Nuclear Power

Contents: A structured discussion concerning the principles and issues behind the use of nuclear power.

Time: Homework plus one double period.

Intended use: GCSE Physics, Chemistry or Integrated 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 develop understanding of the principles of nuclear fission, and its use in the generation of electricity.
- To develop an informed awareness of some of the issues concerned with nuclear power.
- 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 Introduction (sheet I)
1 copy of General Briefing Sheet (sheet GB)
1 copy of Test (sheet T)

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

This structured discussion is intended to give a factual introduction to the generation of electricity from nuclear fission, and to help students weigh up some of the controversial issues related to nuclear power. It is designed for use after a conventional lesson or lessons on the nucleus or nuclear fission. The General Briefing Sheet is no more than a condensed summary.

Procedure

1. Give each student a copy of the General Briefing Sheet on nuclear fission. Allow them time to read and study it – this is best done for homework preceding the lesson.
2. Get them 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 Chairperson their Briefing Sheet (CB). Give Expert's Briefing Sheets (EB1, EB2, EB3, and EB4) to the other four members of the group – a different sheet to each member. If any groups have six members, EB1 could be given to two people. Allow them time to study the sheets. If the timing of lessons permits, it is most effective if students are able to study their briefings beforehand, perhaps for homework.
5. Hand over the running of the group discussions to the Chairpersons. Avoid intervening if possible.

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. Details of these resource materials can be obtained from:

The Information Services Branch
UKAEA
11 Charles II Street
London SW1Y 4QP

The case against nuclear power is well argued in a number of publications from Friends of the Earth. They include books and audio-visual materials. Details can be obtained from:

Friends of the Earth Ltd
377 City Road
London EC1V 1NA

Acknowledgements Figure 1 (Introduction) supplied by the United Kingdom Atomic Energy Authority; Figures 2 and 3 (General Briefing) and Figure 1, (Expert's Briefing 2) are reproduced by permission from Science in Society, Book F, *Energy* (Association for Science Education); Figure 2 (Expert's Briefing 1) by permission from *Chemistry in Context* by G. C. Hill and J. S. Holman (Nelson).

NUCLEAR POWER

Introduction

Why does Britain have nuclear power stations?

Why are nuclear power stations built instead of coal-fired and oil-fired power stations?

Are nuclear power stations safe? Can a nuclear power station explode like a nuclear bomb? Do they give out radiation?

What can be done about the waste produced by nuclear power stations?

These are some of the questions we shall be asking as you use this unit. Before starting you need to know some of the facts about nuclear power. First, you will be given a General Briefing sheet which tells you about nuclear fission. After studying this you will do a short test to check your understanding.

After that you will be working as part of a small group. The group will discuss some of the questions and problems of nuclear power.

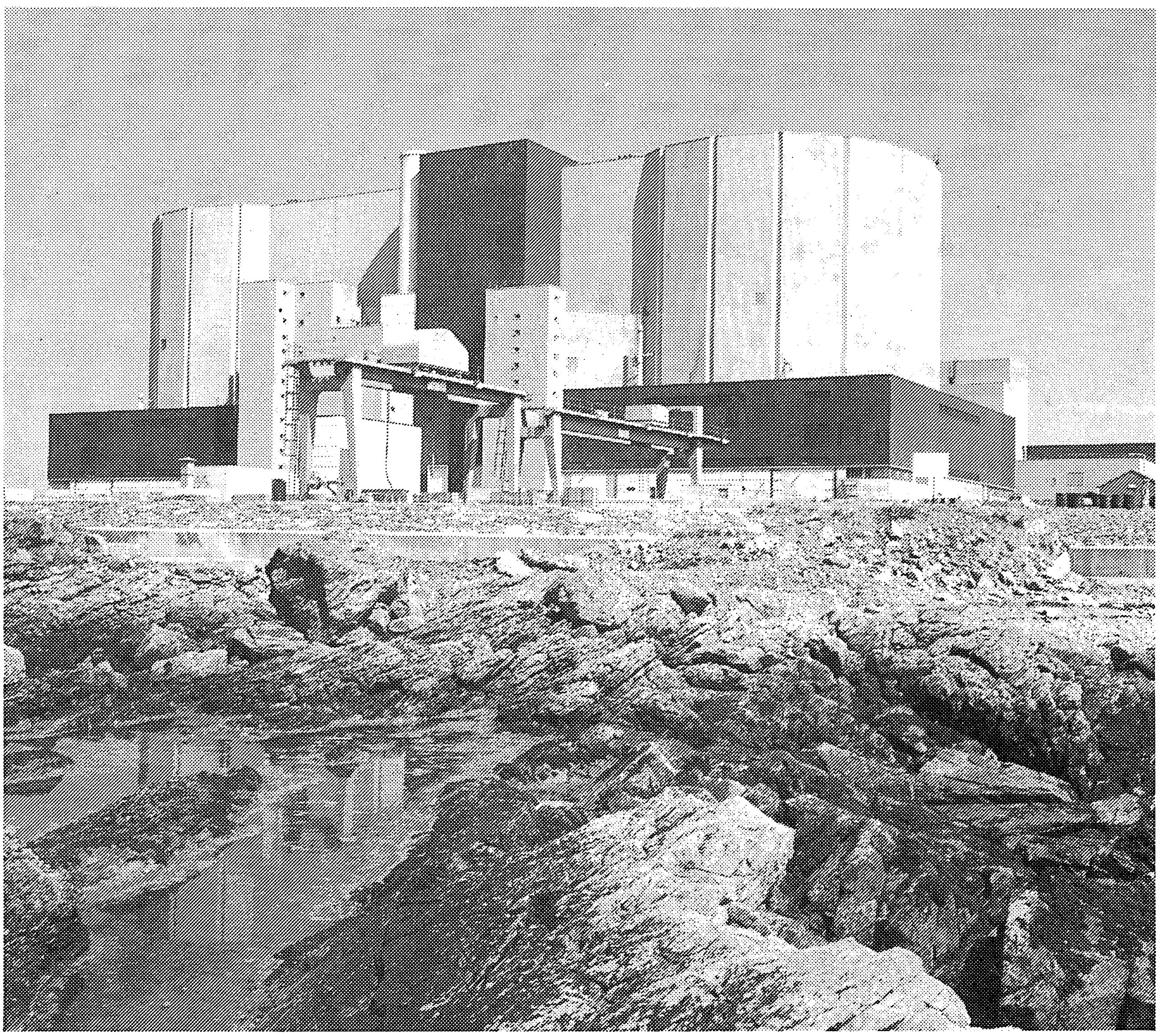

Figure 1 Wylfa Nuclear Power Station, in North Wales

Nuclear Power: General Briefing Sheet

This sheet is a summary of background information concerning nuclear fission.

What is nuclear fission?

Atoms are very small, but they are made of even smaller **sub-atomic particles**. These smaller particles are called protons, neutrons and electrons. At the centre of each atom is a tiny **nucleus**. The nucleus contains positively-charged protons and uncharged neutrons. Outside this central nucleus, the negatively-charged electrons move around (Figure 1).

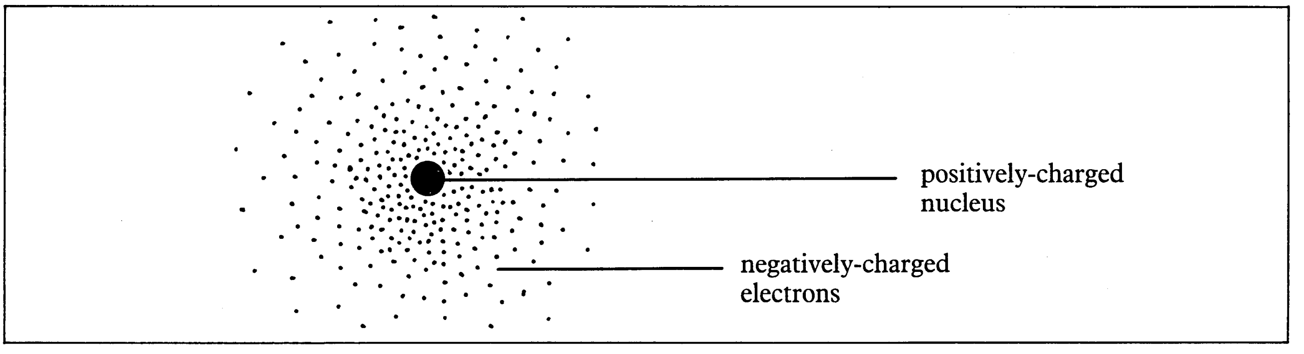

Figure 1 The structure of an atom

Radioactivity

Most of the atoms on Earth have a stable nucleus. This means the nucleus stays the same, and does not normally change. However, in a few atoms the nucleus is unstable. Unstable nuclei try to make themselves stable by throwing out particles or rays. The rays are called **radiation** and the atoms are said to be **radioactive**. A small amount of natural 'background' radiation, from rocks and from outer space, is around us all the time. But radiation can be dangerous to humans – it can cause cancer, deformed children and an illness called radiation sickness. Very large doses of radiation can kill.

What is fission?

Very large nuclei are often especially unstable. As well as giving out radiation, they may split into two smaller nuclei if they are hit in the right way. In the same way as a log can be split in two by hitting with an axe, these large nuclei can be split in two by hitting – with a neutron. This splitting in two is called **fission**. Nuclei that can be split in this way are described as **fissionable**.

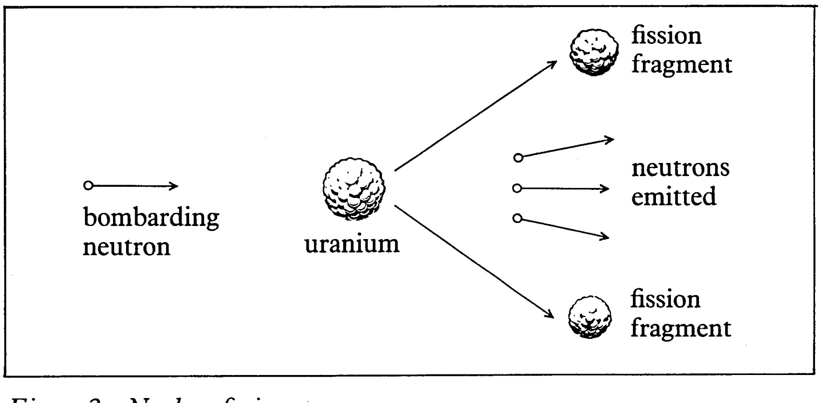

Figure 2 Nuclear fission

Most nuclear power stations use uranium as their fuel. Uranium is a metal whose atoms have very large nuclei. Some types of uranium atoms are fissionable. When this type of uranium nucleus is hit by a neutron, it splits into two smaller nuclei (Figure 2). These nuclei are radioactive.

As the nucleus splits, energy is given out. For a single uranium atom, the amount of energy is only tiny. But each gram of uranium contains many billions of atoms. For *one gram* of uranium, the energy released by fission of all the atoms would be as much as you could get by burning *2.7 tonnes of coal.*

When the uranium nucleus splits, it also releases two or three neutrons. These neutrons may hit other uranium nuclei. If they do, these nuclei may also split. This in turn gives out more neutrons, and so it goes on (Figure 3). This is called a **chain reaction**.

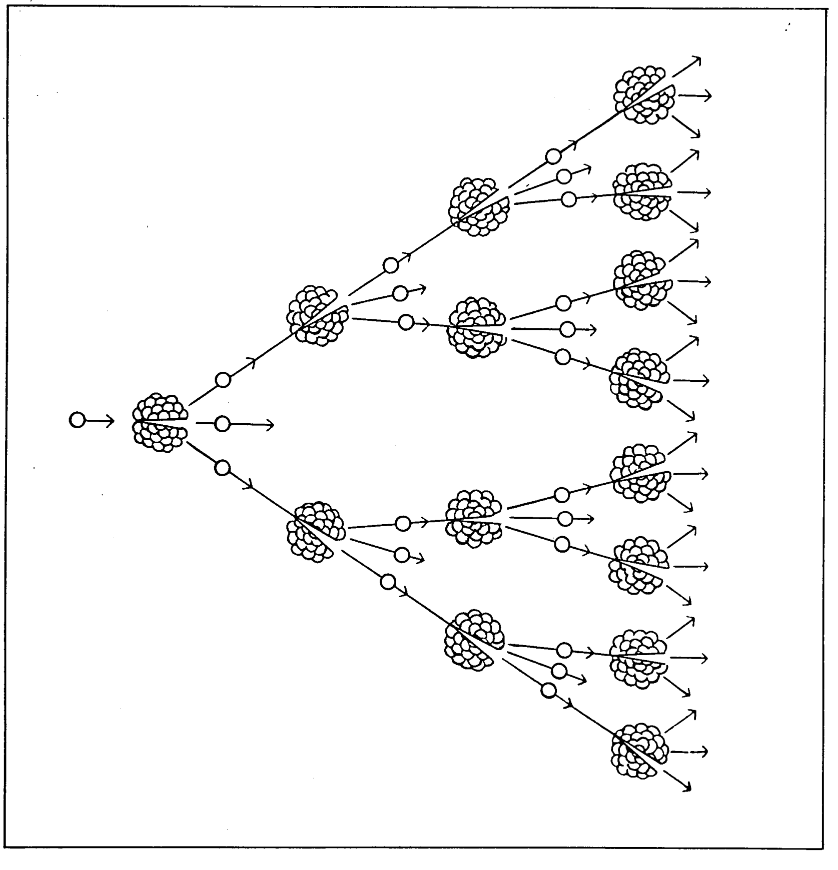

Figure 3 Nuclear fission: a chain reaction

Controlling nuclear energy

The chain reaction can move very quickly if it is not controlled. This is what happens in a nuclear bomb, like the one used in Hiroshima in the Second World War. In a fraction of a second, huge amounts of energy are released in the chain reaction. The result is terrible destruction.

In a nuclear power station, the fission reaction is controlled. This allows the energy to be released steadily. The central part of a nuclear power station is the **nuclear reactor**, which contains the uranium fuel. It also contains a **moderator** to slow down neutrons. This is important because slow neutrons stand a better chance of causing fission of uranium atoms. The moderator is often made of graphite.

The reactor also has **control rods**. These are made of a material which absorbs neutrons. Boron is often used. The control rods can be moved in and out of the reactor core. When they are right in, they absorb lots of neutrons. This stops the chain reaction. When the control rods are pulled out, less neutrons are absorbed. More neutrons are free to cause fission, and the chain reaction goes faster. Thus, by moving the control rods in and out, the fission reaction can be controlled.

Expert's Briefing sheet 1 has more information about nuclear reactors.

Isotopes of uranium

Uranium contains two different types of atom. Both have the same number of protons and electrons. But they have different numbers of neutrons. Atoms which have the same numbers of protons and electrons, but different numbers of neutrons, are called **isotopes**. The two isotopes of uranium are called uranium-235 (^{235}U) and uranium-238 (^{238}U). Table 1 shows the difference between them.

Table 1 Isotopes of uranium

Isotope	*Number of protons*	*Number of neutrons*	*Number of electrons*
uranium-235	92	143	92
uranium-238	92	146	92

Only ^{235}U will normally undergo fission. But only 0.7% of natural uranium is the ^{235}U isotope. The rest is ^{238}U, which does not undergo fission. Some reactors use natural uranium. Others use **enriched** uranium, which has had some of the ^{238}U removed. This increases the percentage of ^{235}U, and makes the uranium a better fuel.

Natural uranium cannot be used in atomic bombs. Bombs need highly enriched uranium. A nuclear reactor could never explode like a nuclear bomb, because the uranium used in the reactor is not enriched enough.

Test on nuclear fission

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

A protons and electrons
B protons and neutrons
C neutrons and electrons
D protons only
E neutrons only

2 A uranium atom can undergo fission if it is hit by:

A radiation
B a proton
C a neutron
D an electron
E another uranium atom

3 Which of the following is an example of nuclear fission?

A A uranium nucleus gives out radiation
B Two hydrogen nuclei join together
C A uranium nucleus absorbs a neutron
D A uranium nucleus splits up to give two smaller nuclei
E A uranium nucleus absorbs an electron

4 Nuclear reactors use uranium as a fuel. In what ways is uranium a different type of fuel from, say, coal or oil?

5 What job is done by the moderator in a nuclear reactor?

6 How do control rods control the fission reaction?

7 What is the difference between natural uranium and enriched uranium?

Nuclear Power: Expert's Briefing Sheet 1

What happens in a nuclear power station?

You will shortly be taking part in a group discussion on nuclear power. You are the only one in your group who has read this sheet, so you will be the expert on what goes on in a nuclear power station. 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.

Briefing

All power stations are energy-converters. They convert heat to electrical energy. In a coal-fired power station, the heat comes from burning coal. In a nuclear power station, the heat comes from the fission of uranium.

Once the heat is released, it is used to boil water and make steam. The steam drives turbines, and the turbines drive electrical generators (Figure 1).

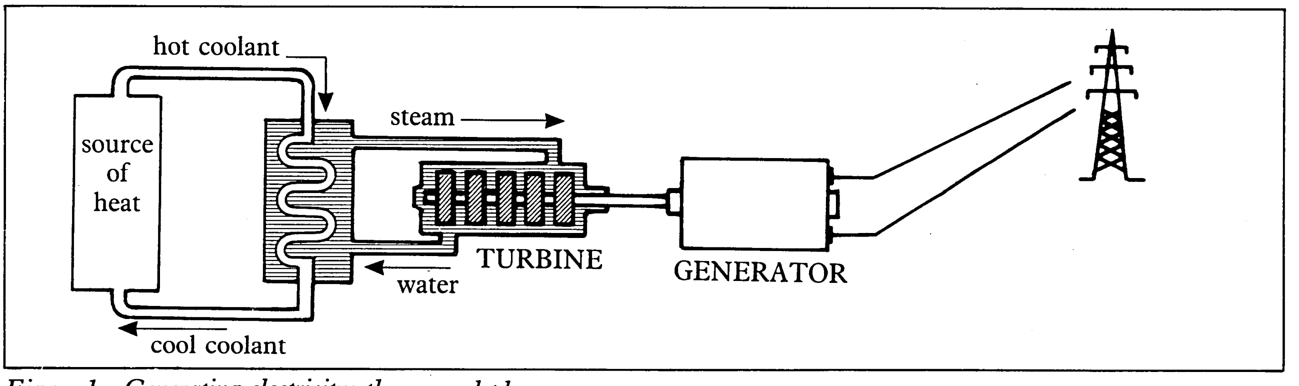

Figure 1 Generating electricity: the general plan.

Nuclear reactors

In a nuclear power station, the heat source is the nuclear reactor. Figure 2 shows a simplified reactor.

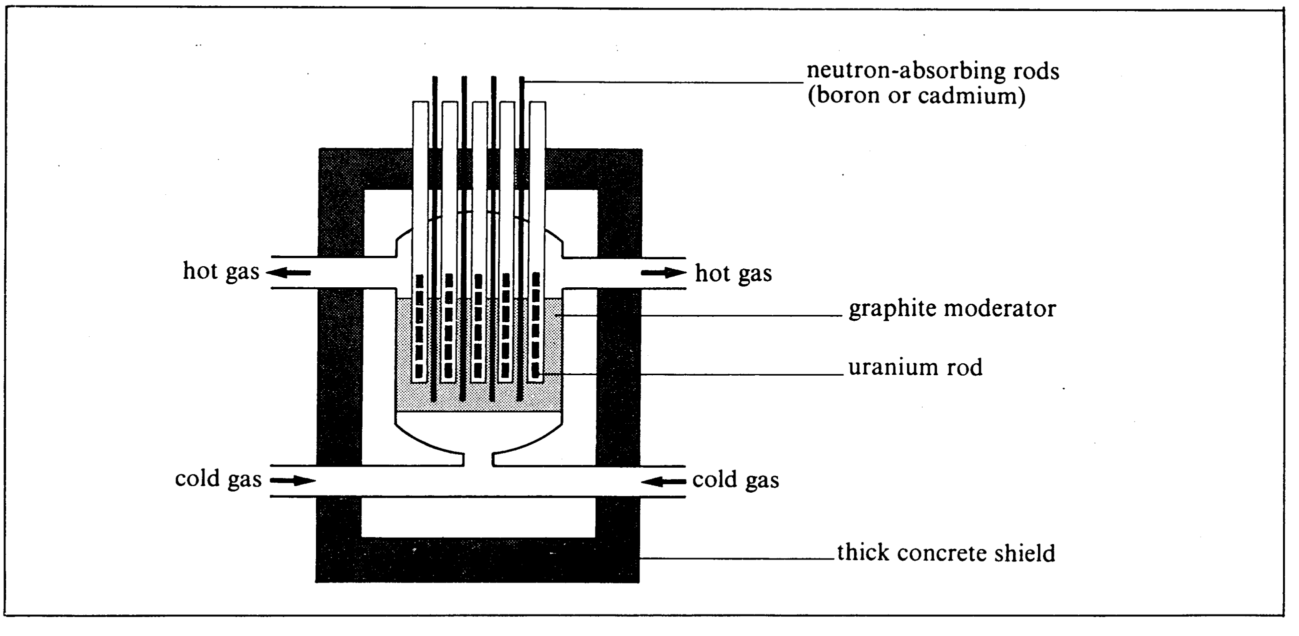

Figure 2 A simplified diagram of a nuclear reactor

The uranium rods are the fuel. The graphite **moderator** slows down neutrons. This makes the neutrons more likely to cause fission. The **control rods** absorb neutrons. By raising or lowering the rods, the fission reaction can be made faster or slower.

As the fission reaction takes place, heat is given out. The heat is taken away by a **coolant**. In the type of reactor shown here, the coolant is a gas – usually carbon dioxide. The hot gas is pumped away to the heat exchanger, where it turns water to steam. The steam drives the turbines which drive the electrical generators.

During the fission reaction, some dangerously radioactive substances are formed. A thick concrete shield stops radiation getting out.

Different types of reactor

Gas-cooled reactors Most of the reactors in British nuclear power stations are gas cooled, like the one shown in Figure 2.

Water-cooled reactors In the USA and many other countries, water-cooled reactors are used. As well as being a coolant, water is used as the moderator. Water-cooled reactors therefore have no graphite moderator. The job is done by the cooling water as it circulates through the reactor. The best known type of water-cooled reactor is the pressurized-water reactor (PWR).

Fast-breeder reactors These reactors use a different element, plutonium, as their fuel. As well as producing heat, these reactors can be used to turn ^{238}U into plutonium. This means they can 'breed' plutonium from ^{238}U. Plutonium is more useful than ^{238}U, because it is fissionable. The fission reaction does not need slow neutrons. 'Fast' neutrons can cause fission of plutonium. So far there is only one experimental fast-breeder reactor in Britain. It is at Dounreay, in the North of Scotland.

Nuclear Power: Expert's Briefing Sheet 2

What happens to nuclear fuel after use?

You will shortly be taking part in a group discussion on nuclear power. You are the only one in your group who has read this sheet, so you will be the expert on what happens to nuclear fuel after use. After you have read this, the Chairperson of your group will be asking the kind 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.

Briefing

Where does nuclear fuel come from?

The fuel for nuclear power stations is uranium. It is mined in various parts of the world, then sent to Britain. At Springfields in Lancashire the uranium is refined. Some of it is enriched to make it a better fuel. The uranium is then made into rods and sent to the power stations.

The uranium rods in a nuclear reactor last for several years. After this time the old rods are removed. They are replaced by new ones.

What happens to the spent fuel rods?

The old, spent fuel rods are very radioactive. They contain **fission products** – the smaller atoms formed when uranium atoms split. These fission products often have unstable nuclei which give off radiation. The rods also contain unused uranium and another element called **plutonium**. Plutonium is useful because it is fissionable. It can be used as a fuel in fast-breeder reactors. Plutonium can also be used to make nuclear bombs.

After they have been removed from the reactor, the spent fuel rods must be treated very carefully. They are first put under water in storage tanks for a few months. During this time, some of the most unstable fission products lose their power.

The fuel rods are now removed and sent to be **reprocessed** at Sellafield in Cumbria (see Figure 1). They make the journey by road or rail in strong, thick, heavily protected flasks. They are still very radioactive.

At Sellafield, plutonium and uranium are separated from the spent rods. They are used for fuel, and some plutonium may be used to make nuclear weapons.

The rest of the spent fuel rods is waste. Some of this waste will stay highly radioactive for thousands of years. At the moment the radioactive waste is stored in stainless steel tanks at Sellafield. Scientists are trying to find ways of safely disposing of it. One possibility is to turn the waste into a solid, glassy form. It could then be buried deep in the Earth, or dumped far out at sea.

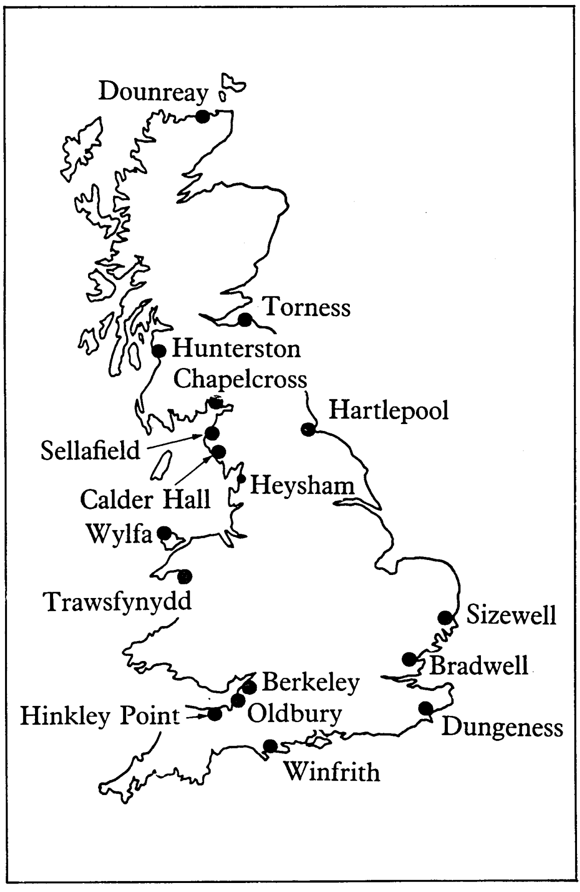

Figure 1 Map showing Britain's nuclear power stations

All this makes up the nuclear fuel cycle (Figure 2).

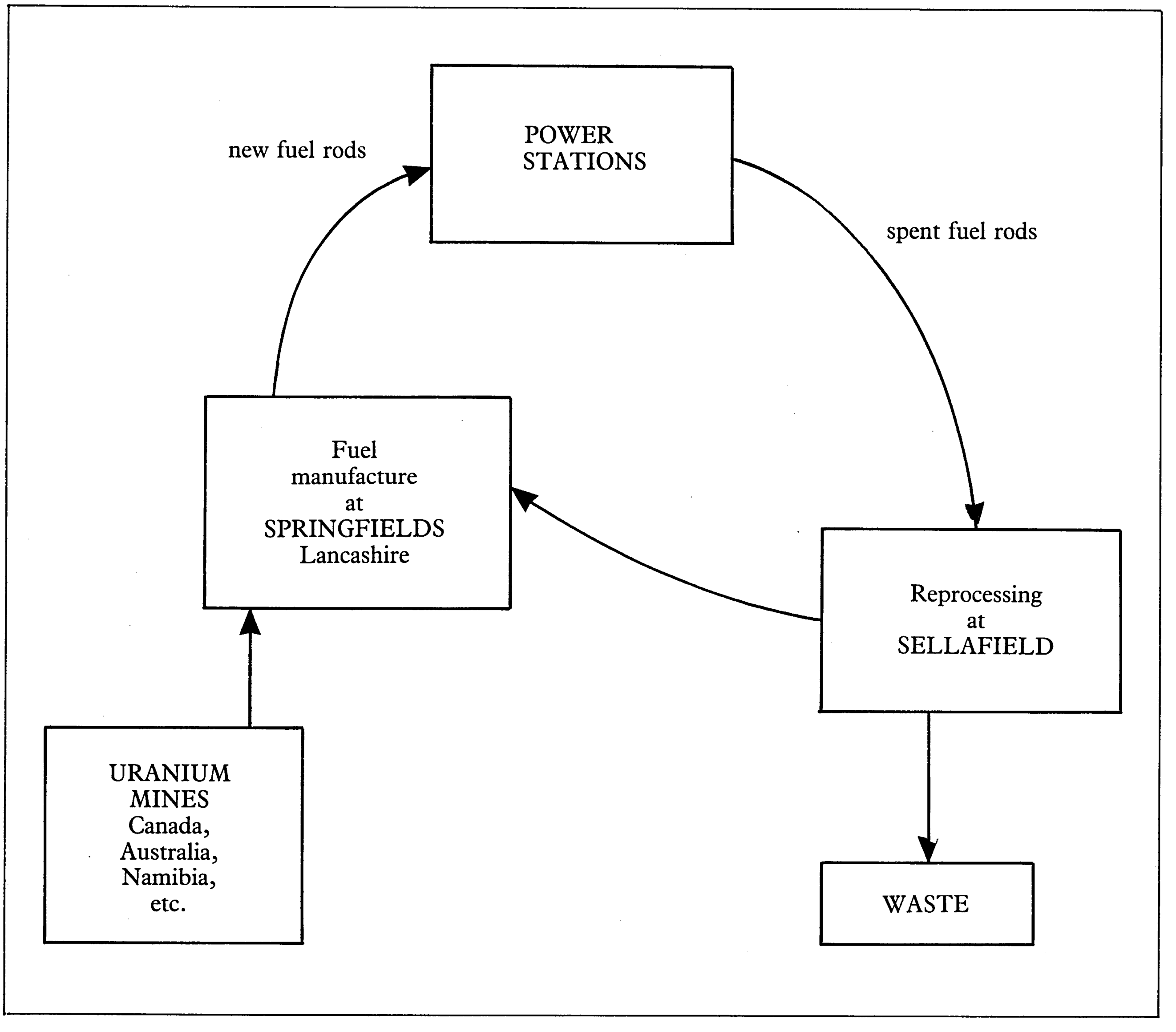

Figure 2 The nuclear fuel cycle

Nuclear Power: Expert's Briefing Sheet 3

Problems and risks of electricity generation

You will shortly be taking part in a group discussion on nuclear power. You are the only one in your group who has read this sheet, so you will be the expert on the problems and risks of electricity generation. After you have read this, the Chairperson of your group will be asking the kind 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.

Briefing

Electricity is a great benefit to our society – think what life would be like without it. But however electricity is generated, there are bound to be some problems and risks. This briefing sheet describes some of the risks of using nuclear energy. Coal is the other major source of electrical energy, and the risks involved in using coal are also described.

The risks of nuclear power

Risks from accidents Nuclear power stations cannot explode like nuclear bombs. But it is possible that a reactor could overheat and leak. This would release dangerously radioactive substances and people living nearby could be killed and injured. A major leakage accident happened at a power station in Chernobyl, Russia in 1986.

However, the Government safety rules for nuclear power stations are very strict. The Central Electricity Generating Board, who run the power stations, say the risk of a major accident is very low. But if one did happen, it would be very serious.

Risks from radiation and leaks Nuclear reactors contain some very radioactive materials. These give off dangerous rays. However, the safety precautions are so strict that very little radiation gets through the protective shields. Occasionally, though, a small leakage does occur by accident. For example, contaminated cooling water has been known to leak out from power stations.

Risks from waste Nuclear reactors produce radioactive fission products. These will stay radioactive for thousands of years. They are kept very secure in strong tanks, but no way has been found of disposing of them for good. Furthermore, transporting of nuclear waste from one place to another could be a hazard, though of course it is always transported in very strong containers.

Risks from terrorists Nuclear power stations produce plutonium. Plutonium can be used to make nuclear weapons. It is possible that terrorists could steal plutonium and try to make a bomb, although this would be a very difficult thing to do.

The risks of coal

Pollution of the air Many pollutants are given off by burning coal. As well as smoke, coal produces acidic gases. These include sulphur dioxide and nitrogen oxides. These gases cause acid rain, which damages trees, fish and buildings. The gases can also affect people's health. Because there are so many large coal-fired power stations, they produce a lot of pollution between them. But power stations are not the only source of acid gases. Cars and lorries produce them too, for example.

Burning coal gives off carbon dioxide. Some scientists are worried that the vast amounts of carbon dioxide given off by coal-burning may have a damaging effect on the atmosphere and the weather.

Risks of coal mining Mining is a dangerous occupation. Between 1982 and 1985 there were 26 accidental deaths in coal mines per year. Far larger numbers of miners risk dying of lung disease. Power stations use a large proportion of Britain's coal, so the risk to miners must be counted as a problem of coal-fired power stations. Uranium is also produced in mines, so the risks to uranium miners must also be considered. However, because uranium is such a concentrated energy source, it is mined in much smaller amounts.

Nuclear Power: Expert's Briefing Sheet 4

Britain's energy sources

You will shortly be taking part in a group discussion on nuclear power. You are the only one in your group who has read this sheet, so you will be the expert on Britain's energy sources. After you have read this, the Chairperson of your group will be asking the kind 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.

Briefing

Britain is more fortunate than many countries where energy is concerned. Coal, oil and natural gas are all found in Britain, or under the sea around the British Isles.

The graph in Figure 1 shows the changes in Britain's energy sources since 1950.

Of course, not all of Britain's energy is used to generate electricity. For example, a lot of oil is used for road transport. But nuclear power can *only* be used to generate electricity.

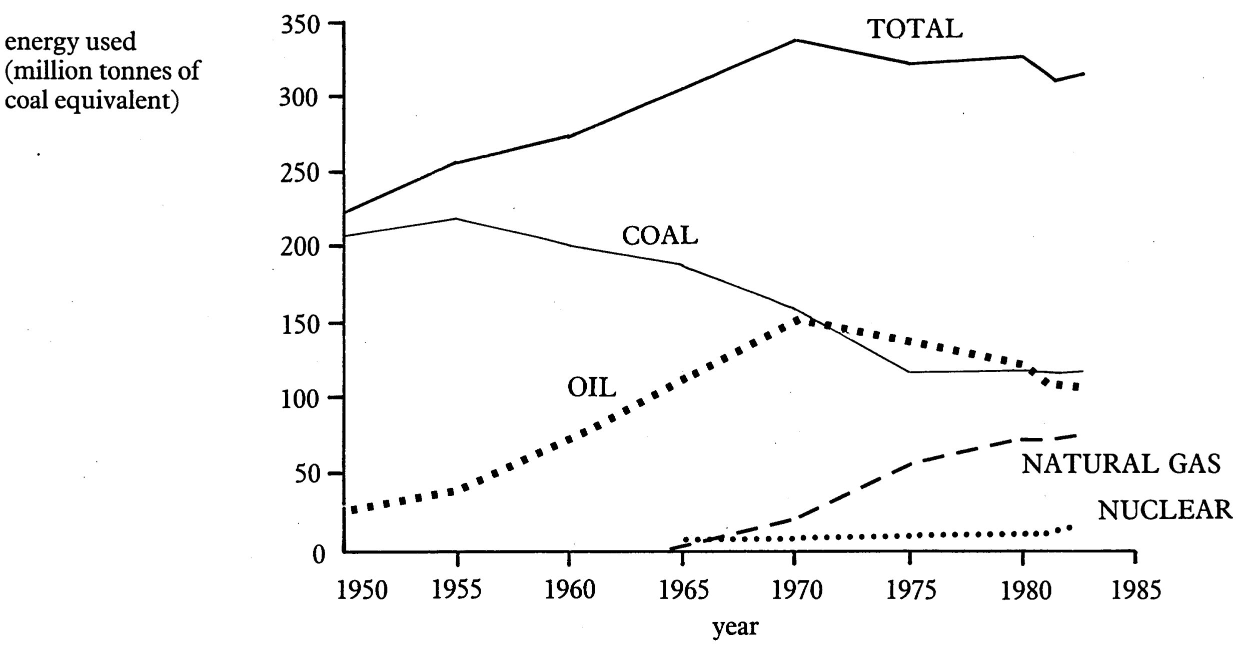

Figure 1 Britain's Energy Sources

In 1983 the percentage contributions of different methods of electricity generation were as shown in Table 1.

Table 1 Percentage contributions of different methods of electricity generation.

Coal	*Oil*	*Nuclear*	*Hydroelectric*
75%	8%	15%	2%

Nuclear power is reckoned to be cheaper than coal or oil for generating electricity.

How much fuel do we have left?

Britain's fuel supplies will not last for ever. Table 2 shows how long different fuels will last if they go on being used at the present rate.

Table 2 Estimated lifetimes of different fuels

Oil	30 years	
Natural gas	50 years	
Coal	300 years	
Nuclear fuel (world reserves)	50 years	(in normal power stations)
Nuclear fuel (world reserves)	2000 years	(using fast-breeder reactors)

The Government have to plan ahead. The older power stations are inefficient and expensive to run. Eventually they have to be replaced. The Government have to decide whether or not to replace them with nuclear stations.

They also need to look at the figures for how much fuel is being used, and how much is left. Look at the graph again. Suppose you had been planning ahead in 1970. What total energy use would you have *predicted* for 1983? What was the *actual* amount? How much energy do you predict we will use in 1995? Planning ahead can be difficult!

Possible energy plans

Britain has to plan ahead to the time when oil and gas run out. There are several possibilities.

1 *Save more energy* This can be done by using energy less wastefully. Cars can be designed to use less petrol. Houses can be better insulated so they waste less heat. New industrial processes can be less dependent on energy.

2 *Use alternative energy sources* Examples of alternative energy sources are solar power, wind power and tidal power. At the moment hardly any electricity is generated by these methods in Britain, because they have not been sufficiently developed.

3 *Build more nuclear power stations* You will shortly be discussing this possibility.

4 *Build more coal-fired power stations* Most of Britain's power stations are already coal-fired. The supplies of coal are large enough to keep even more going. About three-quarters of Britain's coal output is used to generate electricity. But coal has other important uses, such as steel-making and as a source of chemicals. In the future, as oil supplies run out, coal may be used to make liquid fuels to replace oil.

Of course, these different possibilities could be used *together*. In fact many people think it is a good thing not to be too dependent on one single source of fuel.

Nuclear Power: Chairperson's Briefing Sheet

You are Chairperson of a group of students. It is your job to ask questions and chair a discussion on nuclear 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 fission. Each member (except for you) will also have read one Expert's Briefing. The Expert's Briefings are:

1 What happens in a nuclear power station?

2 What happens to nuclear fuel after use?

3 Problems and risks of electricity generation

4 Britain's energy sources

You will begin by asking some specific questions about nuclear power (see below). These questions will probably be answered by one of the Experts, though you should allow others to answer if they want. *Try to act as a 'man or woman in the street' who is trying to find out about nuclear power.* Encourage the Experts to answer in their own words – do not let them read out from the Briefing sheet! Let the Experts draw diagrams on paper, a blackboard or on an overhead projector if they want.

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

Specific questions

(The number after each question refers to the Expert who is most likely to know the answer.)

1 *The nuclear reactor produces heat. How is this converted to electrical energy? (1)*

2 *What is a PWR? (1)*

3 *What is special about fast-breeder reactors? (1)*

4 *How is radiation prevented from escaping from the reactor? (1)*

5 *Where does the uranium fuel for power stations come from? (2)*

6 *What happens when the fuel is used up? (2)*

7 *What happens to all the radioactive waste produced by power stations? (2)*

8 *Some people say nuclear reactors are dangerous. What are the possible dangers? (3)*

9 *Are there dangers from other types of power station? If so, what are they? (3)*

10 *How much of Britain's electricity is generated in nuclear power stations? (4)*

11 *What is the fuel in other types of power stations? (4)*

12 *Why do new power stations have to be built? Why can't Britain use the existing power stations already built? (4)*

13 *Apart from building nuclear power stations, what other possible ways are there of providing energy after oil and gas have run out? (4)*

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 need to build nuclear power stations? Why can't we generate all our electricity from coal and oil?
- Are nuclear power stations as dangerous as some people say? Are other kinds of power stations just as dangerous?
- Would the money spent on nuclear power be better spent on saving energy or on developing alternative energy sources?
- What is the disadvantage of depending on only one energy source, such as coal or oil, for electricity generation?
- If you have time, draw up a list of the advantages and disadvantages of using nuclear power.