

Protection factors



The international trefoil symbol

We cannot feel, see, hear, smell or touch ionizing radiation and so all sources of radioactivity and all places where it is used are marked with the international three-bladed warning symbol.

The methods of control which provide radiation protection include:

1. Control of the duration of the exposure.
2. Control of the distance from the source of radiation.
3. Control of shielding between the source and the persons exposed.

EXPOSURE TIME. The most important method of protection is to restrict the time during which the person is exposed. If a task which has to be performed takes a fixed time at a certain dose rate then the dose received is fixed.
The rule is

dose rate x exposure time = dose

DISTANCE. The reduction of radiation dose rate with distance from a radioactive source follows the famous "inverse square law" provided that the source is small in physical dimensions. Thus a person moving away from a source so that the distance from a source is doubled will have a radiation dose rate which is 1/4 of the dose rate at the closer distance. Of course the opposite effect is produced when a person moves closer to a source, and the radiation dose rate increases four-fold at a point half way towards the source. It follows that it is very dangerous to handle a radioactive source with the bare hands since the distance between the source and the skin is virtually zero.

SHIELDING. The loss of energy which occurs as ionizing radiation passes through matter brings about a reduction in the intensity of the radiation. When a radioactive source emits alpha or beta particles, very good protection can be achieved by inserting a shield of a thickness equal to the *range* of the particle. The range is the distance that the particle can penetrate in the shield material. This distance in the appropriate material is

range

such that the particle energy falls below that needed for ionization. An area with too much gamma radiation can be shielded equally effectively by means of any slab of material which contains the same weight of almost any gamma-absorbing material. Thus each layer of a shield of, say, 100 mm thickness reduces the intensity of the gamma or X-ray to the same fraction of the radiation arriving at the layer. We can find a thickness which will reduce the intensity to one tenth and we call this the *tenth-value thickness* (TVT). A shield of two TVT will reduce the dose rate to one hundredth.

tenth-value thickness

Contamination control

radioactive contamination

Radioactive sources which are not sealed, such as those which are broken (for example, gases or liquids), could be dispersed accidentally and create *radioactive contamination*. This loose radioactive material may then be absorbed by people nearby and will be deposited in tissue, thus giving a radiation dose. This dose is an internal dose of radiation. The limit for work with unsealed radioactive material is the Annual Limit of Intake (ALI). This quantity is calculated by ICRP for each isotope and is an intake which will deliver a dose equal to the annual effective dose limit for radiation workers. The calculations allow 50 years for this dose to be accumulated because in some cases the radioactive material has a long half-life and is strongly retained in the tissue. However, the dose records are entered with the total dose delivered by the intake in the year of exposure.

Control of the internal dose is achieved by restricting the routes through which the radioactive material may enter the body. These are:

a) inhalation, by breathing air containing the radioactive material,
b) ingestion, by swallowing material containing the radioactive material,
c) skin contamination, by entry through wounds and rashes, through the eyes and ears and in some cases absorption through intact skin.

It is therefore necessary to measure contamination in the air and on surfaces. The work must be restricted to special laboratories or enclosures and if necessary the worker may be required to wear respiratory protection and protective clothing. It will be necessary to apply laboratory rules which are very similar to those used in hospital to control the spread of infection. Medical tests will be made as necessary and whole-body counters used to estimate internal radioactive material. The annual limits of intake for the control of inhalation and ingestion of radioactive material by the public are based on lower dose limits and so the concentration limits are lower. Limits for contamination in water consumed by the public are specified for use should environmental contamination occur.

Transport of radioactive materials

The regulations for the transport of radioactive materials are based on international regulations which require the radiation level to be indicated by labels on the outside of the package. Packages are classified according to the contents but packages containing minute amounts of radioactivity may be despatched with no special protection and no external label indicating radioactivity.

Response to an accident

The public is protected from the consequences of an accidental release of radioactivity by the application of countermeasures which will reduce the dose received as a result of the accident. Practically any countermeasures which can be used to protect the public may lead to some penalties and some risk. For example, countermeasures may incur financial penalties, social disruption, inconvenience and hardship and some additional risks will be incurred during transport when people are being evacuated. The decision to apply a countermeasure is based on the balance of the risk of the dose which could be received if nothing was done compared with the risk arising from the protective measure. Intervention levels of dose are calculated to assist the authorities in this decision taking; the dose averted is compared with the *intervention level* to judge if one of the following countermeasures may be used to reduce the dose:

intervention level

a) Sheltering indoors,
b) Distribution of stable iodine tablets,
c) Temporary evacuation including prohibition of entry to contaminated areas,
d) Relocation for a long period,
e) Ban on the consumption of contaminated food and drink.

The response teams for a radiation accident are required to limit their radiation exposure to the annual limit for radiation workers unless immediate remedial work becomes essential. The workers on a nuclear power station may be authorised to receive much higher doses to carry out very high priority work or make rescues.

CHAPTER 7

APPLICATIONS OF IONIZING RADIATION AND RADIOACTIVITY

Medical applications

Radioactive material is used for the investigation and diagnosis of health conditions and for the treatment of some diseases. The following table gives typical doses received by the patient from a single medical examination.

TYPE OF INVESTIGATION	EFFECTIVE DOSE TO PATIENT mSv
Dental X-ray	0.02
Chest X-ray	0.05
Barium meal examination	3
Technetium 99m scan	1 to 5
CAT scan (head)	3

The following table is a summary of the medical applications of radiation and radioactive material.

radiotherapy

APPLICATION	NUCLIDE, MATERIAL OR APPARATUS	PURPOSE
Radiography (X-rays)	X-ray machine.	Examine bones and tissue. 50% are dental, limb or joint examinations.
Fluoroscopy	Contrast media using X-ray machine,	Examine stomach, intestine and urinary system.
Body scan	Computerised axial tomography (CAT) using X-ray machine.	Examine soft tissue including brain.
Imaging	technetium-99m iodine-131 with gamma scanner.	Examine fluids in body, and position of tumours. Functioning of organs.
Labelling	iodine-131	Detect chemical transfers in glands such as thyroid.
Flow	krypton xenon	Output of heart and blood volume. Flow of other fluids.
Activation analysis	Nuclear reactor	Activation of elements such as arsenic and cadmium in biological samples.
Radiotherapy	X-ray machine, accelerator, gamma unit (cobalt-60)	Treatment of cancer and the alleviation of pain.
Curie therapy	radium-226 caesium-137 iridium-192	Treat cancer by placing a radioactive source in the tumour.

Industrial applications

The nuclear power stations apply the heat from the fission of uranuim in a nuclear reactor to make steam which is fed to a turbogenerator to make electricity. The release of radiation is an unwanted byproduct of the proces. The use of radiation in industry for radiography and the application of radioisotopes as *tracers* is based on the same scientific principles as the medical applications.

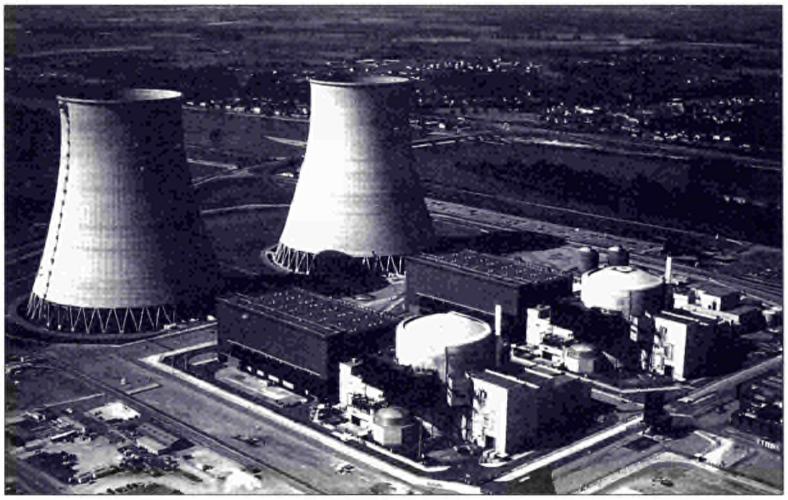
tracers

ELECTRICAL POWER USES. Many designs of reactor have been invented to improve the way that heat can be used to make electricity. The fuel or fissile material is usually uranium, which is sometimes processed to increase the uranium-235 content. The fuel is used to produce the chain reaction in which neutrons released from one fission reaction go on to make another. The fission neutrons are very energetic and can easily escape so they must be moderated in speed by the action of a layer of scattering material, the *moderator*, around each piece of uranium. The total number of neutrons which return to the fuel must be controlled in a reactor to ensure that the reaction continues at a steady pace. Neutron absorbers or *control rods* are adjusted to return the desired number of neutrons. A reactor cannot explode or detonate like an atom bomb because the bomb has neither control rods nor moderators. The heat generated in a reactor must be removed properly, not only to supply steam to the turbines but also to keep the fuel at a satisfactory temperature. A *coolant* must be provided and this may be a gas such as carbon dioxide, CO_2, or a liquid such as water. When water is used it can perform both tasks and may be both a moderator and a coolant. There are many other types of reactor but, taken together, reactors contribute 17% of the world's electricity and the combined experience is a total of 6000 years of reactor operation. The fuel for these reactors is processed from uranium ore, of which there is an abundant supply and for which there is apparently no other large-scale use. For some reactors the concentration of uranium-235 has to be increased from the natural level of 0.7% to 3 % or more by separating it from uranium-238. The metal is made into a gas, uranium hexafluoride, and the lighter gas containing the uranium-235 is separated by membranes or by other mechanical methods. The uranium metal is made into a fuel for the reactor by the manufacture of pellets of the oxide which are assembled in stainless steel tubes tightly sealed to retain the fission products. When the reactor is operating the coolant is also sealed inside a pressure vessel and the whole reactor operates inside a sealed building. This provides several barriers to prevent the escape of fission products.

moderator

control rods

coolant



Nuclear power station.

The following table lists the types of reactor which are used today for electricity production.

	PERCENTAGE OF EACH TYPE OF REACTOR IN EC	COOLANT/ MODERATOR	URANIUM FUEL	COMMENT
Pressurised Water Reactor	*Pressurised Water Reactor* PWR:80	Water/ water.	Enriched	A second water circuit is used to make steam.
Boiling Water Reactor	*Boiling Water Reactor* BWR:9	Water/ water	Enriched	The reactor coolant is allowed to boil and make steam.
Natural Uranium-Gas Graphite Reactor	*Natural Uranium-Gas Graphite Reactor* UNGG:4.5	CO_2 / graphite	Natural	The CO_2 gas heats a separate water circuit to make steam. Similar to UK Magnox reactor
Advanced Gas Cooled Reactor	*Advanced Gas Cooled Reactor* AGR:6.2	CO_2 / graphite	Low enriched	The CO_2 gas heats a separate water circuit.
RBMK	Reactor Bolchoie Molchnastie Kipiachié *RBMK*: 0	Water/ graphite	Low enriched	Involved in the serious accident in the USSR in 1986.

Radiography

The use of radiation for radiography in industry is based on the same scientific principles as those used in medical X-rays. The engineer uses radiation to look for flaws in the pieces of metal used to build ships, bridges, airplanes and other structures where a break could be very dangerous. X-rays of the same kind as those used in medical diagnosis are suitable when the pieces are thin but higher energy X-rays can be produced by means of accelerators. Gamma sources similar to those used for radiotherapy are required when the metal is more than 50 centimetres thick.

Testing

Gamma radiation from a radioactive source can be used by an engineer to "see" through the walls of pipes and containers to detect changes in thickness of the walls and changes in the fluid inside the walls. The amount of radiation passing through the wall or the tank indicates the thickness of the wall or the amount of fluid in the tank.

Activation analysis

In 1934 Joliot and Curie discovered that neutrons can make things radioactive. Engineers had to wait until nuclear reactors were perfected before a sufficient quantity of neutrons could be produced to make this a useful method of testing. As little as one part of iron in a million parts of sand can be detected by measuring the radioactivity induced in the iron after the mixture has been bombarded by neutrons.

Processing

Some chemicals, especially plastics, can be manufactured with the aid of gamma radiation. Very large cobalt-60 sources are needed for this process, in which the raw material is irradiated. The irradiation of medical supplies to make them sterile is designed to ensure that no more than one viable microorganism will survive in a million items of medical equipment and there will be no damage to the medical equipment, bandages and dressings. Microorganisms include bacteria, yeasts, moulds, spores and other related organisms. It is very likely that any visit you make to hospital for treatment will involve the use of radiation-sterilised dressings. You will see no damage to the dressing because radiation attacks only the living bacteria.

Food Irradiation

Gamma radiation is used to decontaminate food which does NOT become radioactive and the consumer is not exposed to any radiation. The food is made safe for consumption by the elimination of microorganisms such as salmonella, campylobacter, listeria etc. Irradiation also delays the sprouting of potatoes and other tubers like onions and garlic and is also used to extend the shelf life of other vegetables and fruits. However, people are wary of this use of radiation on food although considerable waste could be avoided in this way, which is important for those people in the world who are short of food!

Tracers

Radioactivity is a property of the nucleus of an atom and chemical properties are only affected by the outer electrons. A radionuclide behaves just like a normal atom until the moment that it disintegrates and emits radiation. It can then be detected. This property is used to trace the movements of materials in extraordinary places such as the centre of a blast furnace, the rubber on a tyre of a car, the metal inside a bearing and the movement of oil in a pipe-line buried underground.

If a pipe-line should leak, a small quantity of radioactive tracer can be added to the oil and this will come out through the leak and remain in the ground. The radiation from this can be detected from above ground or even from inside the pipe itself.

Research applications

Carbon dating

Very sensitive equipment can measure the amount of the naturally radioactive carbon-14 in organic material. When alive all animals and plants have the same concentration as in the air. When they die the carbon is not replaced from the air and so the level to which the carbon-14 content falls gives a good indication of the how long ago the organism died.

Tracers

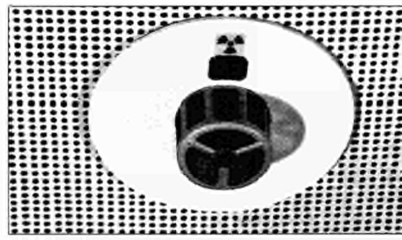
Much of our modern knowledge of biology is due to the use of "labels" of radioactive atoms which can be inserted in molecules such as DNA. The part that the molecule plays in life can be followed.

Domestic applications

A number of domestic appliances and other items in the home contain radioactivity.

Smoke detectors

These are life saving devices which use a radiation detector and a radioactive source, americium-241, which has a 432-year half-life. Smoke particles in the air interfere with the radiation detector and the smoke detector alarm is switched on.



Smoke detector

Luminous dials

When radium was discovered the scientists were able to detect it because the radiation caused certain materials known as phosphors to emit a flash of light. This was applied in clocks and watches in which the hands were painted with radium mixed with the phosphor so that they glowed in the dark. Unfortunately too much radioactivity had to be used and the people who painted the dials ingested the radium and were poisoned. In its place we now use tritium, which makes the phosphor glow; the beta radiation is easily shielded and so the tritium can be used safely. Many of the luminous signs in theatres and other public places now use tritium.

Gas mantles

Thorium is used in the mantles of gas lamps since it glows strongly when heated. The mantles are therefore slightly radioactive.

Military applications.

Atomic bombs

Two atomic bombs have been used in war and they were detonated in 1945 over Hiroshima and Nagasaki. Tremendous damage to life and property was caused by the vast explosive power. Some of the survivors from the effects of the explosion received radiation doses of around 1 gray (approximately equal to 1 sievert) and 47 years later more than half of them are still alive. They have been found to have about a 10% higher cancer risk than other Japanese people.
Atomic bomb tests in the 1960's were carried out in remote places but they released fallout around the world and a small amount is still present.

Nuclear submarines

These are propelled by the power produced in a nuclear reactor. This does not require a supply of air like oil or coal fired engines and is usually of the pressurised water type similar to those used on land for electricity production.

Services

All applications of radioactivity must be properly serviced to ensure safety.

TRANSPORT

The transport of radioactive materials is strictly controlled in accordance with regulations drawn up by the *International Atomic Energy Agency*. Special packages are used according to the type and quantity of radioactivity present. The higher quantities carry the trefoil label. Spent uranium fuel on its way to reprocessing is carried in flasks on special vehicles. These flasks are of a type tested by dropping and by immersion in a fire to ensure that they remain sealed in case of an accident. The reactor fuel is normally stored at the power station for periods of three years so that most of the radioactivity accumulated as fission products may decay. IAEA rules also apply to the transport of other smaller sources for use in hospitals and industry.

International Atomic Energy Agency

WASTE DISPOSAL

The disposal of radioactive waste is also controlled by strict regulations. All radioactive material from hospitals, factories, etc. and even quantities of old luminous-dial wristwatches must be disposed of safely. The fission products from nuclear fission represent the major part of the radioactivity for disposal. There are three categories of radioactive waste:

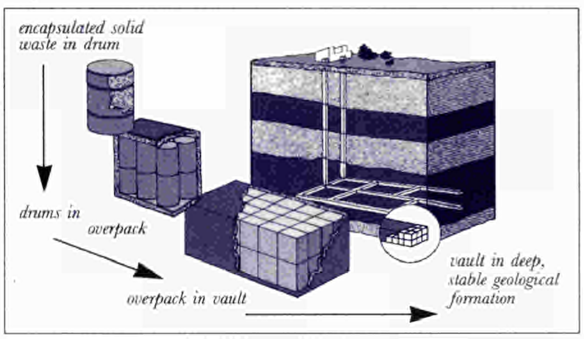
LOW LEVEL WASTE (LLW). Mostly radioactive material with a short half-life and produced in large volumes in the nuclear power programme. About one third of the annual total is produced by hospitals and industry.

INTERMEDIATE LEVEL WASTE (ILW). Contains larger quantities of fission products and high mass number elements called *actinides* which have long half-lives. The radioactive materials generate some heat but the volumes are not large.

actinides

HIGH LEVEL WASTE (HLW). This contains 95% of the radioactivie materials from all the waste streams, which includes most of the fission products and actinides from the fuel. The heating rate is high but the waste is not bulky.

The LLW from reactors is disposed of in the same way as materials from hospitals. ILW has to be sealed in concrete and stored. HLW will be converted to a glass for permanent disposal.



Multi-barrier protection of radioactive waste

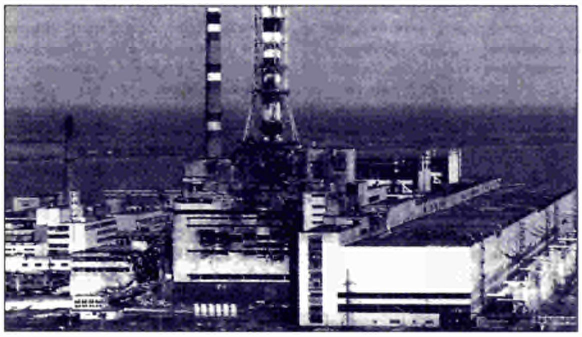
EMERGENCY SERVICES

Any large radioactive source is a potential hazard should the radioactive material be accidentally released into the environment. Between 1945 and 1985 there have been over 170 accidents involving large radioactive sources and 40% were due to industrial gamma radiography units. In the same period there were three accidents to reactors and more recently the Chernobyl reactor accident caused worldwide alarm. Special precautions are provided at reactor sites so that emergency protective action can be taken.

ACCIDENTS INVOLVING RADIATION AND RADIOACTIVITY

Goiânia. In 1978 a radiotherapy source of 50.9 TBq was removed by unauthorised people from an abandoned private hospital in Brazil. It was broken up by a scrap dealer and, as a result, 6 people received doses exceeding 4 Sv and 4 died within 4 weeks. The people who died had handled the source and had ingested up to 1 GBq of caesium-137.

CHERNOBYL. The accident took place when the reactor was undergoing a test and this involved disengaging a number of safety features. The operators then made a series of six violations of the safety rules and these mistakes together with design faults created a situation in which



The site of the Chernobyl power plant

uncontrolled changes in neutrons took place. An explosive release of energy destroyed the reactor and a large fraction of the fission products was released into the air. The accident has so far caused 31 fatalities amongst the fire and recovery teams. Over 40,000 inhabitants of Pripyat were evacuated and many more people were affected by the radioactive debris which fell over large areas of the former USSR. The release of radioactivity ceased when the reactor was sealed in a concrete structure. The total release of radioactivity from the reactor included 70 PBq of caesium-137 (a mass of 22 kg) and 630 PBq of iodine-131. About 1/3 of this fell on Europe with most of the remainder deposited in the USSR. In the first year the maximum European dose was 0.37 mSv in Greece, falling to about 6 µSv in Spain. These doses are small compared to the natural background. Restrictions on the sale and consumption of some foods were applied in Europe for some years after the accident. Very high doses were received by people living in the former USSR and this area is still experiencing public health problems.

SCALE OF REACTOR EVENTS

Reactor accidents are now classified on an International Nuclear Event Scale:

ACCIDENTS

7 A extremely large release of radioactivity causing widespread health and environmental effects. Described as a major accident.

6 A very large release of radioactivity (about 1/10 of scale 7) likely to require the full use of planned countermeasures. Described as a serious accident.

5 A limited release of radioactivity (about 1/10 of scale 6) likely to require partial use of planned countermeasures. This involves severe damage to the reactor. Described as an accident with off-site risk.

4 A minor release but public exposure near the prescribed limits and significant damage to the reactor (about 1 /10 of the damage in scale 5). Described as an accident without significant off-site risk.

INCIDENTS

3 A severe spread of radioactive contamination on-site but a very small release of radioactivity and very little exposure to the public. Described as a serious incident.

2 A significant spread of radioactive contamination on-site. Described as an incident.

1 An operating problem. Described as an anomaly.

0 An event of no safety significance. Described as below scale.

The four lower-scale points are incidents which do not affect the environment and are reported to show how the plant is being run. Examples of the use of this classification are given below:

ACCIDENTS

7 RBMK Reactor Chernobyl,USSR, 1986.

6 Kyshtym Reprocessing Plant, USSR, 1957.

5 Windscale Reactor, UK, 1957 and Three Mile Island Reactor, USA, 1979.

4 Windscale Reprocessing Plant, UK, 1973 and Saint-Laurent Nuclear Power Plant, France, 1980.

INCIDENTS

3 Vandellos Nuclear Power Plant, Spain, 1989.

DOSES FROM IONIZING RADIATION

Natural radiation

COSMIC. The sun and outer space is the source of cosmic radiation and so dose rates increase at high altitudes as we lose the shielding effect of the earth's atmosphere. The passengers and crew of an airplane receive a dose of 0.03 mSv during a 5000 kilometres jet flight; about 10% of this dose is due to neutrons. The annual dose to persons living at high altitude increases by 0.03 mSv per year for each 1000 m increase in altitude. Persons living in northern latitudes receive more cosmic radiation than those in the south. For example, a person living in Scotland receives a 20% higher dose rate from cosmic radiation than a resident of Greece.

GROUND. The gamma dose rate from the rocks below the surface of the earth is about 0.1 μSv per hour and it exceeds 1.0 μSv per hour in some parts of the world where annual dose rates can exceed 10 mSv per year. The dose rate is at its highest over igneous rocks and least over sedimentary rocks.

BUILDINGS. In addition, granite buildings give higher doses to the occupants than wood buildings.

radon

RADON. The radioactive gas, radon-222, is a member of the uranium decay series which is summarised in the Glossary. This naturally radioactive gas is responsible for the most important component of our natural radiation dose. The concentration of radon in the air is between 20 and 2000 Bq per cubic metre in European countries, giving annual doses of between 1 and 10 mSv. The gas enters our houses from the ground below and decays to short half-life radionuclides which are alpha emitters. Our lungs receive the radiation dose from the alpha emitters and so the radon produces an internal dose. Radon concentrations vary throughout the day and are at the lowest when the occupants are opening doors and windows. Houses which have high concentrations exceeding 400 Bq per cubic metre should be protected to prevent radon entry.

INTERNAL. Practically all food contains radioactive potassium-40 which is a natural part of potassium. Milk contains potassium-40 at about 50 Bq/litre and peanuts contain 200 Bq per kilogram. Every adult contains about 145 grams of potassium and therefore carries 5 kBq of the radionuclide. Potassium is an essential element so this quantity cannot be reduced by dieting.

Uranium and its important daughter product, radium, is found everywhere. Some natural water supplies contain radium activity at 10 Bq per litre. Some nuts, particularly brazil nuts, contain over 100 Bq per kilogram.

The atmosphere contains the natural radionuclide carbon-14, which is produced by the action of cosmic radiation on the air. There is about 200 Bq per kilogram in all carbon and this concentration in the carbon of our tissues gives us an annual average dose rate of 12 μSv per year.

Man-made radiation

MEDICAL. Diagnostic X-rays are used for essential medical examinations. They are the second highest contributor to the annual radiation dose.

MISCELLANEOUS. Air travel accounts for most of the dose under this heading. The dose is due to natural radiation but it has been increased by our choice to fly. Fall-out from atmospheric atom bomb tests accounts for an internal dose rate of 10 µSv per year. Tests of atom bombs have declined dramatically since 1965 and finally stopped in 1980 and so the annual dose rate from fall-out is decreasing.

Several household appliances emit radiation. For example, smoke detectors may produce a dose rate of 0.01 µSv per year compared with about 0.004 µSv per year due to a television receiver. Nuclear power station discharges account for about 1 µSv per year and even coal burning contributes about 0.2 µSv per year.

Conclusion

Man-made radiation is a small part of our environment. The types of radiation and radioactivity which are produced are found in nature, sometimes in greater quantities, and so man has not introduced new types of radiation hazard into his environment.

The table below is a summary of the annual doses of ionizing radiation which we receive from natural and man-made ionizing radiation. The table contains information about external dose and internal dose.

Typical annual dose to individuals in Europe

The information used in this table is taken from "Radiation Atlas: Natural Sources of Ionizing Radiation in Europe" (EUR 14470) by B M R Green, J S Hughes and P R Lomas, NRPB Chilton, Didcot, Oxon, prepared for the Directorate-General for the Environment, Nuclear Safety and Civil Protection, Commission of the European Communities, Luxembourg.

The atlas shows that human exposure is variable and is strongly affected by radon concentrations. Annual doses and their percentage contribution are estimated for two cases, (a) an individual in a low radon areas, typical of the UK (this dose pattern is similar to the world average) and (b) an individual living in a higher radon area in Europe (this dose pattern is similar to the European average).

TYPE	NATURE	External	Doses in mSv per year Internal	(a) Low Radon Area mSv/y	%	(b) Average Radon Area mSv/y	%
NATURAL	RADON (1 – 400 Bq per cubic metre)		1 to 20	1	38	3	65
	THORON (fairly constant)		0.15	0.15	6	0.15	3
	FOOD (fairly constant)		0.35	0.35	13	0.35	8
	GAMMA (indoors and outdoors)	0.18 to 0.5		0.4	16	0.4	9
	COSMIC (changes with altitude)	0.26 to 0.32		0.29	11	0.29	6
	TOTAL NATURAL			2.2	84	4.2	91
MAN-MADE	MEDICAL (mainly X-ray, nuclear medicine)	0.33	0.03	0.36	15	0.36	8
	MISCELLANEOUS Discharges: nuclear- 0.001 coal- 0.0002 Air travel, TV etc: 0.01 Fall-out from bomb tests: 0.01 Work exposure: 0.008	0.018	0.011	0.03	< 1	0.03	< 1
	TOTAL MAN-MADE			0.39	16	0.39	9
TOTAL				2.6	100	4.6	100

LIST OF NUCLIDES

The standard way to represent the nuclide of element X with atomic number Z and mass number A is $^{A}X_{z}$.
Thus the isotope of radium with Z = 226 and A = 88 is written $^{226}Ra_{88}$
In this book we refer to a nuclide by the name of the element followed by the mass number and so this example is radium-226.

Name-A	Half-life	Emitter of
americium-241	432 y	alpha
bismuth-210	5 days	beta
caesium-137	30 y	gamma
californium-252	2.64 y	alpha/neutron
carbon-14	5730 y	beta
cobalt-60	5.3 y	gamma
deuterium	stable	-
helium-4	stable	-
iodine-131	8 days	gamma
iridium-192	74 days	beta/gamma
lead-210	22.3 y	beta
oxygen-18	stable	-
plutonium-239	24,400 y	alpha
potassium-40	1280 My	beta/gamma
radium-226	1600 y	alpha
radon-222	3.8 days	alpha
technetium-99m	6 h	gamma
thorium-232	14 G y	alpha/beta/gamma
tritium (hydrogen-3)	12.3 y	beta
uranium-235	700 My	alpha
uranium-238	4.5 Gy	alpha
xenon-133	5.2 days	gamma

PART OF THE URANIUM-238 DECAY SERIES

Name - A	Half-life	Emitter of
Uranium-238 decays to	4.5 billion years	alpha
Thorium-234 then Protactinium-234m then Uranium-234 and then to		
Radium-226 decays to	1600 years	alpha
Radon-222 decays to	3.82 days	alpha
Polonium-218 decays to	3.05 minutes	alpha
Lead-214 decays to	26.8 minutes	beta
Bismuth-214 decays to	19.9 minutes	beta
Polonium-214 decays to	0.00016 seconds	alpha
Lead-210 decays to	22.3 years	beta
Bismuth-210 then Polonium-210 and ends with		
Lead-206	stable.	

PREFIXES

These are the prefixes used in this course which are taken from the Système International.

Prefix letter (1)	Prefix name (2)	Number (3)	Power of 10. (4)
E	exa	1,000,000,000,000,000,000	18
P	peta	1,000,000,000,000,000	15
T	tera	1,000,000,000,000	12
G	giga	1,000,000,000	9
M	mega	1,000,000	6
k	kilo	1,000	3
		1	
m	milli	0.001	-3
μ	micro	0.000001	-6
n	nano	0.000000001	-9
p	pico	0.000000000001	-12
f	femto	0.000000000000001	-15
a	atto	0.000000000000000001	-18

The prefix written in front of the symbol for the unit indicates multiplication of the unit by the value of the prefix. Thus kBq is a 1000 x Bq or 1000 becquerel. It is useful to check the values by using the power of ten column. Thus the fraction of the sievert represented by mSv is Sv/1000 or 0.001 Sv. This may be written as 10-3 x Sv or E-03 Sv. The number -3 is the logarithm of 0.001.

GLOSSARY

ABSORBED DOSE	The amount of energy imparted by the ionizing radiation to unit mass of absorbing material, recorded in gray, Gy. (1 Gy = 1 Joule per kilogram)
ACTINIDE	One of a series of radionuclides with atomic numbers ranging from 89 (actinium) to 103 (lawrencium).
ACTIVITY	The attribute which can express the quantity of a radionuclide. This qualifies the rate at which transformations or changes occur, the activity being expressed in becquerel, Bq. (1 Bq = one transformation per second)
ADVANCED GAS COOLED REACTOR (AGR)	A reactor using gas at high temperature and a graphite moderator.
ALARA PRINCIPLE	The ICRP recommendation that exposures to radiation should be "As Low As Reasonably Achievable", social and economic factors having been taken into account.
ALPHA PARTICLE	Positively charged particle consisting of two protons and two neutrons. Identical to the nucleus of the helium atom.
ATOM	The smallest portion of an element that can combine chemically with another.
ATOMIC NUMBER (Z)	The number of protons in an atomic nucleus.
BECQUEREL	The unit of activity, one change (or transformation) per second.
BETA PARTICLE	The electrons with relatively high energies emitted from the nuclei of many radionuclides.
BOILING WATER REACTOR (BWR)	A reactor using water as a coolant and a moderator. The water is allowed to boil and is supplied directly to the turbines.
CHAIN REACTION	A self-sustaining reaction taking place in a reactor in which one fission reaction produces enough neutrons to cause another reaction.
CHROMOSOME	A thread-like substance in the nucleus of a cell consisting of DNA and other material. It is responsible for the genetic effect, i.e. the transmission of hereditary features.
CONTAMINATION, RADIOACTIVE	The undesirable presence of unsealed radioactive materials on surfaces, in air and in water.
CONTROL ROD	A neutron-absorbing device usually made of boron carbide in the form of a rod which can be moved into the reactor to adjust or stop the chain reaction.
COOLANT	A gas or liquid which removes heat from a reactor.
COSMIC RAYS	Radiation from the sun and outer space.
CYTOPLASM	The active contents of a cell excluding the nucleus and the cell wall.

DECAY See radioactive decay.

DETECTOR A device which indicates the intensity of a radiation field. These include Geiger Mueller counters, ionization chambers and film badges.

DETERMINISTIC EFFECTS (Previously called NON-STOCHASTIC). Effects of radiation which have a threshold dose above which damage is certain to occur.

DNA (deoxyribonucleic acid) The molecule which is a vital component of the chromosome and controls cell function and inheritance.

DOSE The term used loosely for individual absorbed dose or effective dose.

DOSE LIMIT Recommended by the ICRP and authorised by regulatory authorities to apply to occupational and public exposure.

EFFECTIVE DOSE Computed from the absorbed dose by correction for radiation and tissue weighting factors and thus expresses the total risk from the exposure. The effective dose is expressed in sievert, Sv.

ELECTRIC FIELD The forces surrounding an electric charge representing the field strength (unit: Volt per metre) which would affect another charge.

ELECTROMAGNETIC RADIATION Radiation carrying energy and consisting of electric and magnetic WAVES which travel at the speed of light.

ELECTRON Negatively-charged particle with a mass equal to 1/1836 of the mass of a proton. The orbital electrons of an element are responsible for its chemical properties, see beta radiation.

ELECTRON VOLT, eV The energy gained by an electron accelerated through one volt.

ELEMENT A substance in which every atom has the same atomic number.

EQUIVALENT DOSE is computed from the absorbed dose by correction for the radiation weighting factor only and is used for the dose to a single organ.

FISSION PROCESS The division of the nucleus of a heavy element into smaller nuclides, fission fragments, which decay into fission products and with the emission of neutrons.

FUSION The combination of the nuclei of light elements which is accompanied by the release of energy.

GAMMA RAY A quantity of ionizing electromagnetic radiation, without mass or charge, of the type emitted by radioisotopes.

GEIGER-MUELLER COUNTER A device containing a gas mixture from which electrical pulses may be detected to give an indication of ionizing radiation.

GENE A hereditary unit located in the chromosome.

GONADS Ovaries and testes.

GRAY The unit of absorbed dose, the amount of energy imparted to an absorber from radiation (1 Gy = 1 Joule per kilogram).

HALF-LIFE The average time taken for half of a quantity of a radionuclide to decay. Activity is the attribute of quantity and so this is also the time taken for the activity of the radionuclide to lose half its value. Also referred to as 'physical half-life'.

HERTZ The unit of frequency, Hz, one cycle per second.

IAEA The International Atomic Energy Agency.

ICNIRP The International Commission on Non Ionizing Radiation Protection.

ICRP The International Commission on Radiological Protection.

INFRARED RADIATION An electromagnetic radiation with a frequency between light and radiofrequency radiation which is a transmitter of heat.

INTERNAL DOSE The radiation dose received from radioactivity deposited in the body.

INTERVENTION Action taken by the authorities to reduce the radiation dose from sources such as natural radioactivity or activity released in a reactor accident.

INTERVENTION LEVEL The dose at which a particular action to reduce the effects of an emergency, i.e. a countermeasure, may be introduced.

IONIZATION Occurs when a neutral atom or a molecule acquires or loses an electric charge and becomes an ION.

IONIZATION CHAMBER A gas-filled container in which ionization released in the gas is measured as a current.

IONIZING RADIATION Radiation which has sufficient energy to produce ionization in matter; includes alpha particles, beta particles, gamma rays and X-rays (indirectly neutrons can ionize matter as well).

IRPA The International Radiation Protection Association.

ISOTOPE Nuclides with the same number of protons but different numbers of neutrons.

MAGNETIC FIELD The forces around a magnet. The intensity of the field is expressed in ampère/metre.

MASS NUMBER (A) The total number of neutrons and protons in the nucleus of an atom.

MICROWAVE RADIATION The electromagnetic radiation with wavelength 1 mm to 1 m, used in cooking and for communications.

MODERATOR Material used to slow down neutrons from the fission process.

NATURAL URANIUM GAS COOLED REACTOR (UNGG) Natural uranium fuelled reactor, graphite moderated and cooled by CO_2. Similar to the British MAGNOX reactor.

NEUTRON An elementary particle with no electric charge which combines with protons to form an atomic nucleus.

NON-IONIZING RADIATION Radiation that does not ionize matter. Includes radiofrequency and microwave radiation, light and ultraviolet radiation.

NUCLEUS The core of an atom, made up of neutrons and protons.

NUCLIDE A species of atom characterised by the number of protons and neutrons and sometimes by the energy state of the nucleus. See list of nuclides at the end of the glossary.

PHOTOBIOLOGICAL The property of light to influence the biological function of living organisms and so affect growth.

PHOTON The discrete amount of energy (quantum) carried by an electromagnetic ray.

PRACTICE A situation in which people are required to be exposed to sources of radiation, such as medical work or nuclear power.

PRESSURISED WATER REACTOR, (PWR) A reactor using light water as moderator and coolant which is operated at high pressure to prevent boiling.

PROTON An elementary particle with a positive charge which combines with neutrons to form an atomic nucleus.

RADIOACTIVE DECAY The decay of a radionuclide by the spontaneous transformation of the nuclides. The rate of decay is determined by the quantity of the specific nuclide present. The rate is expressed as the ACTIVITY in becquerel, Bq, indicating the number of transformations per second.

RADIOTHERAPY The treatment of cancer by the action of ionizing radiation on a tumour.

RADON A natural radioactive gas, which comes from the uranium normally found in rocks and soils. The entry of this gas into houses from the foundations accounts for a large proportion of our natural radiation dose. Radon-222 is a member of the uranium-238 decay series (see end of Glossary).

RANGE The maximum distance travelled by an alpha or beta particle before it loses energy and is absorbed.

RBMK The USSR reactor involved in the Chernobyl accident.

REACTOR The device for using the chain reaction in uranium or similar material to produce controlled energy.

SIEVERT The unit used for equivalent dose and for effective dose.

STOCHASTIC EFFECTS Radiation effects which are statistically related to the dose; an increase in dose gives an increased probability of the effect.

TENTH VALUE THICKNESS(TVT) The average value of the thickness of a shield needed to reduce the incident radiation intensity to one tenth.

TRACER The use of a radionuclide attached or chemically bonded to a material so that it can be detected by radiation detecting instruments as it passes through a process.

TREFOIL SYMBOL The internationally used three-bladed symbol to warn of the presence or the potential presence of ionizing radiation.

ULTRASOUND High-frequency mechanical vibrations transmitted as waves with a frequency above the audible sound range.

ULTRAVIOLET RADIATION Electromagnetic radiation from the sun of wavelength 100 to 400 nm.

WEIGHTING FACTORS The factors used to correct for the effectiveness of the RADIATION or the sensitivity of TISSUE exposed to ionizing radiation.

X-RAY A form of ELECTROMAGNETIC RADIATION with no mass or charge which is generated in a machine by accelerating electrons on to a target.

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INFORMATION

Further information can be obtained from the following addresses:

COMMISSION OF THE EUROPEAN COMMUNITIES,
DG XI – ENVIRONMENT, NUCLEAR SAFETY AND CIVIL PROTECTION

Mr D. Teunen
Centre Wagner C 325
Rue Alcide De Gasperi
L-2920 Luxembourg
Tel. XX/352/4301-36389
Fax XX/352/4301-34646

Ireland

COMMISSION OF THE EUROPEAN COMMUNITIES
OFFICE IN IRELAND

Jean Monnet Centre
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COMMISSION OF THE EUROPEAN COMMUNITIES
OFFICE IN THE UNITED KINGDOM

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COMMISSION OF THE EUROPEAN COMMUNITIES
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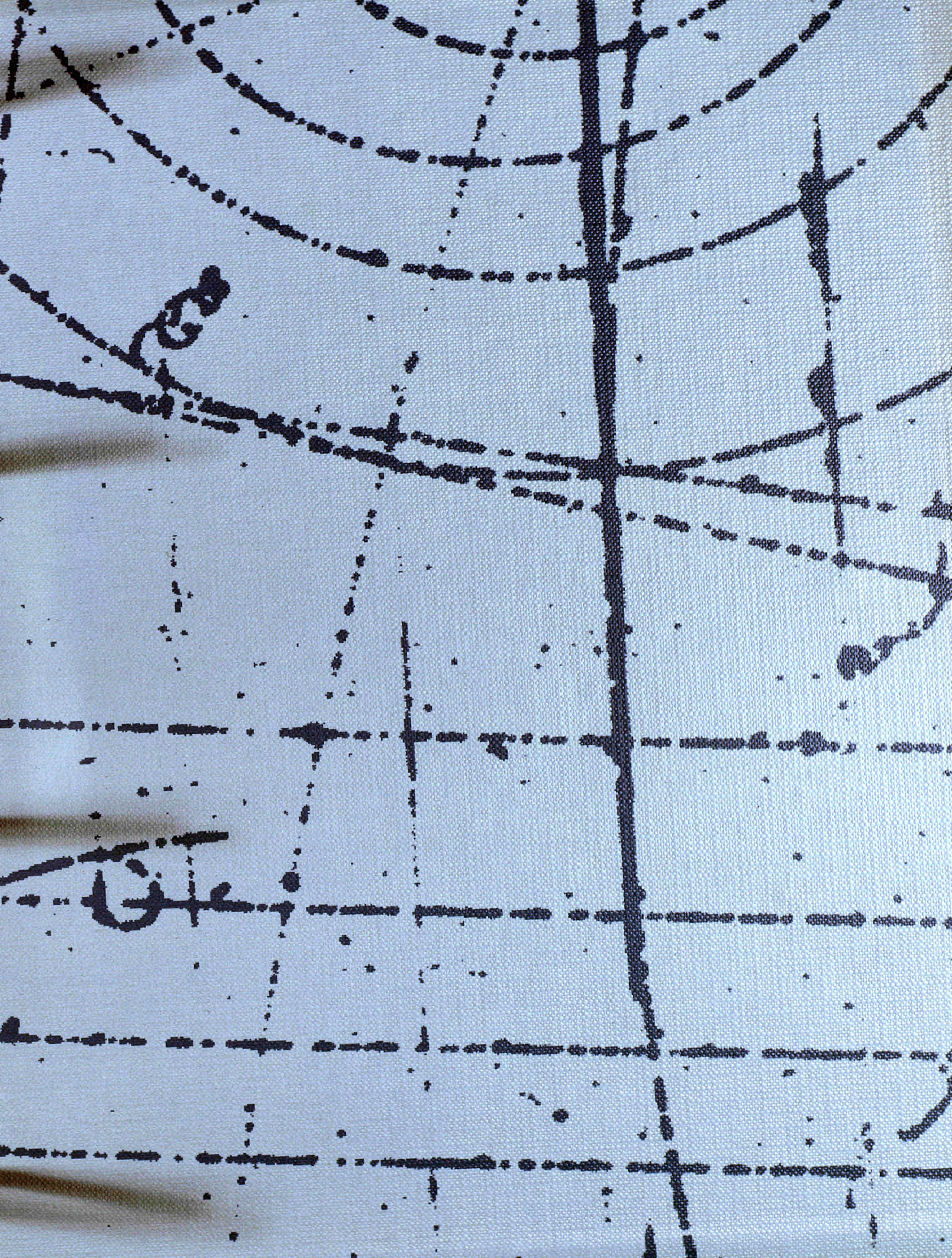
Sodel Photothèque EDF: V-18, M. Morceau III-8, M. Brigaud III-12, III-19/IV-5
ITAL: V-19

COLOPHON

Graphic design	Gert-Jan Bloemers, Oss, The Netherlands
Cover- & technical illustrations, lay-out & lithography	Theo Rabou, Vught, The Netherlands
Character-design of Paul, Angela and uncle Tom	Yon Prüst, Studyo-N, Vught, The Netherlands



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