Radiation — how much do you get?

Contents: A data-handling exercise which allows students to estimate their own radiation dose. This is accompanied by information and questions about the risks of radiation.

Time: Two periods or more, depending on the number of parts attempted.

Intended use: GCSE Physics, Chemistry, and Science courses. Links with work on radioactivity, nuclear power and pollution. It is assumed that students will have done some prior work on the nature of ionizing radiation.

Aims:

- To complement work on radioactivity and the potentially harmful effects of radiation
- To develop awareness of the extent to which we are exposed to natural and artifical radiation
- To develop awareness of the relative risks from radiation and other hazards
- To provide an opportunity to practise the skills of making estimates, reading data from maps and tables and evaluating data.

Requirements: Students' worksheets No.807. Students will need access to an atlas with a map of Great Britain.

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This unit consists of a short introduction followed by three parts:

Part 1 How are radiation doses measured?
Part 2 Working out your own dose
Part 3 What are the risks?

It may be better to omit Part 1 with some students and to concentrate on Part 2, which is the principle part. A record sheet is supplied to help the students to assess their radiation dose. In some cases the teacher may also want to simplify or omit Part 3.

Part 1 How are radiation doses measured?

This part can be used as background information for teachers if preferred. However, some students may be interested to understand the difference between the various units which feature in the news from time to time.

The discussion of units used to measure radiation has been simplified and teachers will find a fuller account of the topic in *Living with Radiation* from the National Radiological Protection Board (NRPB) (see *Further Resources*).

The energy transferred by radiation to unit mass of matter is called the *absorbed dose* and it is measured in *grays*. (The original unit of absorbed dose was the *rad.*)

Equal absorbed doses do not have equal biological effects. Alpha radiation, for example, is more harmful than beta radiation. This is allowed for by calculating the *dose equivalent* measured in *sieverts*. The dose equivalent is calculated by multiplying the absorbed dose by a factor to allow for the different ways that the various types of radiation affect living tissues. (The original unit for dose equivalent was the *rem.*)

A further complication arises because the risk of cancer, or genetic damage, is not the same in all tissues for a given dose equivalent. This is allowed for by taking the dose equivalent in each of the main organs of the body and multiplying it by a weighting factor related to the risk associated with that organ. The sum of the weighted dose equivalents is called the *effective dose equivalent*, which is also measured in sieverts.

The distinction between dose equivalent and effective dose equivalent is not mentioned in the unit. In general it is enough to know that the effective dose equivalent gives an indication of the risk to health from exposure to radiation. With some pupils it may be better to omit Part 1 and simply to tell them that radiation doses to the body are measured in sieverts.

Fractions and decimals are avoided in the unit by giving all the data in microsieverts, μSv. For many pupils it will be enough that they appreciate the relative contributions of the different sources of radiation. Detailed discussion of the meaning of the units is not required.

Teachers may like to note that many people (including reporters in the media) frequently confuse *radiation* with *radioactive materials*. The misconception leads to statements such as: 'There is radiation stored in the rocks'.

Part 2 Working out your own dose

All the information in this part of the unit has been supplied by the NRPB.

It is important to remind the students that all the figures are averages and they can only use the information supplied to make *estimates* of their total radiation dose. The unit is designed to make them aware of the main sources of radiation and the relative size of the likely doses from the different sources.

Ground and buildings

Figure 3 is based on a systematic survey of gamma ray dose rates by the NRPB. The dose rate will not be exactly the same in each area of the map and strictly the key should give ranges of values. However, only single values are quoted for each region to make it easier for students. The range is at least ± 50 μSv a year for each area.

On average people spend about 90 per cent of their time indoors and the dose rate indoors is significantly higher than outdoors. The average dose outdoors is about 200 μSv per year, while the average value indoors is 400 μSv per year.

Radiation from the air

The latest NRPB report about radiation exposure due to radon in homes was published in January 1987. The map in Figure 4 is based on that work and has been supplied by the NRPB. Again the key has been simplified and there is a range of values in each region.

Radon concentrations build up wherever there is restricted ventilation. The level of radon in homes depends mainly on the rate of input from the ground. Our exposure depends more on where we live than on the type of building we live in.

Most of the dose is from radon-222 daughters and not the gas itself. The four immediate decay products are polonium-218, lead -214, bismuth-214 and polonium-214. These are solids which form a radioactive aerosol in air. The two polonium isotopes are alpha emitters with short half-lives.

Radiation from medical treatments

The estimated doses for chest and dental X-ray examinations assume that more than one film will be used. These are the most common examinations. Examinations of other parts of the body generally involve considerably higher doses.

Radiation from nuclear power

The radiation dose from the nuclear industry to any given person depends on many factors including the location of their home, the fraction of the time they spend out of doors, their breathing rate, body size, diet and metabolism. So there can be a wide range of individual doses for a given level of contamination.

The values quoted in the unit are estimates for average members of the population.

Considerable variations in the dose from nuclear installations are possible. The figures given in the unit represent estimates of the likely dose for people living near power stations and fuel preparation plants. The doses could be higher or lower. The table below shows the NRPB estimates of the upper limits to the doses to the **most exposed** individuals from the nuclear power industry in 1984.

Stage	*Released to*	*Maximum dose μSv per year*
Fuel preparation	Air	5
	Water	50
Reactor operation	Air	100
	Water	350
Fuel reprocessing	Air	200
	Water	840

It should be remembered that radiation from long-lived nuclear waste produced by nuclear plants operating today will continue for hundreds of years. This future radiation needs to be taken into consideration when comparing the doses from nuclear installations with doses from other sources.

The table concerning the Chernobyl accident is taken from a preliminary report from the NRPB published in January 1987. Clearly the bulk of the radiation dose to individuals was received during the first year after the accident.In the first year, caesium-134 and caesium-137 contributed from 65 to 90 per cent of the average dose with the remainder being due to iodine-131.

It will only be possible to make a rough estimate of the 'Chernobyl dose' from this table. Students may need help from the teacher in making this estimate.

Part 3 What are the risks?

The way in which cancer is induced by radiation is not fully understood but groups of people who have been exposed to high doses of radiation do suffer a higher than average number of cancers. The problem is to estimate the risk from low-level radiation. At the moment estimates are made by a linear extrapolation from the observed risks from high-level radiation as shown in Figure 6.

The number of cancers may be small compared with those induced by other causes. For example, it is estimated that there will be about 1000 fatal cancers in the EEC as a result of the Chernobyl disaster. These cancers are predicted to develop over a few decades. This has to be compared with an estimated 30 million cancers in the same population over the next fifty years. Figures such as these make it impossible to detect the long-term health impact of low-level radiation.

There is a worldwide consensus that current estimates of the risks are unlikely to be in error by more than a factor of 2 or 3. Some dissenters from the general view argue that the risk is substantially higher; others suggest that it is substantially lower.

Further resources

1 Related SATIS units: Unit 204, *Using Radioactivity*, has information about the uses of radioisotopes, including medical uses; Unit 508, *Risks*, includes material on the risks of nuclear power.

2 The SATIS Audiovisual tape-slide programme, *Radiation Around Us*, is a simple treatment of the topic of low-level radiation and might make a suitable introduction to this unit.

3 A fuller treatment of the topic can be found in *Living with Radiation*, a booklet obtainable from the Information Officer, National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ.

Acknowledgements Figures 3 and 4 are reproduced by permission of the National Radiological Protection Board.

RADIATION — how much do you get?

We cannot see or smell or taste radiation. It is only in the last hundred years or so that we have been able to detect it. But people have always been exposed to radiation even before there was nuclear power or nuclear weapons.

Radiation reaches the earth from outer space. There are also naturally radioactive materials in buildings and in our food. Figure 1 shows some of the sources of the radiation to which our bodies are exposed all the time.

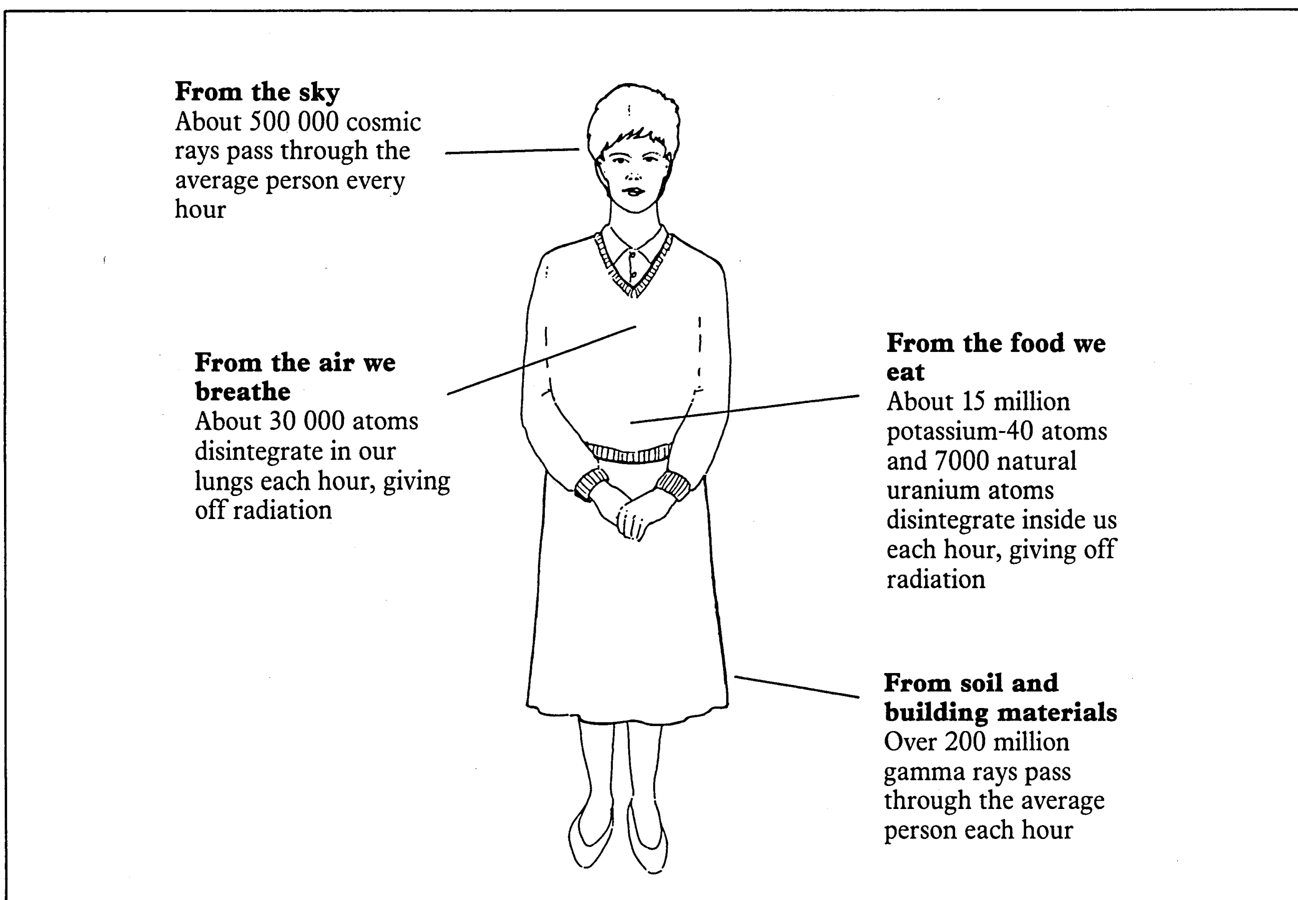

Figure 1 The main sources of our radiation dose

In this unit the word **radiation** means all the rays and particles which have enough energy to cause damage to living things. They include alpha and beta particles, gamma rays and X-rays. When something is exposed to radiation we say that it has been **irradiated.**

This unit is in three parts:

Part 1 tells you how radiation is measured.

Part 2 gives the information you need to estimate your own radiation dose

Part 3 discusses the risks of radiation and how it might affect your health.

Part 1 How are radiation doses measured?

Measures of radiation are quite often in the news. You may have heard various units being used including **becquerels, grays** and **sieverts.**

Why different units? What do they mean?

Radioactive decay

The nucleus of an atom changes during radioactive decay. It is possible to measure the number of nuclei which change per second in a sample. If one atomic nucleus decays per second the activity is one **becquerel, Bq.**

Energy transfer

Radiation carries energy. It transfers this energy to the matter which absorbs the radiation. The amount of energy transferred by radiation is measured in grays. One **gray, Gy,** is equal to **one joule per kilogram.** The more energy transferred, the greater the amount of damage the radiation can do.

Biological effects

Some types of radiation are more damaging to living things than others. Also some parts of the body are more at risk from radiation than others. This is allowed for by calculating an effective dose, measured in **sieverts, Sv.**

1 Sv is a large dose of radiation so we normally use millisieverts, mSv and microsieverts, μSv.

$$1 \text{ mSv} = \frac{1}{1000} \text{ Sv}$$

$$1 \text{ μSv} = \frac{1}{1\,000\,000} \text{ Sv}$$

You are going to make an estimate of your radiation dose in the last year. You will be given a record sheet to fill in as you work through the sections. All the units are in **microsieverts,** μSv.

Part 2 Working out your own dose

It is impossible to work out your exact radiation dose. But we can use average figures to make an estimate. Remember that your actual dose may vary widely from these averages.

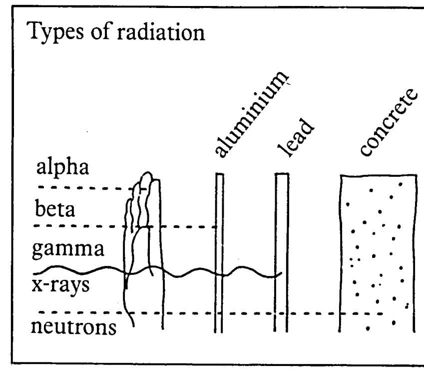

Figure 2 How different types of radiation can pass through different materials

Radiation from outer space — cosmic rays

Cosmic rays are high energy radiations from outer space. The atmosphere protects us from the full effect of cosmic rays. So the higher you live, or the higher you fly, the bigger your dose from cosmic rays.

Cosmic rays are also affected by the magnetic field of the earth. More cosmic rays reach the surface at the poles than at the equator. So the radiation dose from this source is higher the further north you go in Britain.

The average dose at sea level in the UK is **280 µSv per year**
Add **5 µSv per year** for every 100 m above sea level
Add **5 µSv per year** for every 100 miles north of the south coast of England
Add **4 µSv per hour** of air travel during the year

Fill in lines 1 to 4, the dose from cosmic rays, on the record sheet. Add up the values and enter the total in line 5.

Radiation from the ground and buildings

Some radioactive elements are found in the soil and in rocks. They include uranium, thorium and one form of potassium. Some rocks are more radioactive than others.

The gamma rays from these radioactive elements irradiate us all. Gamma rays can pass through materials in a way that alpha and beta particles cannot (see Figure 2).

Building materials are extracted from the earth, so they are radioactive too. We spend about 90 per cent of our time indoors. The indoor dose rates are higher than the outdoor values. They may be as much as twice as high.

The dose we get depends on where we live. You can make a rough estimate of your average dose each year by looking at the map in Figure 3. The map shows the doses out of doors.

Enter the value for the area where you live on line 6 of the record sheet.

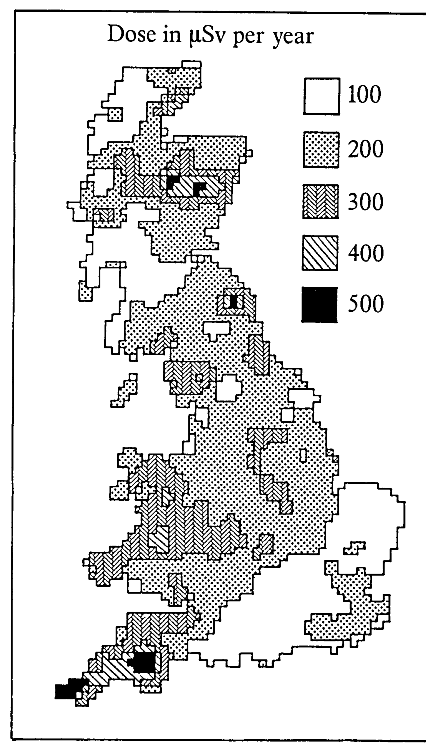

Figure 3 Gamma ray doses out of doors

Radiation from the air

Radon is a radioactive gas. It is formed by the decay of uranium and thorium in rocks and in the soil. The gas escapes from the soil and mixes with the air. Out of doors it is not a problem. But in a building it can be trapped. It can build up to levels which may be dangerous. We breathe in this radioactive gas and so it irradiates our lungs.

There are wide variations in the radon levels in the air in Britain. You can see this from the map in Figure 4. This means that you can only make a rough estimate of your likely dose.

Enter the value for your area in line 7 of the record sheet.

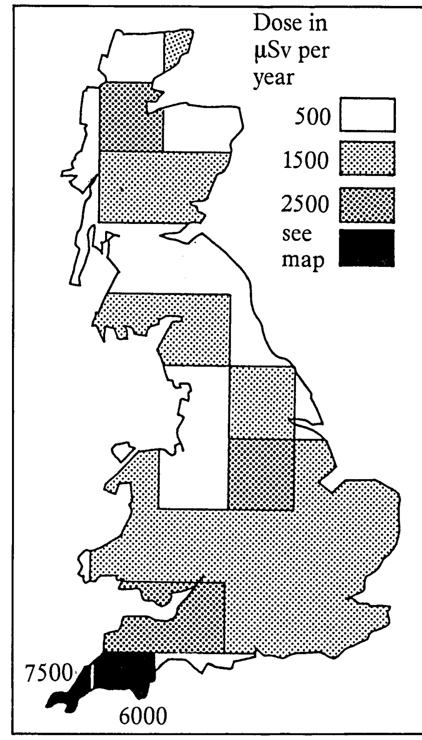

Figure 4 Radon map of Britain

Radiation from food and drink

There are radioactive elements in our food and drink. These irradiate the insides of our bodies. One of the major sources of this radiation is a radioactive form of potassium. Compounds of this form of potassium are present in food in tiny amounts.

Your dose will depend on your age, sex and diet. It is difficult to allow for variations, so take the average value. This is thought to be **370 µSv per year.**

Enter the value in line 8 of the record sheet. Then add up the values for the four main sources of natural radiation and enter the total in line 9.

Radiation from medical treatments

The commonest use of radiation in medicine is in chest X-rays. These X-rays do not come from radioactive elements but from a special X-ray tube. Your teeth may be X-rayed when you go to the dentist.

Radioactive elements are used in medicine to help investigate diseases and to treat cancers.

Your dose will depend on the treatments you have had in the last year. Typical doses for X-ray examinations are as follows:

Chest X-ray **50 µSv**
Dental X-ray **20µSv**

Enter your doses (if any) in lines 10 to 12 of the record sheet. Add up the values and put the total in line 13.

Radiation from nuclear weapons testing

Nuclear weapons were tested in the atmosphere until the test ban treaty of 1963 which was signed by most of the countries concerned. France and China have exploded bombs in the atmosphere since the treaty. The radioactive elements from test explosions are blasted high into the atmosphere. Then they gradually fall to the ground.

As you might expect, the fall-out from the tests has decreased since the ban. We are affected by the radioactive elements from this source because we may breathe them in or take them in our food. We are also exposed to radiation from fall-out on the ground.

The dose from nuclear weapons testing is estimated to be **10 μSv per year.** (Just before the test ban it was 80 μSv per year.) In areas of high rainfall the dose may be about 40 per cent higher.

Fill in line 14 on the record sheet.

Radiation from nuclear power

The nuclear power industry releases radioactive elements into the air, into rivers and into the sea.

Radiation is released from other places where work is done with radioactive isotopes. These include the radiochemical centres at Amersham and Cardiff, the United Kingdom Energy Authority installation at Harwell and the Ministry of Defence at Aldermaston. However, the average doses from these sources are estimated to be very low — less than 0.03 μSv per year even for those who live nearby.

Your dose from these sources depends on where you live and on what you eat. The total **average** dose from these sources is estimated to be **2 μSv per year.**

Your dose could be higher if you live near a nuclear plant (Figure 5). If you live close to Sellafield and eat much sea food you could have a dose as high as 1000 μSv from air, water and your diet. You could use the following figures as *very rough* averages. The actual dose could be lower or higher.

Add **1 μSv per year** if you live within 5 miles of a fuel preparation plant
Add **10 μSv per year** if you live within 5 miles of a nuclear power station
Add **50 μSv per year** if you live within 5 miles of Sellafield

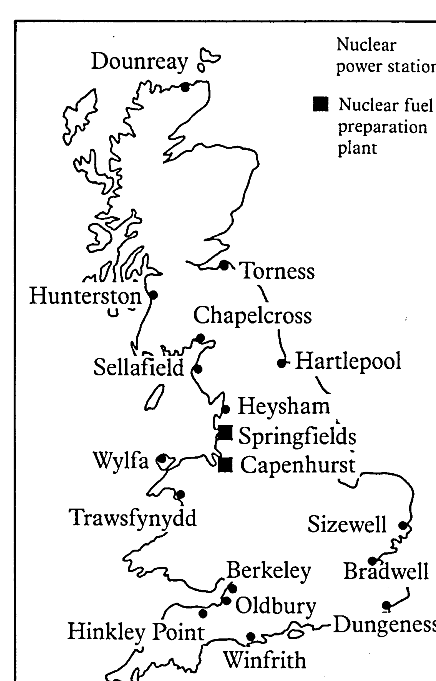

Figure 5 Nuclear installations in Britain

The Chernobyl accident happened in April 1986. Radiation from the accident will add to your dose. The size of the dose will depend on where you live. Table 1 gives you values for different parts of the country. The first column shows the dose in the first year after the accident. The second column shows the **total** dose over **50 years.** Use the table to make an estimate of your dose in the last year.

Now fill in lines 15 to 17 on the record sheet. Add the values and put the total in line 18.

Table 1 Radiation doses from the Chernobyl accident

Region	*Dose in first year /µSv*	*Total dose over 50 years/µSv*
Cumbria N. Wales, SW Scotland	190	270
Rest of England	20	25
Rest of Wales	29	37
Rest of Scotland	83	150
N. Ireland	97	170

Other sources of radiation

Most people are exposed to a variety of other sources of radiation. Sources include luminous watches, TV sets and fire detection devices. The radiation from these domestic appliances is small and amounts to not more than **1 µSv per year** on average.

There are traces of radioactive elements in the ash from burning coal. Some of this ash is carried into the air and can give an average dose of about **4 µSv per year.**

Now fill in lines 19 and 20 on the record sheet. Add the values and put the total in line 21.

Add up the values for the four main sources of artificial radiation. Enter the total in line 22.

Finally add the figures in lines 9 and 22 to get your total dose for the year. Write the value in on line 23.

Now answer questions 1 to 6.

Questions

1 *What is your total annual dose in microsieverts, µSv?*

2 *(a) How much of your radiation dose comes from natural sources?*

(b) Work out the fraction of your radiation dose which comes from natural sources.

3 *What is the largest artificial source of radiation in your dose?*

4 *Draw a bar chart to show the sizes of the various parts of your annual dose of radiation.*

5 *Why do the average doses from artificial sources vary across the country?*

6 *You have been using average doses to compare the amount of radiation you get from different sources. What is the problem with making the comparison this way?*

Part 3 What are the risks?

Low-level radiation

The average dose of radiation in England from all sources is about 2200 μSv per year. This is *low-level* radiation. As you know from Part 2, your own dose depends on where you live and where you travel.

Everyone knows that **high-level** radiation is very dangerous. It is more difficult to decide on the size of the risks from **low-level** radiation. At the moment it is assumed that there is some risk from any radiation dose, however small. This is shown in Figure 6.

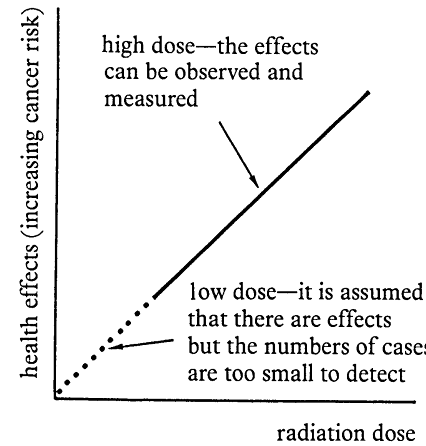

Figure 6

What are the dangers?

People are worried that radiation causes cancer. It may also have genetic effects so that future generations will be affected.

Our knowledge about the effects of radiation comes from various studies. Survivors of the atomic bomb attacks at Hiroshima and Nagasaki have been studied since the end of the Second World War.

Some hospital patients have received large radiation doses as part of their medical treatment. There have been studies of the effects.

A number of surveys have been made of the health of people working in the nuclear industry and of people who live near nuclear installations.

The risks of low-level radiation are too small to be measured directly. Instead, they are estimated using a graph such as Figure 6. The line showing the **observed** effects of high-level radiation is extended back in a straight line into the regions where the effect is too small to detect.

Why is it hard to be sure?

A dose of 1000 μSv is believed to lead to a risk of 1 in 100 000 of getting a cancer over the next 40 years or so. At the moment it is estimated that the average annual dose of 2200 μSv causes 1200 deaths from cancer per year in Britain.

These numbers are small when compared with the 145 000 cancer deaths each year in Britain. The numbers vary from year to year. This means that it is hard to detect the small number of deaths from artificial radiation.

Cancer and other effects of radiation usually take many years to develop. In that time people may have been exposed to many other factors which cause the disease. This makes it difficult to be sure what caused the cancer in the first place.

Table 2 compares the risk of death from radiation with the risks from other sources.

What are the guidelines?

Scientific studies can estimate the risks from radiation, but in the end it is governments which decide policy. There are three guidelines:

Risks and benefits

The first guideline says that no practice should be adopted unless the benefits are greater than the risks.

X-rays are used in medicine because of the benefits of spotting a disease early, but there is a risk. Clearly it would be wrong to have a mass X-ray programme likely to cause more cancers than might be found by the survey.

The risks of radiation from nuclear power also have to be balanced against the benefits. Those who work in the industry have a higher risk than the general public. There is the risk of reactor accidents and the problem of looking after nuclear waste.

The alternative to nuclear power is to burn fuels such as coal and oil. These alternatives have their problems too. Burning fuels increases the amount of carbon dioxide in the air and in time this may have serious effects on the climate. Burning coal in power stations is a major cause of acid rain.

Keeping doses as low as is reasonably achievable

It is assumed that no radiation dose is free from risk. So it makes sense to keep doses low. It can become very expensive to reduce doses below a certain level. Someone has to decide how much it is worth spending to reduce what may already be a small risk.

Dose limits

The idea of a dose limit is that doses should not exceed the agreed limits. At the moment in Britain the limit is 50 000 μSv per year for people who work in the nuclear industry. It is 1000 μSv per year for the general public. In other words, the guideline says that no member of the public should receive more than 1000 μSv of artificial radiation in any year.

The limits are based on the judgement of scientists. In Britain it is the National Radiological Protection Board which advises governments on the limits.

Now answer questions 7 and 8.

Table 2

Cause of death	*Risk of death per year*
Lung cancer from smoking 20 cigarettes a day	1 in 200
Natural causes for a 40-year-old adult	1 in 850
Accidents on the road	1 in 10 000
Accidents at work	1 in 40 000
Radiation dose at a rate of 1000 μSv per year	1 in 80 000

Questions

7 *People living near a nuclear power station are likely to have a higher radiation dose than the rest of the population. What benefits, if any, can there be for these people? Would you expect all these people to be opposed to nuclear power?*

8 *Here are two possible guidelines:*

A Keep radiation doses as low as is reasonably achievable.

B Keep radiation doses as low as is technically possible.

(a) What are the differences in the meaning of the two guidelines?

(b) Present policy is based on guideline A. Some people argue that we should apply guideline B - whatever the cost - because we are not yet sure about the effects of radiation. What do you think?

My estimated radiation dose per year

		μSv/y	μSv/y	μSv/y
Dose from cosmic rays	1 Average dose at sea level			
	2 Allowance for height above sea level			
	3 Allowance for distance north of the south coast			
	4 Air travel (total dose in the year)			
	5 Total dose in the year			
Dose from the ground and buildings	6 Average dose in the year (enter the value from Figure 3 for your area)			
	7 Average dose in the year (enter the value from Figure 4 for your area)			
Dose from food and drink	8 Average dose in Britain			
	9 Total from natural sources			
Dose from medical treatments	10 Chest X-ray			
	11 Dental X-ray			
	12 Other treatments			
	13 Total in one year			
Dose from nuclear weapons testing	14 Estimated annual dose in Britain			
Radiation from nuclear power	15 Average dose in Britain			
	16 Additional dose if living close to a nuclear power station or processing plant			
	17 Chernobyl accident			
	18 Total			
Other sources of radiation	19 Domestic appliances			
	20 Ash from coal burning			
	21 Total			
	22 Total from artificial sources			
Grand total	**23 Total from all sources**			