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.

Authors: Richard Taylor and Andrew Hunt

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.

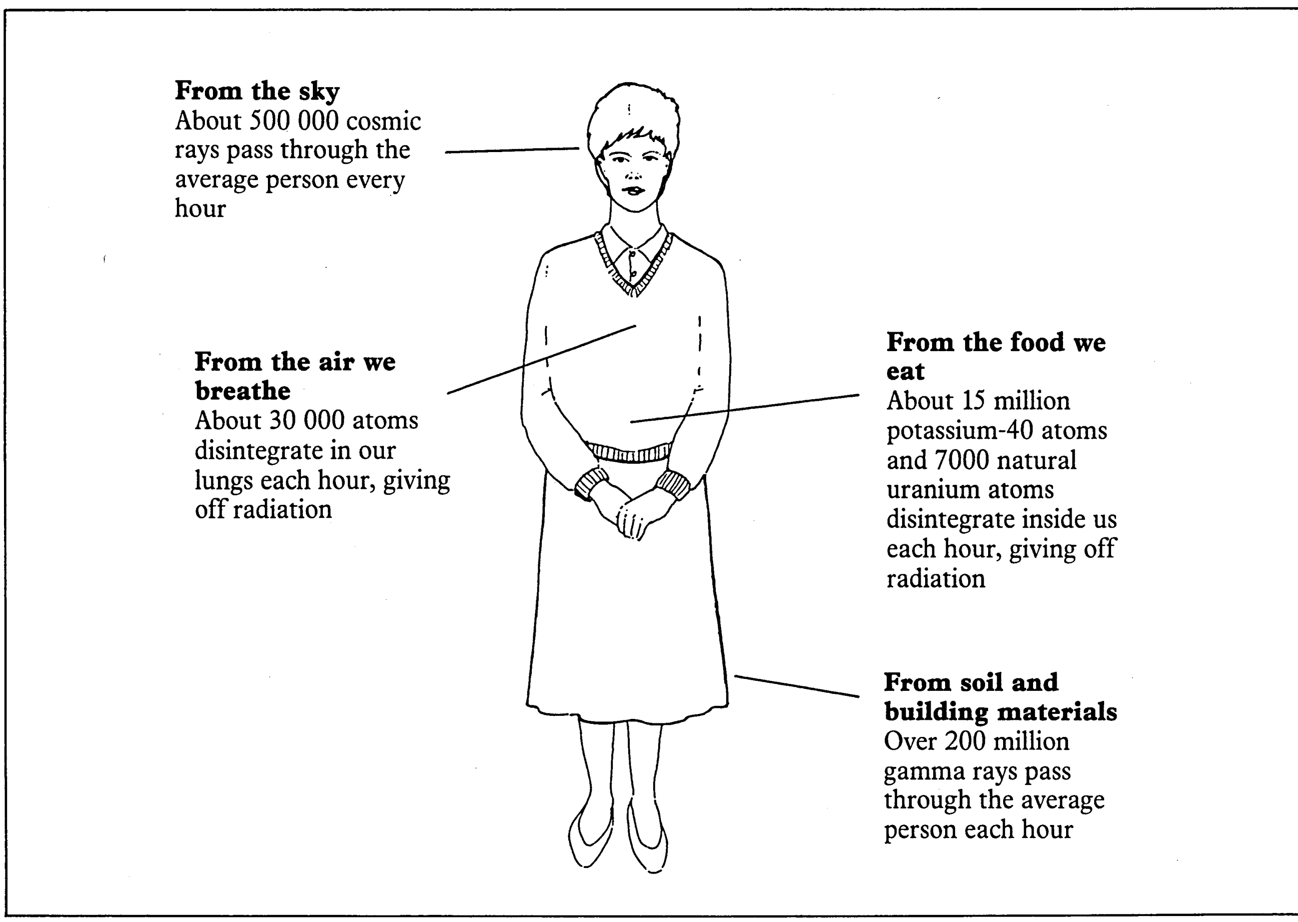


Figure 1 The main sources of our radiation dose

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.

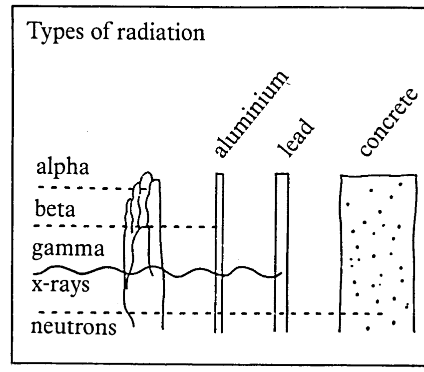


Figure 2 How different types of radiation can pass through different materials

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.

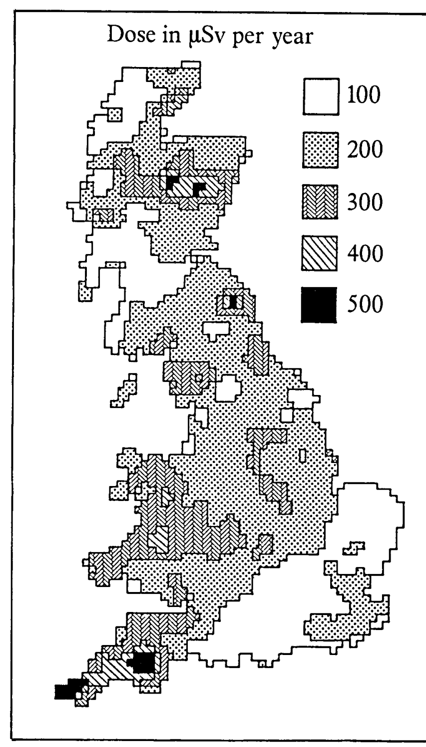


Figure 3 Gamma ray doses out of doors

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.

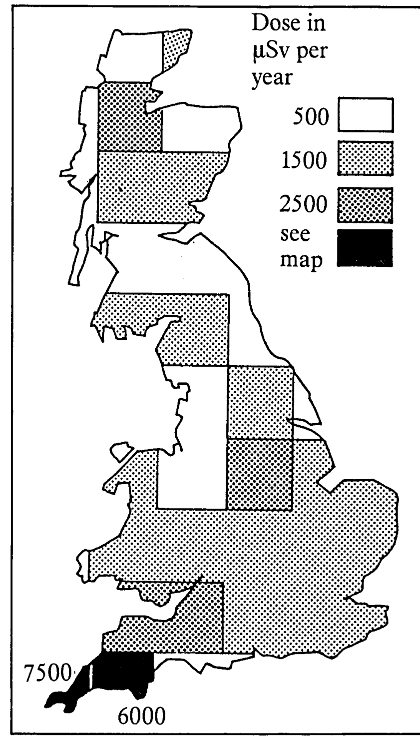


Figure 4 Radon map of Britain

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

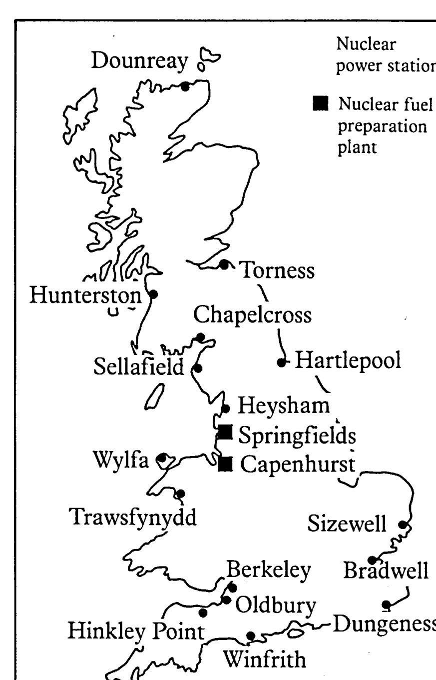


Figure 5 Nuclear installations in Britain

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.

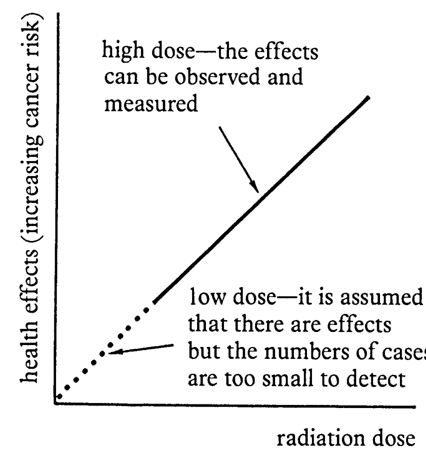


Figure 6

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**			

Nuclear Fusion

Contents: A structured discussion on the possibility of using nuclear fusion to generate electricity.

Time: Homework plus 1 double period.

Intended use: GCSE Physics, Chemistry or Science. Most likely to be of use at the end of a GCSE course, in the fifth year, and could also be used at sixth-form level. Links with work on nuclear structure, radioactivity, nuclear fission, generation of electricity and energy sources.

Aims:

- To complement and revise prior work on atomic structure, radioactivity and energy supply
- To introduce the principles of nuclear fusion, and its use in the generation of electricity
- To develop an informed awareness of some of the issues concerned with nuclear fusion
- To promote an awareness of the value of working with other countries
- To provide an opportunity to practise communication skills and to encourage students to enter into discussion.

Requirements:
For each member of the class:
1 copy of the Introduction (Sheet I)
1 copy of the General Briefing (Sheets GB)
1 copy of the Test (Sheet T)

For each group of five students:
1 copy of each of the Expert's Briefing Sheets (Sheets EB1, EB2, EB3, EB4)
1 copy of the Chairperson's Briefing Sheets (Sheets CB)

Author: Gerry Gibbons

This structured discussion is intended to give a factual introduction to the generation of electricity from nuclear fusion and to help students weigh up some of the issues related to nuclear fusion. It is designed for use after they have studied the atomic nucleus and nuclear energy. The General Briefing is no more than a condensed summary. The teacher may well want to go through the material covered in the General Briefing with the class before starting the discussion.

Procedure

1 Give each student a copy of the General Briefing. Allow time to read and study it — this is best done for homework preceding the lesson.

2 Get students to do the test. This should take no more than 15 minutes. Go through the answers.

3 Form the class into groups of five. Each group should have a Chairperson, chosen for his or her potential for leading a discussion. If the class does not divide neatly into groups of five, have some groups of six.

4 Give the Chairpersons their Briefing Sheets (CB). Give Expert's Briefing Sheets (EB1, EB2, EB3, EB4) to the other four members of each group — a different briefing to each member in a group. If any groups have six members, EB1 could be given to two people. Allow them time to study the sheets before beginning the discussion. If the timing of lessons permits, it is most effective if students are able to study their briefings beforehand, perhaps for homework.

Other resources

The United Kingdom Atomic Energy Authority produce a wide range of resources, many of them free. They include leaflets, booklets, posters, audio-visual packs and films. Naturally, these materials put the case in favour of nuclear power.

UK Atomic Energy Authority
Information Services Branch
11 Charles II Street
London SW1Y 4QP

Particular information on fusion research can obtained from:

The Information Centre
UKAEA
Culham Laboratory
Abingdon
Oxon OX14 3DE

Acknowledgements Figure 1 (Sheet I) and Figure 2 (EB1)/Figure 1 (EB2) from material supplied by United Kingdom Atomic Energy Authority; Figure 3 (GB) reproduced as line drawing by courtesy of UKAEA Culham Laboratory; Figure 1 (EB4) from diagram in W.Häfele, et al., *Fusion and Fast Breeder Reactors* (International Institute for Applied Systems Analysis).

NUCLEAR FUSION

Introduction

In power stations the generators are run by turbines. Energy is needed to produce high pressure steam which drives the turbines. The energy often comes from burning fuels such as coal or oil.

In nuclear power stations the energy comes from fission (splitting) of uranium atoms. In the future the energy may come from nuclear fusion (joining).

Here are some of the questions you will think about as you discuss the ideas in this unit.

- What will happen in about 100 years' time when oil and uranium have nearly run out?
- Can we get the energy we need from renewable sources such as the wind, the sun and waves?
- The sun and stars get their energy from nuclear fusion. Can we overcome the problems of controlling this source of energy on earth?
- Can fusion become a safe, clean and economic way of producing electricity?

Before starting you need to know some of the facts about nuclear fusion. First, you will be given a General Briefing. After studying this you will do a short test to check your understanding.

After that you will be working in a small group. You will discuss some of the questions and problems of using fusion power to generate electricity.

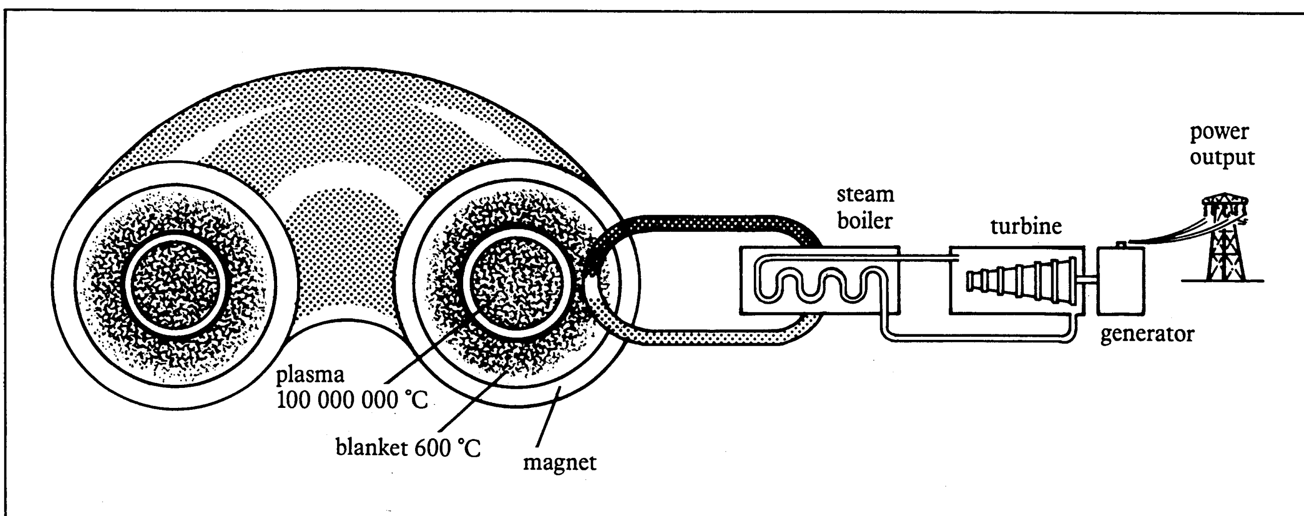


Figure 1 A diagram showing the main parts of a fusion power station

General Briefing

This is a summary of the theory of nuclear fusion.

What is nuclear fusion?

Nuclear fusion means joining together very light atoms. This is the opposite of what happens in normal nuclear power stations. They get their energy by splitting heavy atoms.

The energy of the sun comes from nuclear fusion. Can fusion be controlled? Can we make a small 'sun on earth' and use the energy to generate electricity?

Hydrogen atoms

Hydrogen atoms exist in three forms. Most hydrogen atoms have just one proton and one electron. Some hydrogen atoms have a neutron as well. This form of hydrogen is called deuterium. A third form has two neutrons and is called tritium.

Atoms which have the same number of protons and electrons but different numbers of neutrons are called **isotopes.** So there are three isotopes of hydrogen as shown in Figure 1.

Hydrogen and deuterium are not radioactive. Tritium is radioactive.

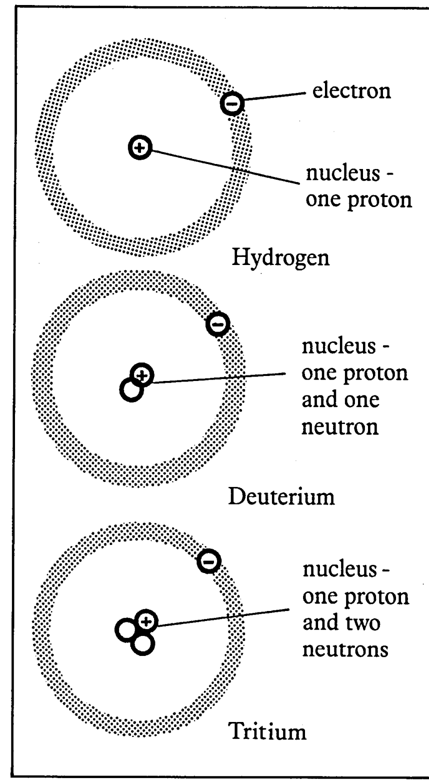


Figure 1 The three isotopes of hydrogen

Fusion Fuels

Deuterium and tritium are fuels for fusion reactors. A cubic metre of water contains 34 g of deuterium, so there is plenty of this fuel in the world — enough to supply fusion reactors for millions of years.

Tritium does not occur naturally in large quantities, so it has to be formed inside the reactor. Tritium can be formed in a fusion reactor by bombarding lithium with neutrons.

The problems of nuclear fusion

Fusion is the joining together of two **nuclei**. This is a much more difficult task than joining **atoms** together chemically.

There are big problems, but the reward is a supply of energy which will last practically for ever. Research towards a fusion reactor began in the late 1940s in Britain, America and the USSR. Since the early 1960s these countries and others have exchanged information. Progress has been made but we still do not know whether it is possible to make electricity commercially by nuclear fusion.

Fusion is difficult because the positive charges on the two nuclei repel each other. A big force is needed to push them together so that they join.

A temperature of 100 000 000°C is necessary for fusion reactions. At this temperature the atoms are moving fast enough. They have enough energy to overcome to repulsive force pushing them apart. They can get close enough to fuse (join).

Plasma

At the very high temperatures needed for fusion all gases become plasmas. The electrons and nuclei of the atoms separate. Because plasmas needed for fusion are so hot, they cannot be kept in an ordinary container. But plasmas can be contained in magnetic fields. A magnetic 'cage' can be made to hold them.

Energy from fusion

The idea of a fusion reactor goes like this. Deuterium and tritium fuse to form helium and high speed neutrons (Figure 2). Helium is not radioactive.

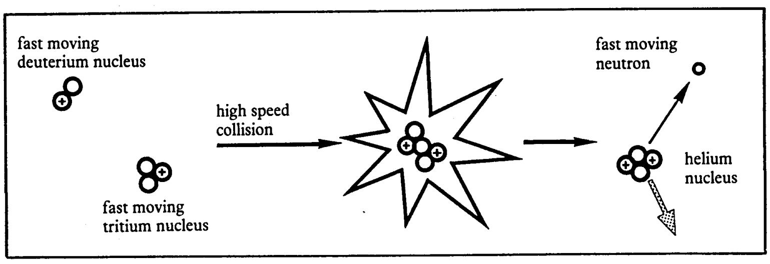


Figure 2 The process of nuclear fusion. In the plasma the atoms have lost their electrons. The nuclei have to collide fast enough to overcome the repulsion between the positive charges.

In a fusion reactor the neutrons are stopped by lithium atoms. The lithium is in the 'blanket' around the reactor. As the neutrons slow down their energy is transferred to heat water and turn it into steam. The steam is then used to generate electricity.

The tritium needed by the reactor is made as the lithium blanket is bombarded by neutrons.

Lithium and the materials used to make the reactor are not radioactive. However, the walls of the reactor become radioactive when they are bombarded by neutrons.

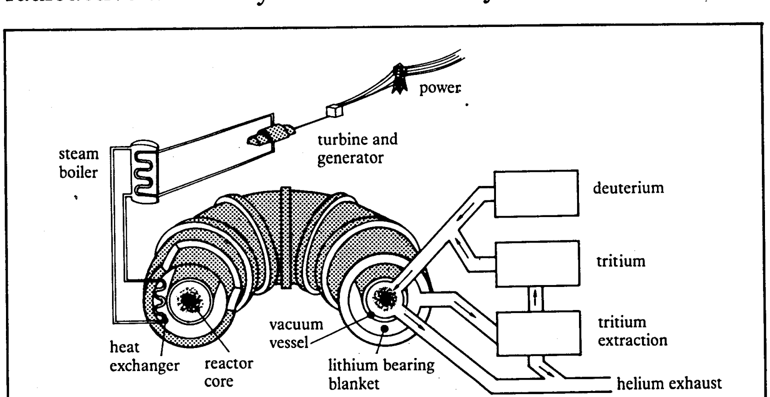


Figure 3 A scheme for a fusion reactor

Test on nuclear fusion

1 Which particles are found in the nucleus of an atom?

2 What is the difference between nuclear fission and nuclear fusion?

3 What are isotopes?

4 Where will the deuterium needed for fusion power come from?

5 Where will the tritium needed come from?

6 Why is a very high temperature needed for fusion?

7 What happens to the atoms when a gas becomes a plasma?

8 What job is done by the lithium blanket in a fusion reactor?

9 How will the energy from fusion be used to generate electricity?

10 Why are people now interested in the possibility of using nuclear fusion to generate electricity?

Expert's Briefing 1

The problem of containment

You will shortly be taking part in a group discussion on nuclear fusion. You are the only one in your group who has read this briefing, so you will be the expert on the problem of containment.

After you have read this, the Chairperson of your group will be asking the kinds of questions a 'man or woman in the street' might ask. Try to answer them as simply as possible, in your own words. Draw diagrams if it helps your answers. It is especially important that you understand and can explain the Tokomak system shown in Figure 2.

In nuclear fusion, nuclei in the plasmas react at very high temperatures. The 'problem of containment' is how to contain these plasmas for long enough to get energy out.

At temperatures of 100 000 000°C, ordinary containers would vaporize. However, plasma can be contained by magnetic fields. Scientists have investigated many different shapes of magnetic fields to find the best magnetic cage.

Fusion research started in universities around 1948 in apparatus no larger than a dinner plate. Gradually, larger devices were built, producing higher temperature plasmas for longer times. Different shapes of magnetic fields were studied. They led to the 'Tokamak system' first pioneered by scientists in the Soviet Union. In this system, plasmas are both heated and contained in a Tokamak.

The word Tokamak is Russian. It describes the shape of the plasma and the way it is contained.

In a Tokamak, plasma is heated in a doughnut shaped container, called a torus (Figure 1). It is heated by a large electric current produced by a transformer (Figure 2). The plasma is kept in place by the combination of two magnetic fields. One is produced by the plasma current and the second by the field coils.

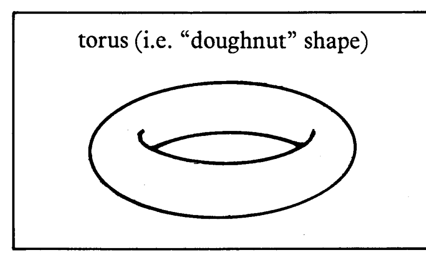


Figure 1 The torus

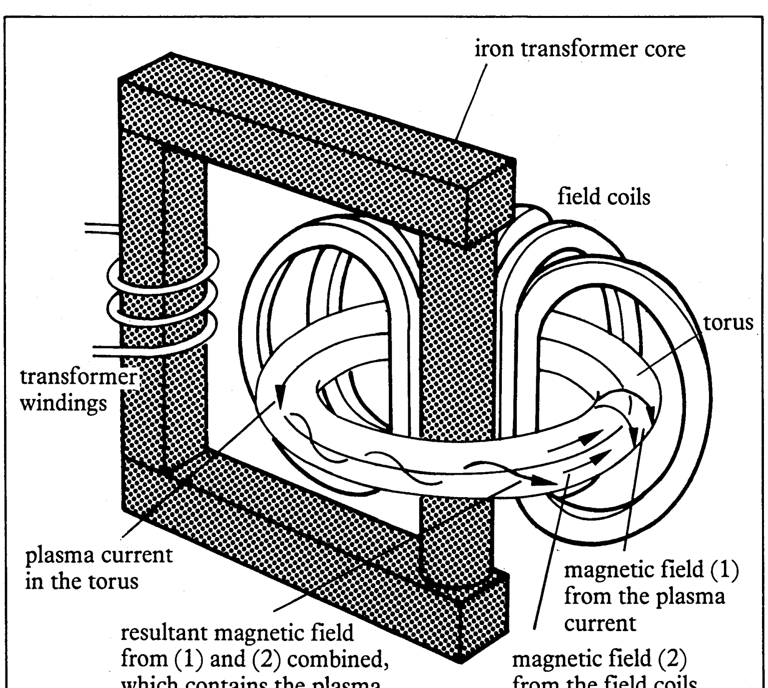


Figure 2 The Tokamak system

The magnetic 'cage' is able to keep in the plasma because the plasma is made up of charged particles (nuclei and electrons). As they move in the magnetic field, these charged particles experience a force which keeps them in place.

JET (The Joint European Torus)

JET is the largest Tokamak in the world. It is at Culham, near Oxford. JET is about 11.5 metres high and 15 metres in diameter.

The costs of JET are shared by the countries of the European Community together with Sweden and Switzerland. About half the team of scientists, engineers and administrators are British.

In the first three years of JET's experimental programme (1983-86) progress has been very impressive. Temperatures up to 140 000 000°C have been obtained in deuterium plasma. However, the containment of the plasma is not yet good enough for a working reactor. In the remaining five years of operation (1987-92) JET aims at getting the containment of plasmas closer to the conditions required in a reactor.

Expert's Briefing 2

Getting the conditions right

You will shortly be taking part in a group discussion on nuclear fusion. You are the only one in your group who has read this briefing, so you will be the expert on getting the conditions right in a fusion reactor.

After you have read this, the Chairperson of your group will be asking the kinds of questions a 'man or woman in the street' might ask. Try to answer them as simply as possible, in your own words. Draw diagrams if it helps your answers.

- A project called JET is a stage in a long research programme to find out whether fusion can be controlled as a source of energy.
- The second stage will be to develop the technology to show that the energy from fusion can produce electricity.
- The third stage will be to build an economical power station.

At the moment we are only at the first stage - trying to release controlled energy from fusion.

The three main problems

In order for fusion to happen, three conditions have to be met:

1 The temperature must be 100 000 000°C or more
2 The density of the plasma must be high enough
3 The plasma must be contained for a long enough time.

The big problem is to achieve all these conditions at the same time.

Heating the plasma

In the JET experiments, a transformer is used to produce a very large current flow in the plasma (Figure 1). The plasma is

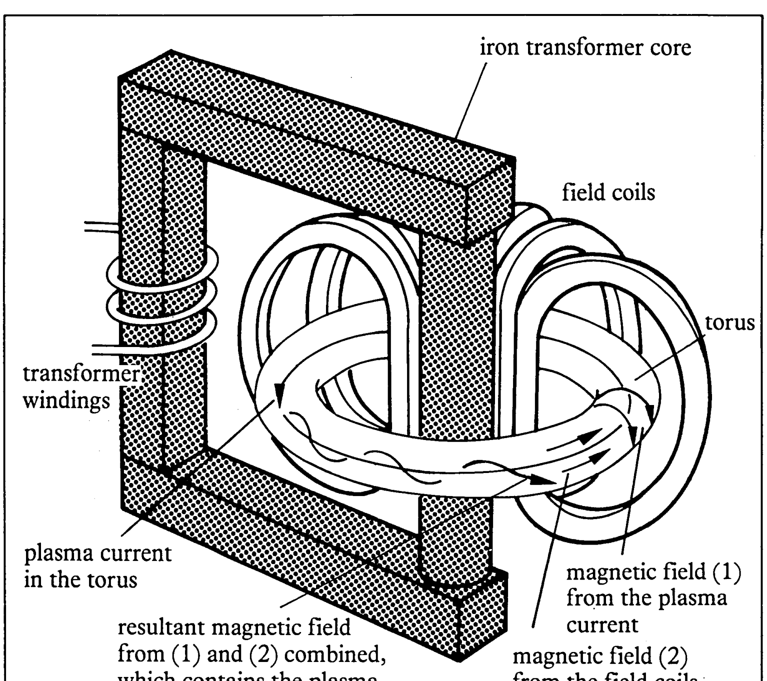


Figure 1

not a perfect conductor. In other words it has electrical resistance, and it heats up as the current flows. This is similar to the heating of an electric bar fire as a current flows through the heating wires. Unfortunately the plasma's resistance falls as it heats up. When the temperature reaches about 30 000 000°C it cannot be heated much more just by increasing the current.

Two extra methods of heating are used. One of these is to beam radiofrequency waves at the plasma. These waves are the right frequency to be absorbed by the plasma. This method works like a microwave cooker.

The second method is to bombard the plasma with high energy hydrogen or deuterium atoms. These fast atoms are fired in and they give their energy to the plasma.

Using all three heating methods it is possible to reach temperatures above 100 000 000°C.

Other problems

There are many other problems which need more research. For example:

- What materials should the reactor torus be made of? Can they stand being continually bombarded by neutrons?
- How can the fuel be put in, and the used fuel be removed?
- Can superconductors be used to make the coils which produce the magnetic field? (Superconductors have no resistance at low temperatures and so they waste less energy.)
- How can the energy released be transferred to raise steam?
- How can the whole system be made sufficiently reliable, safe and economic to run?

Expert's Briefing 3

You will shortly be taking part in a group discussion on nuclear fusion. You are the only expert on the world energy scene.

After you have read this, the Chairperson of your group will be asking the kinds of questions a 'man or woman in the street' might ask. Try to answer them as simply as possible, in your own words. Draw diagrams if it helps your answers.

World Energy Scene and European Collaboration

The World Energy Scene

Throughout the world we are using up reserves of petroleum, natural gas, coal and uranium. These reserves are limited. We must therefore turn to other energy resources.

Alternative power sources such as geothermal energy, wind and the tides, seem most unlikely to provide all the energy we need.

Coal reserves are large but coal is a useful source of chemicals. Coal can be the base for making a wide range of chemical products. Many people think that coal is 'too good to burn'.

Three sources need to be considered to meet our long-term energy needs:

- Fission breeder reactors
- Controlled nuclear fusion
- Solar energy

The graph in Figure 1 (on the next page) shows one future possibility. Remember it is impossible to predict the future — it is only a guess!

You can see from Figure 1 that coal will be important in the future. Uranium fission in ordinary nuclear power stations will only be useful for a relatively short time.

Fission breeder reactors, like the one at Dounreay in Scotland, could be important. These reactors use plutonium as their fuel. As well as producing energy these reactors can be used to turn uranium into plutonium. They can 'breed' more fuel.

However, there are worries about the dangerous radioactive waste from breeder reactors. Politicians may decide not to build them.

Fusion is a possible solution, but we do not yet know if we can make it work.

Working together on fusion research

There are four main fusion-research programmes being carried out in the world. America, Japan, the USSR and Europe have international agreements to keep each other informed of technical progress.

Fusion research is carried out in many countries in Europe as part of a coordinated programme. The JET (Joint European Torus) project was set up in 1978 as a major research project into nuclear fusion.

The European fusion programme has three long-term objectives.

1 *Scientific*
To show that energy can be gained from controlled nuclear fusion.

2 *Technical*
To prove that it is possible to design and construct a machine that will produce electricity from fusion.

3 *Commercial*
To show that a fusion powered nuclear station could produce electricity economically on an industrial scale.

The JET project will study the first of these. The costs are immense. European collaboration is needed to share the costs.

> The cost of the JET project up to 1992 is estimated as £750 million. This covers design, construction and operation.
>
> 80 per cent of the cost is paid by Euratom (European Atomic Energy Community). 10 per cent is paid by the UK where the experiment is based.
>
> The remainder is paid by the countries taking part in the experiment.

> Key to the terms in Figure 1.
>
> *Energy sources:*
> NG Natural Gas
> **FUS Nuclear fusion**
> NUC Nuclear fission
> REN Renewable sources (wind, solar)
> HYD Hydroelectric power
> N-C Renewable sources which are not commercial (firewood and dung)
>
> In this graph all the energy sources are compared to oil. Gtoe stands for Gigatonnes of oil equivalent.
>
> (1 gigatonne = 1 000 000 000 tonnes)

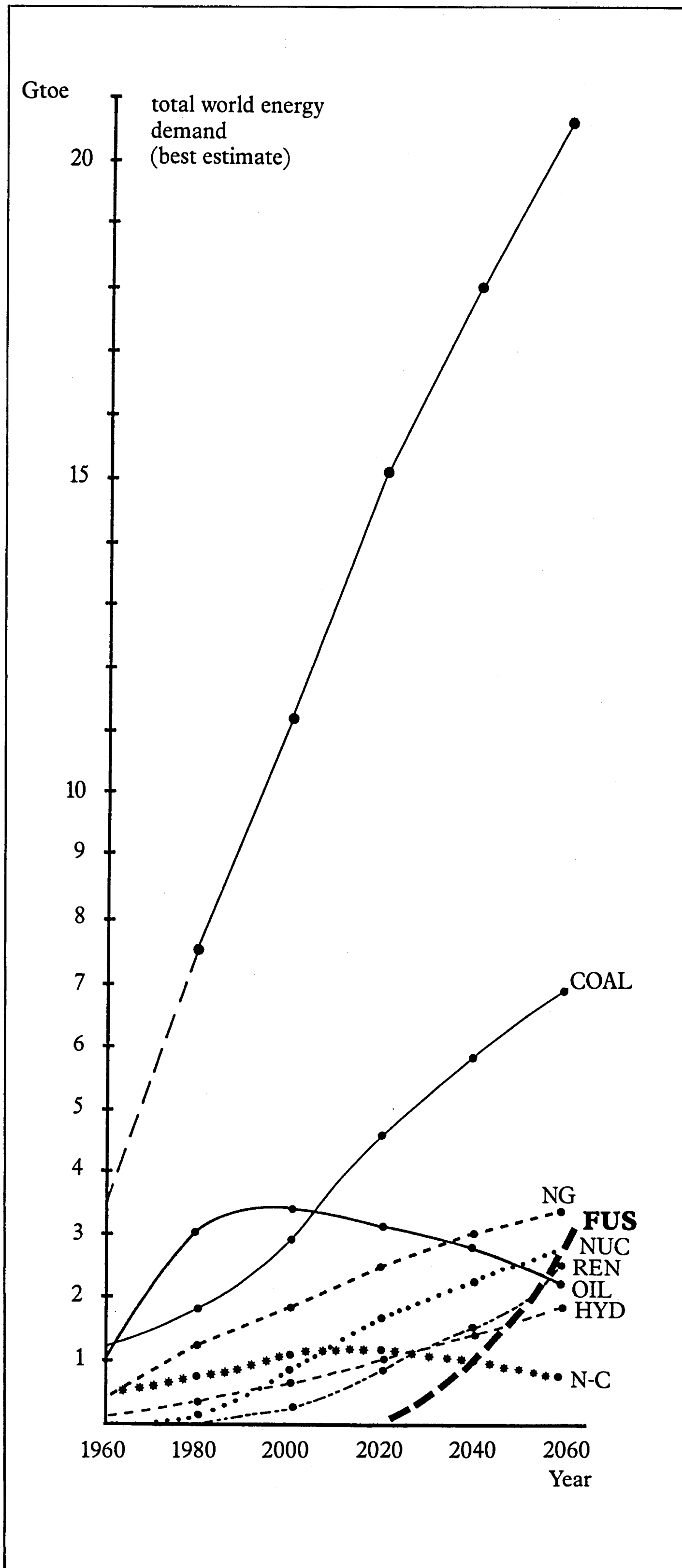


Figure 1 Possible use of energy sources up to the year 2060

Expert's Briefing 4

The advantages and disadvantages

You will shortly be taking part in a group discussion on nuclear fusion. You are the only person in your group who has read this briefing, so you will be the expert on the advantages and disadvantages.

After you have read this the Chairperson of your group will be asking the kinds of questions a 'man or woman in the street' might ask. Try to answer them as simply as possible in your own words. Draw diagrams if it helps.

Advantages of fusion power

1 New sources of energy will be required as oil becomes increasingly scarce and coal is needed as a raw material for industry. Fusion could become that major new source of energy.

2 Fusion fuels are very plentiful, cheap and are well distributed throughout the world. The first generation of fusion power stations will use deuterium (from water) and lithium (mined from the earth). Eventually it is hoped that the more difficult fusion reactions using deuterium alone will be used. This would provide an almost limitless source of energy.

3 Small quantities of fuel are required. Only about one tonne of fuel per year would be used in a 1000 megawatt fusion power station.

4 The fusion reactor will be a very safe system. At any given time the amount of fuel in the reactor will only be sufficient for a few tens of seconds' operation.

5 Fission reactors produce long-lived radioactive products, which require storage and supervision for very long periods of time. Fusion reactors do not produce these dangerous products. There will be no radioactive waste fuel from a fusion reactor.

6 Conventional power stations release chemical pollutants into the atmosphere, causing acid rain and other problems. Fusion reactors do not.

Disadvantages

1 It has not yet been proven that fusion can be made to work on an industrial scale.

2 A fusion reactor is likely to be very expensive to build, although the fuel costs will be very low.

3 The structure of the reactor will become radioactive and the reactor vessel (torus) will need to be replaced several times during the life of the reactor. However the radioactivity can be cut down by choosing materials carefully. Storage of radioactive waste may be needed for less than 100 years.

4 Fusion power is only suitable for highly industrialised nations. It is not likely to be appropriate for developing countries.

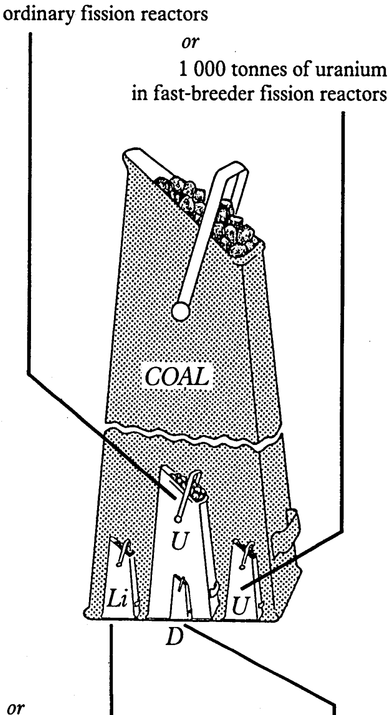
Do you know that . . .

To provide the equivalent of the *world's annual electricity consumption,* in power stations, we would have to use each year:

1 700 000 000 tonnes of coal

or
85 000 tonnes of uranium in ordinary fission reactors

or
1 000 tonnes of uranium in fast-breeder fission reactors



or
1 000 tonnes of lithium in a deuterium-tritium fusion reactor

or
135 tonnes of fuel in a deuterium-deuterium fusion reactor

Figure 1

Chairperson's Briefing

You are Chairperson of a group of students. It is your job to ask questions and chair a discussion on nuclear fusion power. Much of the success of the session depends on how well you do your job!

Everyone in your group will have read the General Briefing on nuclear fusion. Each member (except for you) will also have read one Expert's Briefing. The Expert's Briefings give details about:

1 The containment problem
How can the very hot plasma be kept in place?

2 Getting the conditions right
How can the conditions for fusion be achieved?

3 The world energy scene
What will be the demand for electricity in the future ? How can the demand be met?

4 Advantages and disadvantages of fusion power
Is fusion power likely to be safe? Will it be economical if it can be made to work? Will it create pollution problems?

You will begin by asking some specific questions about nuclear fusion power. You need not stick to the suggested questions if there are others you want to ask. These questions will probably be answered by one of the Experts, though you should allow others to answer if they wish. *Try to act as a 'man or woman in the street' who is trying to find out about nuclear fusion.*

Encourage the Experts to answer in their own words - do not let them read out from the Briefing sheets! Let the Experts draw diagrams on paper, on a blackboard or on an overhead projector if they wish.

After the specific questions, you will raise some general points for discussion. By this time your group should have a reasonable idea of the facts behind nuclear fusion power. Try to encourage everyone to enter into the discussion.

You will find the suggested questions on sheet CB2.

Specific questions

1 *Why do the experts think that we will need an energy source like fusion in the future?*

2 *What are the fuels for fusion?*

3 *What is a Tokamak?*

4 *What is a plasma?*

5 *What temperature must be reached before fusion can start?*

6 *How is the temperature raised to the required temperature?*

7 *Why is it difficult the achieve the conditions needed for fusion?*

8 *What are the main advantages of fusion power?*

9 *How can energy from fusion be used to generate electricity?*

10 *Where is fusion research being carried out?*

11 *Why is fusion research being organised by a group of countries working together?*

General points for discussion

Encourage everyone to take part. Some of these may have already been covered in the 'Specific questions' session, in which case you could leave them out.

- Do we really need nuclear fusion - if so why?
- Do the possible benefits justify the enormous effort required?
- Will fusion give cheap, clean, inexhaustible energy?
- Will fusion power be safe ?
- Is it right to share our knowledge of fusion with other countries?
- Will fusion power solve the energy needs of developing countries if it can be made to work?
- Could we speed up research to get fusion power more quickly? If so how?
- Would it be better to spend the money on research into alternative energy sources instead of fusion research?
- Instead of spending all this money and effort on fusion research, wouldn't we do better to try and cut down the amount of energy we use?