

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

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Task. Read the text and translate it into Ukrainian. Use vocabulary.

The Biosphere At Risk

In the Earth's atmosphere, the warming effect of "greenhouse gases" is an undisputed phenomenon.

Without it, the globe would be covered in ice. For thousands of years, a fairly constant level of greenhouse



gases created the moderate environment in which civilisation evolved.

In the 21 st century, human activity could cause a doubling of these heat-trapping gases. In geological time, such change is sudden and with little precedent.

In the next fifty years, the global population will use more energy than the total consumed in all previous history. Human Coal-fired heat and future of radical change - either in the way we produce energy or in the health of our planet.

Most energy today comes from burning fossil fuel to make electricity, run factories, power vehicles and heat homes. Fossil resources - coal, oil and natural gas - are being consumed so fast as to Impacts of global warming the 21st century.



With all fossil energy, waste products are dispersed directly into the air. Much of this waste takes the form of greenhouse gases such as carbon dioxide. Each year fossil fuel waste adds 25 billion tonnes of carbon dioxide to the atmosphere. This equates to 70 million tonnes each day - or 800

tonnes a second.

To analyze the effects of the rapid build-up of heat-trapping gases, world experts are cooperating through the UN's Intergovernmental Panel on Climate Change. The dynamics of climate change are complex and subject to competing theories. But scientists agree that increased greenhouse gases are causing the Earth to capture more solar heat. For most climate scientists, man-made greenhouse gases explain why the decade of 2000-2009 was the warmest on instrumental record of global surface temperature (since 1850).

Climate experts are virtually unanimous in warning that the build-up of the greenhouse gases could, in the century ahead, become catastrophic. Rising sea levels, extreme temperatures, violent storms, devastating droughts and the spread of disease would destroy food production and human habitability in many regions. These experts warn that radical climate change could eventually destabilize the entire biosphere.

All nations are involved in climate change - in both cause and effect. North Americans release carbon dioxide into the atmosphere at a daily rate of 54 kilograms - or 120 pounds - per person. In Europe and Japan, daily per capita emissions are more than 23 kilograms - or 50 pounds. In fast-developing China, with 1.4 billion people, the emissions level already exceeds 6 kilograms - or 13 pounds - for each person each day.

Nuclear Power Today

Nuclear generation began more than 50 years ago and now generates as much global electricity as was produced then by all sources. Some two-thirds of world population lives in nations where nuclear power plants are an integral part of electricity production and industrial infrastructures. Half the world's people live in countries where new nuclear power reactors are in planning or under construction. Thus, a rapid expansion of global nuclear power would require no fundamental change - simply an acceleration of existing strategies.

Today nearly 440 nuclear reactors produce electricity around the world. More than 15 countries rely on nuclear power for 25% or

more of their electricity. In Europe and Japan, the nuclear share of electricity is over 30%. In the U.S., nuclear power creates 20% of electricity.

Nuclear power is power (generally electrical) produced from controlled (i.e., non-explosive) nuclear reactions. Commercial plants in use to date use nuclear fission reactions. Electric utility reactors heat water to produce steam, which is then used to generate electricity. In 2009, 15% of the world's electricity came from nuclear power, despite concerns about safety and radioactive waste management. More than 150 naval vessels using nuclear propulsion have been built.

Nuclear fusion reactions are widely believed to be safer than fission and appear potentially viable, though technically quite difficult. Fusion power has been under intense theoretical and experimental investigation for many years.

Both fission and fusion appear promising for some space propulsion applications in the mid- to distant-future, using low thrust for long durations to achieve high mission velocities.

Nuclear Power is a Waste. No one wants such a legacy

Every nuclear power station converts uranium fuel rods through nuclear fission into highly radioactive nuclear waste. Nuclear waste constitutes a life-threatening hazard because of its radioactive emissions. People, animals and plants need to therefore be shielded from it for several hundreds of thousands of years. Nuclear power stations have been in operation for some 50 years but to date no one knows how nuclear waste can ultimately be stored. Worldwide there is not one safe and secure disposal option for the highly radioactive waste produced by nuclear power stations. In the short period of time that nuclear power has been used, it is leaving behind - in the shape of the resultant nuclear waste - a dead hand of historical dimensions for the Earth. If prehistoric man had already had nuclear power stations we would even today still be having to maintain a watch over his waste.

Vocabulary:

fossil fuel – викопне, природне паливо

unanimous-одностайний

nuclear fuel- ядерна паливо – матеріали, які слугують для отримання енергії в ядерному реакторі

nuclear power plant – атомна електростанція – електростанція, в якій атомна (ядерна) енергія перетворюється в електричну

nuclear power reactor- ядерний реактор – пристрій, в активній зоні якого відбувається ланцюгова реакція поділу ядер важких елементів, в результаті якої відбувається виділення енергії

nuclear fission reaction-реакція ядерного поділу

nuclear propulsion-ядерна рушійна сила

fusion power-термоядерна потужність

fission power-потужність поділу

fuel rod-паливний стрижень

disposal-видалення

Task. Translate into English

Ядерна енергія (атомна енергія) — внутрішня енергія атомних ядер, що виділяється при деяких ядерних перетвореннях. Використання ядерної енергії засновано на здійсненні ланцюгових реакцій розподілу важких ядер і реакцій термоядерного синтезу легких ядер.

Атомна енергія — енергія, що виділяється під час перетворень атомних ядер. Перетворення ці можуть відбуватися спонтанно або від діяння нейтронів і прискорених заряджених частинок. Ця енергія в мільйони разів перевищує хімічну енергію, напр. при горінні. Атомна енергія зумовлюється ядерними силами, які діють між нуклонами, тобто нейтронами, і протонами.

Енергія зв'язку, яка припадає на 1 нуклон, неоднакова для різних ядер. Для одержання атомної енергії можна користуватися ядерними реакціями поділу і ядерними реакціями синтезу. Реакції синтезу можуть відбуватися тільки тоді, коли ядра наближаються одне до одного на відстань, меншу за 10^{13} см, на якій починають діяти ядерні сили. Зближенню ядер

протидіють кулонівські сили відштовхування; тому, щоб ці сили подолати, ядра повинні мати достатню енергію. Одержання вільних нейтронів і прискорення руху заряджених частинок вимагає витрати енергії. Імовірність попадання таких частинок у ядра дуже мала. Тому витрачена енергія перевищує енергію, яка виділяється при ядерних реакціях. Енергетичний вигравш можна дістати тільки в тому випадку, коли перетворення відбувається внаслідок ланцюгових реакцій. Реакції синтезу можуть бути ланцюговими при дуже високих температурах — в десятки і навіть сотні мільйонів градусів. За цих умов речовина існує у вигляді плазми, і енергія окремих частинок плазми достатня для подолання кулонівського відштовхування. Такі високі температури існують в надрах зірок, однією з яких є Сонце. Саме внаслідок термоядерних реакцій синтезу Сонце випромінює енергію. В галузі оволодіння керованими термоядерними реакціями синтезу вже розв'язано одну з основних проблем — термічну ізоляцію плазми, яка здійснюється за допомогою магнітних полів. Особливо важливим у реакціях синтезу є те, що як «пальне» для них можна використовувати дейтерій у практично необмеженій кількості. Дейтерій же міститься у важкій воді, яка є домішкою до води морів і океанів. Ланцюгові реакції поділу можуть відбуватися тому, що поділ кожного ядра супроводиться виділенням кількох нейтронів, які при захваті їх іншими ядрами знову можуть спричинити поділ з виділенням нових нейтронів, і т. д. Якщо створити умови, при яких кількість виділених нейтронів, що спричиняють поділ нових ядер, буде, в середньому більша від одиниці на один поділ, то ланцюгова реакція безперервно розвиватиметься. Якщо ж ланцюгова реакція розвивається дуже швидко, то вона набуває характеру вибуху, напр. в атомній бомбі. Після вибуху атомної бомби виникає дуже висока т-ра. яка є необхідною умовою протікання термоядерних реакцій; це використовується поки що лише у водневій бомбі. Швидкість ланцюгових реакцій поділу регулюють поки що тільки в ядерних реакторах. Енергія, що виділяється внаслідок цих реакцій, відводиться від реактора у вигляді тепла за допомогою теплоносіїв, якими можуть бути вода, пара, рідкі метали, гази тощо. Ця теплова енергія

використовується на ядерних електростанціях і в атомних двигунах.

Do you know?

Економічна перевага атомних електростанцій над тепловими безперервно зростатиме як внаслідок їхнього удосконалення, так і внаслідок подорожчання кам'яного вугілля, торфу, нафти і природного газу, запаси яких у верхніх шарах Землі швидко зменшуються. При сучасних темпах зростання використання енергії цих запасів палива може вистачити на 100—150 років, використання ж ядерних реакцій поділу урану, торію і плутонію зможє збільшити цей строк ще на 200—300 років. Лише оволодіння термоядерними реакціями синтезу забезпечить людство енергією в необмеженій кількості і на необмежений термін.

Першу у світі атомну електростанцію було збудовано в СРСР і вперше експлуатовано 27 червня 1954.

У 1959 в СРСР закінчено будівництво першого в світі криголама «Ленин» з атомним двигуном.

Task. Read the text and translate it into Ukrainian. Use vocabulary.

Energy for the World - Why Uranium?

About half a million years ago human beings learned to make fire. We took our first steps in the use of mechanical energy with the harnessing of wind and water power. Later, the industrial revolution, based on coal and steam power, laid the foundations for today's technological society, with significant developments such as the internal combustion engine and the large-scale generation of electricity.

Together with this increasing energy consumption, it has been possible for the world to sustain an ever increasing population. At present, however, three quarters of world energy production is consumed by the one quarter of the world's population living in the industrialised countries.

A population increase will have a dramatic impact on energy demand, at least doubling it by 2050, even if the developed countries

adopt more effective energy conservation policies so that their energy consumption does not increase at all over that period.

Energy can be considered in two categories - primary and secondary.

- Primary energy is energy in the form of natural resources, such as wood, coal, oil, natural gas, natural uranium, wind, hydro power, and sunlight.
- Secondary energy is the more useable forms to which primary energy may be converted, such as electricity and petrol.
Primary energy can be renewable or non-renewable:
- Renewable energy sources include solar, wind and wave energy, biomass (wood or crops such as sugar), geothermal energy and hydro power.
- Non-renewable energy sources include the fossil fuels - coal, oil and natural gas, which together provide over 80% of our energy today, plus uranium.

The availability of energy

There is no shortage of primary energy. The sun pours an abundance on to our planet each day. We see this energy in a variety of forms, ranging from solar radiation, through wind and waves, to trees and vegetation which convert the sun's rays into plant biomass. In addition, there is an enormous amount of energy in the materials of the earth's crust, the fossil fuels also storing energy from the sun. Uranium is an energy source which has been locked into the earth since before the solar system was formed, billions of years ago.

The challenge today is to move away from our heavy dependence on fossil fuels and utilise non-carbon energy resources more fully. Concerns about global warming are a major reason for this.

Fossil fuels have served us well. Coal was the first to be widely used industrially and to increase people's standard of living. Oil is a convenient source of energy. Because of its easy availability and low price, it played an important role in the economic development of many countries during the past century. It remains vital for much transport. Natural gas is widely used alongside coal and oil, as a very versatile fuel.

But the question of "Why Uranium?" puts the focus on energy sources which are suitable for electricity. Generating electricity already accounts for 40% of primary energy use, and at 2.7% per

year, demand for it is growing twice as fast as for total energy worldwide.

Hydro-electric generating facilities have the attraction of providing electricity without polluting the atmosphere. They harness the energy of falling water, which can occur naturally, but more often has to be engineered by the construction of large dams with lakes behind them. The advantages of hydro-electricity have long been appreciated and today it provides 18% of the world's power. In many countries most of the suitable dam sites have already been used, thus limiting further major development of this source.

Other renewable energy sources have more potential for increased use, but also have characteristics which limit their ability to play a major role in meeting electricity needs, bearing in mind that much of the demand is for continuous, reliable supply:

Solar energy

has considerable logical and popular appeal.

However, for electricity generation solar power has limited potential, as it is too diffuse and too intermittent. First, solar input is interrupted by night and by cloud cover, which means that solar electric generation plant can typically only be used to a small proportion of its capacity. Also, there is a low intensity of incoming radiation and converting this to high-grade electricity is still

relatively inefficient (less than 20%), though this has been the subject of much research over several decades.



On a small scale (and at relatively high cost) it is possible to store electricity. On a large scale any solar electric generation has to be worked in with other sources of electricity with full back-up.

While it is true that sunlight itself is free, the capital, energy and materials costs of conversion, maintenance and storage are extremely high. The main role of solar energy in the future will be that of direct heating.



Wind, like the sun, is 'free' and is increasingly harnessed for electricity. About 20,000 megawatts capacity is now installed around the world. However, in meeting most electricity demand, similar back-up issues arise as for solar. It is not always available when needed, and some means is required to provide substitute capacity for windless periods. Nevertheless, costs have come down, and contracts for electricity from some new US plants are as low as for conventional sources.

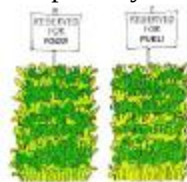


Geothermal

energy comes from natural heat below the earth's surface. Where hot underground steam can be tapped and brought to the surface it may be used to generate electricity. Such geothermal sources have potential in certain parts of the world, and some 8000 MWe of capacity is operating. There are also prospects in other areas for pumping water underground to very hot regions of the earth's crust and using the steam thus produced for electricity generation.



Biomass. Most forests and agricultural crops are technically capable of being converted into some form of energy, even if the primary purpose of the crop is to provide food. There are also some 'energy farms', where crops are produced solely for energy production. Such farms however compete with other crops for water, fertiliser and land use, thus requiring some choice between fuel and food. Biomass does provide a useful and growing source of energy, especially for rural communities in third world countries, and organic waste and water plants can be used to produce methane or 'biogas'. Nevertheless, it is only likely to play a very small role overall.



Thus as we head into a new century, the only energy resources available for economic large-scale electricity generation are likely to be gas, coal and nuclear.

Oil has generally become too expensive to use for electricity and it has the great advantage of being a portable fuel suitable for transport. Wherever possible it is conserved for special uses, such as transport and in the petrochemical industry.

Gas can be seen in the same way as oil, as being too valuable to squander for uses such as large-scale electricity generation. But after the oil price shocks of the 1970s, increased exploration efforts revealed huge deposits of natural gas in many parts of the world and today these are extensively used for power stations. The main virtue of gas however is that it can be reticulated safely and cheaply to domestic and industrial users and burned there to provide heat very efficiently. It is also a valuable chemical feedstock.

Coal is abundant and world production is about 3.5 billion tonnes per year, most of this being used for electricity. It dominates the scene, and produces 38% of all electricity worldwide, while uranium produces 16%. In OECD countries the figures are closer together: 38% and 24% respectively.

Uranium is also abundant, and technologies exist which can extend its use 60-fold if demand requires it. World mine production is about 35,000 tonnes per year, but a lot of the market is being supplied from secondary sources such as stockpiles, including material from dismantled nuclear weapons. Practically all of it is used for electricity.

Which should be used?

World reserves of coal are, in theory, large enough to produce the electricity we shall need for more than a hundred years. However, it is likely that more and more of the coal mined in the future will be converted into the more valuable liquid fuels and so will not be available for electricity generation. There are also environmental and other problems associated with the increased mining and burning of coal.

The difference in the heat value of uranium compared with coal and other fuels is important (though both are used at about 33% thermal efficiency in the power station). A one million kilowatt (1,000 MWe) power station* consumes about 3.1 million tonnes of black coal each year, or about 24 tonnes of uranium (as UO_2) enriched to about 4% of the useful isotope (U-235). This requires the

mining of over 200 tonnes of natural uranium which may be recovered from, say, 25-100,000 tonnes of typical uranium ore.

*operating at 80% capacity

Vocabulary:

uranium - уран

harness - використовувати

steam power – парова тяга, парова енергія

primary energy – первинна енергія

secondary energy – вторинна енергія

an abundance – надлишок, велика кількість

versatile fuel – універсальне паливо

fossil fuel – викопне, природне паливо

fertiliser - добриво

to squander - марнувати

reticulate - сітчастий

virtue – сила, дія, ефективність

abundant – багатий, рясний

crude oil – неочищена нафта

Task. Translate into English

Природні види палива — кам'яне вугілля, включаючи паливні продукти, одержані при збагаченні та сортуванні на підприємствах вугільної промисловості, буре вугілля (лігніт), сланці горючі, торф паливний, дрова опалювальні, деревинні відходи лісозаготівлі, деревинні відходи деревообробки, відходи сільськогосподарського виробництва (солома, качани та стебла кукурудзи, лушпиння соняшникове та рисове тощо), інші види первинного твердого палива (непридатні шпали, рудникові стійки, дерев'яна тара тощо), нафта, включаючи газовий конденсат, природний газ, до якого входить шахтний метан.

рідке та газове паливо, яке є альтернативою відповідним традиційним видам палива і яке видобувається з нетрадиційних джерел та видів енергетичної сировини;

Нетрадиційні джерела та види енергетичної сировини - сировина рослинного походження, відходи, тверді горючі речовини, інші природні і штучні джерела та види енергетичної сировини, у тому числі нафтові, газові, газоконденсатні і нафтогазоконденсатні вичерпані, непромислового значення та техногенні родовища, важкі сорти нафти, природні бітуми, газонасичені води, газогідрати тощо, видобуток і переробка яких потребує застосування новітніх технологій і які не використовуються для виробництва (видобутку) традиційних видів палива;

До альтернативних видів рідкого палива належать:

- горючі рідини, одержані під час переробки твердих видів палива (вугілля, торфу, сланців);
- спирти та їх суміші, олії;
- горючі рідини, одержані з промислових відходів;
- паливо, одержане з нафти і газового конденсату нафтових, газових та газоконденсатних родовищ непромислового значення та вичерпаних родовищ, з важких сортів нафти та природних бітумів, якщо це паливо не належить до традиційного виду.

До альтернативних видів газового палива належать:

- газ (метан) вугільних родовищ, а також газ, одержаний у процесі підземної газифікації та підземного спалювання вугільних пластів;
- газ, одержаний під час переробки твердого палива, природних бітумів, важкої нафти.
- газ, одержаний з природних газових гідратів, та підгідратний газ;
- газ, одержаний з промислових відходів;
- стиснений та зріджений природний газ, зріджений нафтовий газ, вільний газ метан, якщо вони одержані з газових, газоконденсатних та нафтових родовищ непромислового значення та вичерпаних родовищ і не належать до традиційних видів палива.

Сфера альтернативних видів палива - сфера діяльності, пов'язана з виробництвом (видобутком), транспортуванням, зберіганням та споживанням альтернативних видів палива.

Task. Read the text and translate it into Ukrainian

The Fuel Cycle in Brief.

Mining

Uranium deposits are found in rocks around the world. The two largest producers of uranium are Canada and Australia. Uranium is recovered either by mining hard rock or by in situ leaching (ISL), where dissolved from the orebody in situ, the solution then being pumped back to the surface. If uranium is mined the rock is crushed and then leached to dissolve out the uranium, which is then precipitated out of solution as the uranium oxide U_3O_8 , sometimes known as 'yellowcake'.

Conversion, Enrichment and Fuel Fabrication

Most reactors use fuel enriched in the U-235 isotope. The solid uranium oxide from the mine is converted into the gas UF_6 , which is then enriched in the U-235 isotope by one of two physical methods of enrichment. *Diffusion* enrichment, works by exploiting the different speeds at which U-235 and U-238 pass through a membrane. *Centrifuge* enrichment, works by passing the gas through spinning cylinders, the centrifugal force moving the heavier U-238 to the outside of the cylinder, leaving a higher concentration of U-235 on the inside. Uranium dioxide pellets are produced from the enriched UF_6 gas.

Electricity Generation

Nuclear reactors produce electricity by heating water to make steam. The steam is then used to drive turbines that generate electricity. In this sense nuclear power plants are similar to other thermal power stations, where the heat from burning coal or gas is used to produce steam. A key difference of nuclear reactors is that they don't emit carbon dioxide. A nuclear *chain reaction* is so-called because when a U-235 atom splits (or fissions) in the reactor's core the released neutrons cause other uranium atoms to undergo fission. A moderator slows down the neutrons to achieve this. The nuclear reactor uses control rods to ensure that this chain reaction occurs at a controlled rate.

Used Fuel Management

Used fuel from a nuclear reactor is first stored to allow most of the radioactivity to decay. Then it can either be reprocessed to recover the reusable portion, or it may be disposed of directly as waste. In reprocessing, the used fuel is dissolved and the uranium and plutonium in the used fuel are separated from the waste fission products. Plutonium can then be combined uranium to make Mixed Oxide Fuel (MOX), which can be used in many modern reactors. Reprocessed uranium can be used in new uranium oxide fuel. No underground facilities have yet been built for used fuel, although several are planned.

Waste Management

Nuclear wastes range from low level wastes, which contain barely radioactive materials which are called through to high level wastes such as used nuclear fuel that is not destined for reprocessing. Low level waste facilities are already in operation, taking wastes not only from the power generation sector, but also those from nuclear medicine. High level waste is currently kept in storage facilities and will finally be put into specially engineered underground repositories.

Decommissioning

Nuclear facilities are decommissioned after the end of their operating lives. All nuclear materials, machinery and plant are removed and it is ensured that the site is returned to a state where it can be used for new purposes.

Transport

Nuclear materials, such as feedstock in the fuel manufacture process, new fuel, used fuel and wastes are transported between nuclear facilities by road, rail and sea in specially designed containers. Care is taken to ensure that this is safe even in accident situations

Vocabulary:

fuel cycle – паливний цикл (реактора)

to mine - видобувати

in situ – на своєму місці

to leach – вимивати, вилуговувати

orebody – суцільне родовище, рудний шток

to dissolve – розчиняти, випаровувати

precipitate – осаджувати, прискорювати

«yellowcake» - неочищений оксид урану (отримав таку назву через те, що утворює осад жовтого кольору)

conversion - переробка

enrichment - збагачення

fuel fabrication – вироблення палива

UF₆ – гексафторид урану (сіль шостивалентного урану й фтороводневої кислоти, сполука, яка використовується під час проміжної стадії процесу збагачення урану, необхідного для вироблення палива для АЕС)

to exploit – розробляти (родовище)

spinning cylinder – циліндр, що обертається

to emit – випромінювати, випускати

to fission – ділитись, розщеплюватись

to split – розколюватись, ділитись

moderator – сповільнювач (яд. реакцій)

control rod – регулюючий стрижень

decommissioning - списування

feedstock – склад для заготовок

Task. Read the text and translate it into Ukrainian

Getting uranium from the ground

Uranium is a relatively common metal, found in rocks and seawater. Over half of the world's production of uranium from mines is in Canada and Australia.

Uranium ore is recovered by excavation or by in situ leaching techniques. Excavation may be underground or open pit mining.

After the uranium has been mined it is milled. the uranium ore is crushed to a fine slurry, which is then leached with sulfuric acid to produce concentrated U_3O_8 , commonly known as 'yellowcake'.

In situ leaching involves pumping a liquid into the ground to dissolve the uranium and then pumping that liquid back to the surface.

Mining and Milling

There are two main types of mining. In general, open pit mining is used where deposits are close to the surface and underground mining is used for deep deposits, typically greater than 120 m deep.

Underground mines have relatively small surface disturbance and the quantity of material that must be removed to access the ore is considerably less than in the case of an open pit mine.

In the case of underground uranium mines, special precautions, consisting primarily of increased ventilation, are required to protect against airborne radiation exposure.

After the uranium ore has been mined it is milled. Milling, which is generally carried out close to a uranium mine, extracts the uranium from the ore. Most mining facilities include a mill, although where mines are close together, one mill may process the ore from several mines

At the mill the ore is crushed and ground to a fine slurry. Sulfuric acid or a strong alkaline solution is used to dissolve the uranium to allow the separation of uranium from the waste rock. It is then recovered from solution and precipitated as uranium oxide (U_3O_8) concentrate. This is sometimes referred to as 'yellowcake' and generally contains more than 80% uranium. The original ore may contain as little as 0.1% uranium.

After drying and usually heating it is packed in 200-litre drums as a concentrate.

The remainder of the ore, containing most of the radioactivity and nearly all the rock material, becomes tailings, which are placed in engineered facilities near the mine (often in mined out pits). Tailings contain long-lived radioactive materials in low concentrations and toxic materials such as heavy metals; however, the total quantity of radioactive elements is less than in the original ore, and their

collective radioactivity will be much shorter-lived. These materials need to be isolated from the environment.

Conversion and Enrichment

Uranium found in nature consists largely of two isotopes, U-235 and U-238. The production of energy in the form of heat in nuclear reactors is from the 'fission' or splitting of the U-235 atoms. Natural uranium contains 0.7% of the U-235 isotope. The remaining 99.3% is mostly the U-238 isotope which does not contribute directly to the fission process.

Uranium-235 and U-238 are chemically identical, but differ in their physical properties, particularly their mass. The nucleus of the U-235 atom contains 92 protons and 143 neutrons, giving an atomic mass of 235 units. The U-238 nucleus also has 92 protons but has 146 neutrons - three more than U-235, and therefore has a mass of 238 units.

Uranium is enriched in U-235 by gaseous diffusion or centrifuge technology. Both of these processes work on the principle of separating the lighter U-235 from the heavier U-238, when in the form of uranium hexafluoride gas.

Some reactors, for example the Canadian-designed Candu and the British Magnox reactors, use natural uranium as their fuel, but most types require uranium enriched to 3 to 5 percent U-235 .

Conversion

Uranium enrichment requires the material to be in gaseous form. The product of a uranium mine is not directly usable and the uranium oxide must be converted into uranium hexafluoride (UF₆) which is a gas at relatively low temperature.

There are conversion plants in Europe, Russia or North America . At a conversion facility, the U₃O₈ is first refined to uranium dioxide, which can be used as the fuel for those types of reactors that do not require enriched uranium. Most is then converted into uranium

hexafluoride, ready for the enrichment plant. It is shipped in strong metal containers.

Gaseous diffusion enrichment

The diffusion process involves forcing uranium hexafluoride gas under pressure through a series of porous membranes. As U-235 molecules are lighter than the U-238 molecules they move faster and have a slightly better chance of passing through the pores in the membrane. The UF₆ which diffuses through the membrane is thus slightly enriched, while the gas which did not pass through is slightly depleted in U-235.

This process is repeated many times in a series of diffusion stages called a cascade. The enriched UF₆ product is withdrawn from one end of the cascade and the depleted UF₆ is removed at the other end. The gas must be processed through some 1400 stages to obtain a product with a concentration of 3% to 4% U-235.

At present the gaseous diffusion process accounts for about 40% of world enrichment capacity. However, because they are old and energy-inefficient, most gaseous diffusion plants are being phased out over the next five years in favour of centrifuge enrichment technology.

The large tricastin enrichment plant in France (beyond cooling towers) the four nuclear reactors in the foreground provide over 3000 MWe power for the plant.

Centrifuge enrichment

Like the diffusion process, the centrifuge process uses UF₆ gas as its feed and makes use of the slight difference in mass between U-235 and U-238. The gas is fed into a series of



vacuum tubes, each containing a rotor one to two metres long and 15-20 cm diameter. When the rotors are spun rapidly, at 50,000 to 70,000 rpm the outer wall of the spinning cylinder moves at between 400 and 500 meters per second to give a million times the acceleration of gravity. Centrifugal force causes the heavier molecules with U-238 increase in concentration towards the

cylinder's outer edge. There is a corresponding increase in concentration of U-235 molecules near the centre.

The enriched gas forms part of the feed for the next stages while the depleted UF₆ gas goes back to the previous stage. Eventually enriched is drawn from the cascade at the desired concentration and depleted uranium is removed for storage .

Enrichment of reprocessed uranium



A bank of centrifuges at a urenco plant

In some countries used fuel is reprocessed to recover its uranium and plutonium, and to reduce the final volume of high-level wastes. The plutonium is normally recycled promptly into mixed-oxide (MOX) fuel, by mixing it with depleted uranium. The uranium can be re-enriched,

usually through the centrifuge process.

Task. Translate into English.

Найперша стадія уранового виробництва — концентрування. Порода подрібнюють і змішують з водою. Важкі компоненти суспензії осідають швидше. Якщо порода містить первинні мінерали урану, то вони осідають швидко: це важкі мінерали. Вторинні мінерали урану легші, в цьому випадку раніше осідає важка пуста порода. (Втім, далеко не завжди вона справді порожня; в ній можуть бути багато корисних елементів, у тому числі і уран). Наступна стадія — вилуговування концентратів, перетворення урану в розчин. Розрізняють кислотне і лужне вилуговування. Перше — дешевше, оскільки для видобування урану використовують сірчану кислоту. Але якщо у вихідній сировині, як, наприклад, в урановій смолці, уран знаходиться в чотирьохвалентном стані, то цей спосіб непридатний: чотирьохвалентний уран в сірчані

кислоті практично не розчиняється. У цьому випадку потрібно або вдатися до лужного вилугування, або попередньо окиснити уран до шестивалентного стану. Не застосовують кислотне вилугування і в тих випадках, якщо урановий концентрат містить доломіт або магнезит, що реагують з сірчаною кислотою. У цих випадках використовують гідроксид натрію. Проблема вилугування урану з руд вирішує кисневе продування. У нагріту до 150 °С суміш уранової руди з сульфідними мінералами подають потік кисню. При цьому з сірчистих мінералів утворюється сірчана кислота, яка і вимиває уран. На наступному етапі з отриманого розчину потрібно вибірково виділити уран. Сучасні методи — екстракція та іонний обмін — дозволяють вирішити цю проблему. Тепер розчин містить не тільки уран, але й інші катіони. Деякі з них у певних умовах ведуть себе так само, як уран: екстрагуються тими ж органічними розчинниками, осідають на тих же іонообмінних смолах, випадають в осад при тих же умовах. Тому для селективного виділення урану доводиться використовувати багато окислювально-відновних реакцій, щоб на кожній стадії позбавлятися від того чи іншого небажаного попутника. На сучасних іонообмінних смолах уран виділяється дуже селективно. Методи іонного обміну та екстракції хороші ще й тим, що дозволяють досить повно витягати уран з бідних розчинів (вміст урану — десятки частки граму на літр). Після цих операцій уран переводять у твердий стан — в один із оксидів або в тетрафторид UF_4 . Але цей уран ще треба очистити від домішок елементів з великим перерізом захвату теплових нейтронів — бору, кадмію, гафнію. Їх вміст в кінцевому продукті не повинний перевищувати стотисячних і мільйонних часток відсотка. Для видалення цих домішок технічно чисту сполуку урану розчиняють в азотні кислоти. При цьому утворюється уранілнітрат $\text{UO}_2(\text{NO}_3)_2$, який при екстракції трибутил-фосфатом і деякими іншими речовинами додатково очищається до потрібних кондицій. Потім ця речовина кристалізуються (або осаджують пероксид $\text{UO}_4 \cdot 2\text{H}_2\text{O}$) і починають обережно прожарюють. В результаті цієї операції утворюється оксид урану UO_3 , який відновлюють воднем до UO_2 . На діоксид урану UO_2 при температурі від 430 до 600 °С

діють сухим фтористим воднем для отримання тетрафториду UF_4 . З цієї сполуки відновлюють металевий уран за допомогою кальцію або магнію.

Task. Read the text and translate it into Ukrainian.

Fuel Fabrication

Most nuclear reactors use fuel made comprising of pellets of uranium dioxide encased in metal tubes, which are arranged in fuel assemblies. Uranium dioxide fuels are used in PWR, BWR and Candu reactors.

Uranium Dioxide Fuel Manufacture

In a fuel fabrication plant enriched UF_6 gas is converted to uranium dioxide (UO_2), which is formed into ceramic fuel pellets by baking it at a high temperature (over 1400°C).

The pellets are then encased in metal tubes, usually made of zirconium alloy (zircalloy) or stainless steel, to form fuel rods. The rods are then sealed and assembled in clusters to form fuel assemblies for use in the core of the nuclear reactor.

Fuel Types

Pressurized water reactor (PWR) fuel consists of cylindrical rods of



Zircalloy tubes filled with UO_2 pellets put into bundles. The Zircalloy tubes are about 1 cm in diameter, and the fuel cladding gap is filled with helium gas to improve the conduction of heat from the fuel to the cladding. There are about 179-264 fuel rods per fuel bundle and about 121 to 193 fuel bundles, about 4 metres in length, are loaded into a reactor core. Control rods are inserted through the top directly into the fuel bundle.

In boiling water reactors (BWR), the fuel is similar to PWR fuel except that the bundles are "canned". That is there is a thin tube surrounding each bundle. In BWR fuel bundles, there are about 500-800 fuel rods per assembly. Each BWR

fuel rod is back filled with helium to a pressure of about three atmospheres (300 kPa).

CANDU fuel bundles are about a half meter in length and 30 cm in diameter. They consist of sintered (UO₂) pellets in Zirconium tubes, welded to Zirconium end plates. Each bundle is roughly 20 kg, and a typical core loading is on the order of 4500 bundles. Current CANDU designs do not need enriched uranium to achieve criticality (due to their more efficient heavy water moderator), however, some newer concepts call for low enrichment to help reduce the size of the reactors.

Vocabulary:

pressurized-water reactor (PWR) - водо-водяний ядерний реактор

boiling-water reactor (BWR) - киплячий ядерний реактор

pressurized heavy water reactor (CANDU) - важководний водо-водяний ядерний реактор, який було розроблено у Канаді (from Can(ada) + the initial letters of deuterium and uranium)

pellet – брусок, блок, катишок

to encase – упаковувати, вставляти

zirconium - цирконій

fuel rod – паливний стрижень

to seal – ізолювати, герметично закривати

fuel assembly – касета елементів, що виділяють тепло

core – серцевина, сердечник, ядро

bundle - вузол

sintered - агломерований

What is Uranium?

Uranium is a very heavy metal which can be used as an abundant source of concentrated energy. It is common in the Earth's crust and is found in economic concentrations in a wide variety of geological settings.

Unlike fossil fuels which are combined with oxygen in burning to release a lot of heat, uranium atoms can be made to split, or fission, to release heat. A kilogram of natural uranium produces as much

heat as 20 tonnes of coal. This is harnessed to make steam and generate power.

It was discovered in 1789 by Martin Klaproth, a German chemist, in the mineral called pitchblende. It was named after the planet Uranus, which had been discovered eight years earlier.

Uranium was formed in super novae about 6.6 billion years ago. While it is not common in the solar system, today its slow radioactive decay provides the main source of heat inside the Earth, causing convection and continental drift.

The high density of uranium means that it also finds uses in the keels of yachts and as counterweights for aircraft control surfaces, as well as for radiation shielding.

The Uranium Atom

Uranium is the heaviest of all the naturally-occurring elements (hydrogen is the lightest). Uranium is 18.7 times as dense as water.

Like other elements, uranium occurs in several slightly differing forms known as 'isotopes'. These isotopes differ from each other in the number of particles (neutrons) in the nucleus. Natural uranium as found in the Earth's crust is a mixture largely of two isotopes: uranium-238 (U-238), accounting for 99.3% and uranium-235 (U-235) about 0.7%.

The isotope U-235 is important because under certain conditions it can readily be split, yielding a lot of energy. It is therefore said to be 'fissile' and we use the expression 'nuclear fission'.

Like all radioactive isotopes, uranium atoms decay. U-238 decays very slowly, its half-life being about the same as the age of the Earth (4500 million years). This means that it is barely radioactive, less so than many other isotopes in rocks and sand. Nevertheless it generates 0.1 watts/tonne as decay heat and this is enough to warm the Earth's core. U-235 decays slightly faster.

Energy from the uranium atom

When the nucleus of a U-235 atom captures a moving neutron it splits in two (fissions) and releases some energy in the form of heat. During the fission two or three neutrons are thrown off.

If enough of these expelled neutrons are captured by the nuclei of other U-235 atoms to split, releasing further neutrons, a fission 'chain reaction' occurs. When this happens over and over again, many millions of times, a very large amount of heat is produced from a relatively small amount of uranium.

Inside the nuclear reactor

In a nuclear reactor the uranium fuel is assembled in such a way that a controlled fission chain reaction can be achieved.

Nuclear power stations and fossil-fuelled power stations of similar capacity have many features in common. Both use heat to produce steam to drive turbines and generators. However, the fissioning of uranium atoms replaces the burning of coal or gas. Burning coal or gas oxidises carbon to produce carbon dioxide. This is not produced in the fissioning of uranium.

The chain reaction that takes place in the core of a nuclear reactor is controlled by rods which absorb neutrons and which can be inserted or withdrawn to set the reactor at the required power level.

The fuel elements are surrounded by a substance called a moderator to slow the speed of the emitted neutrons and thus enable the chain reaction to continue. Water, graphite and heavy water are used as moderators in different types of reactors.

Advanced Nuclear Power Reactors

- **The next two generations of nuclear reactors are currently being developed in several countries.**
- **The first (3rd generation) advanced reactors have been operating in Japan since 1996. Late 3rd generation designs are now being built.**
- **Newer advanced reactors have simpler designs which reduce capital cost. They are more fuel efficient and are inherently safer.**

The nuclear power industry has been developing and improving reactor technology for more than five decades and is starting to build

the next generation of nuclear power reactors to fill orders now materialising.

Several generations of reactors are commonly distinguished. Generation I reactors were developed in 1950-60s, and outside the UK none are still running today. Generation II reactors are typified by the present US fleet and most in operation elsewhere. Generation III are the Advanced Reactors discussed in this paper. The first are in operation in Japan and others are under construction or ready to be ordered. Generation IV designs are still on the drawing board and will not be operational before 2020 at the earliest.

About 85% of the world's nuclear electricity is generated by reactors derived from designs originally developed for naval use. These and other second-generation nuclear power units have been found to be safe and reliable, but they are being superseded by better designs.

Reactor suppliers in North America, Japan, Europe, Russia and elsewhere have a dozen new nuclear reactor designs at advanced stages of planning, while others are at a research and development stage. Fourth-generation reactors are at concept stage.

Third-generation reactors have:

- a standardised design for each type to expedite licensing, reduce capital cost and reduce construction time,
- a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets,
- higher availability and longer operating life - typically 60 years,
- further reduced possibility of core melt accidents,
- resistance to serious damage that would allow radiological release from an aircraft impact,
- higher burn-up to reduce fuel use and the amount of waste,
- burnable absorbers ("poisons") to extend fuel life.

The greatest departure from second-generation designs is that many incorporate passive or inherent safety features which require no active controls or operational intervention to avoid accidents in the event of malfunction, and may rely on gravity, natural convection or resistance to high temperatures.

Vocabulary:

advanced reactor – сучасний реактор

fleet – військово-морський флот
 naval – військово-морський
 to expedite – прискорювати, швидко виконувати
 rugged - грубий
 vulnerable – сприйнятливий, піддатливий

Nuclear Power Reactors

- **Most nuclear electricity is generated using just two kinds of reactors which were developed in the 1950s and improved since.**
- **New designs are coming forward and some are in operation as the first generation reactors come to the end of their operating lives.**
- **Over 16% of the world's electricity is produced from nuclear energy, more than from all sources worldwide in 1960.**

A nuclear reactor produces and controls the release of energy from splitting the atoms of certain elements. In a nuclear power reactor, the energy released is used as heat to make steam to generate electricity. (In a research reactor the main purpose is to utilise the actual neutrons produced in the core. In most naval reactors, steam drives a turbine directly for propulsion.)

The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

There are several components common to most types of reactors:

Fuel. Usually pellets of uranium oxide (UO_2) arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core.*

* In a new reactor with new fuel a neutron source is needed to get the reaction going. Usually this is beryllium mixed with polonium, radium or other alpha-emitter. Alpha particles from the decay cause a release of neutrons from the beryllium as it turns to carbon-12. Restarting a reactor with some used fuel may not require this, as there may be enough neutrons to achieve criticality when control rods are removed.

Moderator. This is material in the core which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite.

Control rods. These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it.* In some reactors, special control rods are used to enable the core to sustain a low level of power efficiently. (Secondary shutdown systems involve adding other neutron absorbers, usually as a fluid, to the system.)

* In fission, most of the neutrons are released promptly, but some are delayed. These are crucial in enabling a chain reacting system (or reactor) to be controllable and to be able to be held precisely critical.

Coolant. A liquid or gas circulating through the core so as to transfer the heat from it. . In light water reactors the water moderator functions also as primary coolant. Except in BWRs, there is secondary coolant circuit where the steam is made. (see also later section on primary coolant characteristics)

Pressure vessel or pressure tubes. Usually a robust steel vessel containing the reactor core and moderator/coolant, but it may be a series of tubes holding the fuel and conveying the coolant through the moderator.

Steam generator. (not in BWR) Part of the cooling system where the primary coolant bringing heat from the reactor is used to make steam for the turbine.

Containment. The structure around the reactor core which is designed to protect it from outside intrusion and to protect those

outside from the effects of radiation in case of any malfunction inside. It is typically a metre-thick concrete and steel structure.

There are several different types of reactors as indicated in the following table.

Nuclear power plants in commercial operation

Most reactors need to be shut down for refuelling, so that the pressure vessel can be opened up. In this case refuelling is at intervals of 1-2 years, when a quarter to a third of the fuel assemblies are replaced with fresh ones. The CANDU and RBMK types have pressure tubes (rather than a pressure vessel enclosing the reactor core) and can be refuelled under load by disconnecting individual pressure tubes.

If graphite or heavy water is used as moderator, it is possible to run a power reactor on natural instead of enriched uranium. Natural uranium has the same elemental composition as when it was mined (0.7% U-235, over 99.2% U-238), enriched uranium has had the proportion of the fissile isotope (U-235) increased by a process called enrichment, commonly to 3.5 - 5.0%. In this case the moderator can be ordinary water, and such reactors are collectively called light water reactors. Because the light water absorbs neutrons as well as slowing them, it is less efficient as a moderator than heavy water or graphite.

Practically all fuel is ceramic uranium oxide (UO_2 with a melting point of 2800°C) and most is enriched. The fuel pellets (usually about 1 cm diameter and 1.5 cm long) are typically arranged in a long zirconium alloy (zircaloy) tube to form a fuel rod, the zirconium being hard, corrosion-resistant and permeable to neutrons.* Numerous rods form a fuel assembly, which is an open lattice and can be lifted into and out of the reactor core. In the most common reactors these are about 3.5 to 4 metres long.

*Zirconium is an important mineral for nuclear power, where it finds its main use. It is therefore subject to controls on trading. It is normally contaminated with hafnium, a neutron absorber, so very pure 'nuclear grade' Zr is used to make the zircaloy, which is about

98% Zr plus tin, iron, chromium and sometimes nickel to enhance its strength.

Burnable poisons are often used (especially in BWR) in fuel or coolant to even out the performance of the reactor over time from fresh fuel being loaded to refuelling. These are neutron absorbers which decay under neutron exposure, compensating for the progressive build up of neutron absorbers in the fuel as it is burned. The best known is gadolinium, which is a vital ingredient of fuel in naval reactors where installing fresh fuel is very inconvenient, so reactors are designed to run more than a decade between refuellings.

Vocabulary:

to improve - вдосконалювати

to release - звільнюватись

propulsion - рушійна сила

fission - розподіл, поділ

emitter - випромінювач

hafnium - гафній

boron - бор

insert - опускати

withdraw - виймати

to halt - зупиняти

to sustain - підтримувати

shutdown - зупинка

promptly - швидко

to delay - затримуватись

crucial - ключовий

robust steel - загартована сталь

vessel – посудина

containment – будова, структура

convey - спрямовувати,направляти

concrete - цемент

intrusion - втручання

malfunction - несправність, дефект

gas-cooled reactor (AGR & Magnox)– реактор з газовим охолодженням

Light water graphite reactor (RBMK) - графіто-газовий ядерний реактор

Fast neutron reactor (FBR) - реактор на швидких нейтронах

Pressurised Water Reactor (PWR)

This is the most common type, with over 230 in use for power generation and several hundred more employed for naval propulsion. The design of PWRs originated as a submarine power plant. PWRs use ordinary water as both coolant and moderator. The design is distinguished by having a primary cooling circuit which flows through the core of the reactor under very high pressure, and a secondary circuit in which steam is generated to drive the turbine.

A PWR has fuel assemblies of 200-300 rods each, arranged vertically in the core, and a large reactor would have about 150-250 fuel assemblies with 80-100 tonnes of uranium.

Water in the reactor core reaches about 325°C, hence it must be kept under about 150 times atmospheric pressure to prevent it boiling. Pressure is maintained by steam in a pressuriser. In the primary cooling circuit the water is also the moderator, and if any of it turned to steam the fission reaction would slow down. This negative feedback effect is one of the safety features of the type. The secondary shutdown system involves adding boron to the primary circuit.

The secondary circuit is under less pressure and the water here boils in the heat exchangers which are thus steam generators. The steam drives the turbine to produce electricity, and is then condensed and returned to the heat exchangers in contact with the primary circuit.

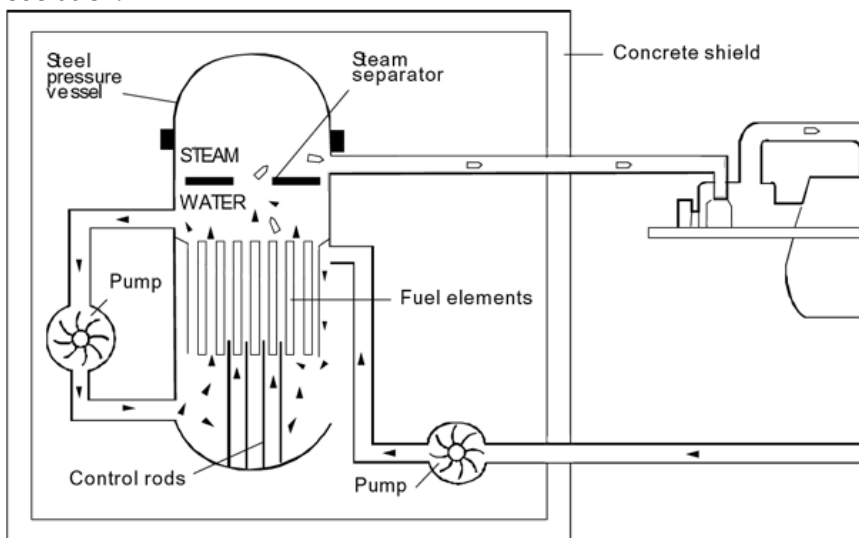
Boiling Water Reactor (BWR)

This design has many similarities to the PWR, except that there is only a single circuit in which the water is at lower pressure (about 75 times atmospheric pressure) so that it boils in the core at about 285°C. The reactor is designed to operate with 12-15% of the water

in the top part of the core as steam, and hence with less moderating effect and thus efficiency there.

The steam passes through drier plates (steam separators) above the core and then directly to the turbines, which are thus part of the reactor circuit. Since the water around the core of a reactor is always contaminated with traces of radionuclides, it means that the turbine must be shielded and radiological protection provided during maintenance. The cost of this tends to balance the savings due to the simpler design. Most of the radioactivity in the water is very short-lived, so the turbine hall can be entered soon after the reactor is shut down.

A BWR fuel assembly comprises 90-100 fuel rods, and there are up to 750 assemblies in a reactor core, holding up to 140 tonnes of uranium. The secondary control system involves restricting water flow through the core so that more steam in the top part reduces moderation.



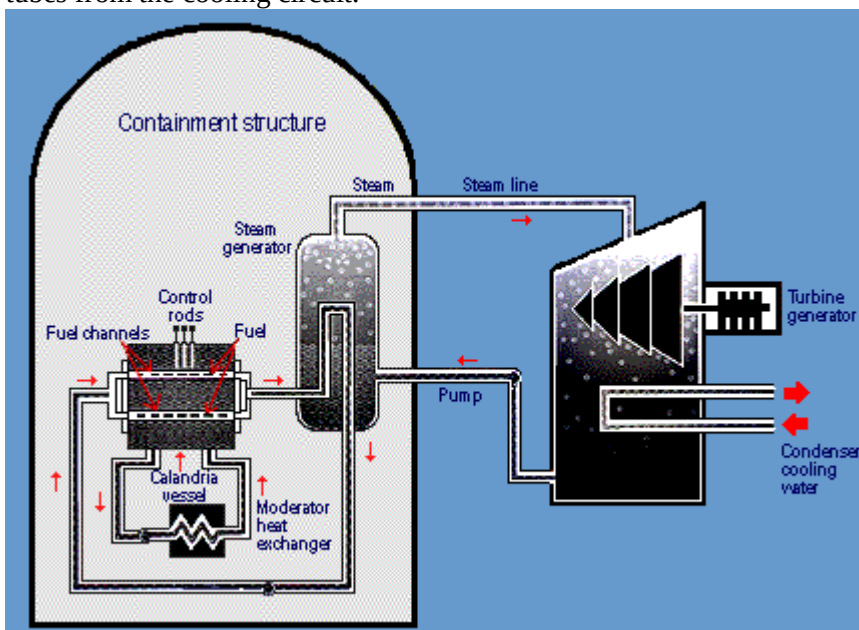
Pressurised Heavy Water Reactor (PHWR or CANDU)

The PHWR reactor design has been developed since the 1950s in Canada as the CANDU, and more recently also in India. It uses

natural uranium (0.7% U-235) oxide as fuel, hence needs a more efficient moderator, in this case heavy water (D_2O).**

** with the CANDU system, the moderator is enriched (i.e. water) rather than the fuel, - a cost trade-off.

The moderator is in a large tank called a calandria, penetrated by several hundred horizontal pressure tubes which form channels for the fuel, cooled by a flow of heavy water under high pressure in the primary cooling circuit, reaching $290^{\circ}C$. As in the PWR, the primary coolant generates steam in a secondary circuit to drive the turbines. The pressure tube design means that the reactor can be refuelled progressively without shutting down, by isolating individual pressure tubes from the cooling circuit.

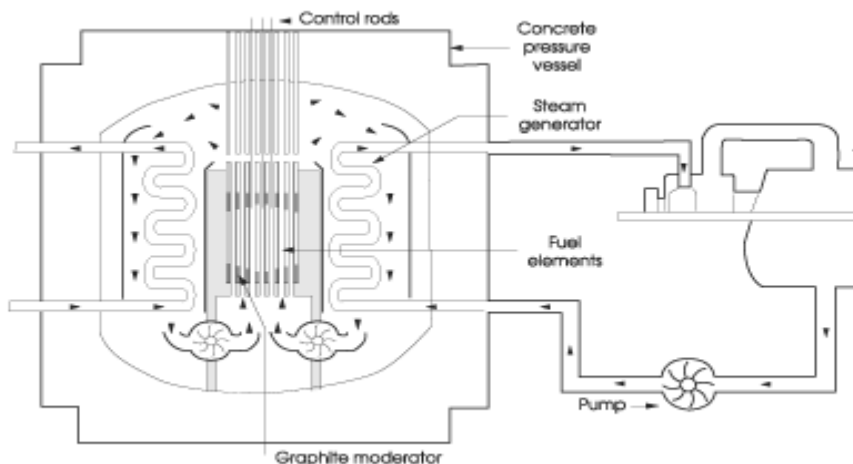


A CANDU fuel assembly consists of a bundle of 37 half metre long fuel rods (ceramic fuel pellets in zircaloy tubes) plus a support structure, with 12 bundles lying end to end in a fuel channel. Control rods penetrate the calandria vertically, and a secondary shutdown system involves adding gadolinium to the moderator. The heavy water moderator circulating through the body of the calandria vessel

also yields some heat (though this circuit is not shown on the diagram above).

Advanced Gas-cooled Reactor (AGR)

These are the second generation of British gas-cooled reactors, using graphite moderator and carbon dioxide as coolant. The fuel is uranium oxide pellets, enriched to 2.5-3.5%, in stainless steel tubes. The carbon dioxide circulates through the core, reaching 650°C and then past steam generator tubes outside it, but still inside the concrete and steel pressure vessel. Control rods penetrate the moderator and a secondary shutdown system involves injecting nitrogen to the coolant.



The AGR was developed from the Magnox reactor, also graphite moderated and CO₂ cooled, and two of these are still operating in UK. They use natural uranium fuel in metal form.

Light water graphite-moderated reactor (RBMK)

This is a Soviet design, developed from plutonium production reactors. It employs long (7 metre) vertical pressure tubes running through graphite moderator, and is cooled by water, which is allowed

to boil in the core at 290°C, much as in a BWR. Fuel is low-enriched uranium oxide made up into fuel assemblies 3.5 metres long. With moderation largely due to the fixed graphite, excess boiling simply reduces the cooling and neutron absorption without inhibiting the fission reaction, and a positive feedback problem can arise, which is why they have never been built outside the Soviet Union.

Advanced reactors

Several generations of reactors are commonly distinguished. Generation I reactors were developed in 1950-60s and very few are still running today. They mostly used natural uranium fuel and used graphite as moderator. Generation II reactors are typified by the present US fleet and most in operation elsewhere. They typically use enriched uranium fuel and are mostly cooled and moderated by water. Generation III are the Advanced Reactors, the first few of which are in operation in Japan and others are under construction and ready to be ordered. They are developments of the second generation with enhanced safety.

Generation IV designs are still on the drawing board and will not be operational before 2020 at the earliest, probably later. They will tend to have closed fuel cycles and burn the long-lived actinides now forming part of spent fuel, so that fission products are the only high-level waste. Many will be fast neutron reactors.

More than a dozen (Generation III) advanced reactor designs are in various stages of development. Some are evolutionary from the PWR, BWR and CANDU designs above, some are more radical departures. The former include the Advanced Boiling Water Reactor, a few of which are now operating with others under construction. The best-known radical new design is the Pebble Bed Modular Reactor, using helium as coolant, at very high temperature, to drive a turbine directly.

Considering the closed fuel cycle, Generation 1-3 reactors recycle plutonium (and possibly uranium), while Generation IV are expected to have full actinide recycle.

Fast neutron reactors (FNR)

Some reactors (only one in commercial service) do not have a moderator and utilise fast neutrons, generating power from plutonium while making more of it from the U-238 isotope in or around the fuel. While they get more than 60 times as much energy from the original uranium compared with the normal reactors, they are expensive to build. Further development of them is likely in the next decade, and the main designs expected to be built in two decades are FNRs. See also Fast Neutron Reactors and Small Reactors papers.

Floating nuclear power plants

Apart from over 200 nuclear reactors powering various kinds of ships, Rosatom in Russia has set up a subsidiary to supply floating nuclear power plants ranging in size from 70 to 600 MWe. These will be mounted in pairs on a large barge, which will be permanently moored where it is needed to supply power and possibly some desalination to a shore settlement or industrial complex. The first will have two 40 MWe reactors based on those in icebreakers and will operate at Severodvinsk, in the Archangel region. Five of the next seven will be used by Gazprom for offshore oil and gas field development and for operations on the Kola and Yamal peninsulas. One is for Pevek on the Chukotka peninsula, another for Kamchatka region, both in the far east of the country. Further far east sites being considered are Yakutia and Taimyr. Electricity cost is expected to be much lower than from present alternatives.

Lifetime of nuclear reactors.

Most of today's nuclear plants which were originally designed for 30 or 40-year operating lives. However, with major investments in systems, structures and components lives can be extended, and in several countries there are active programs to extend operating lives. In the USA most of the more than one hundred reactors are expected to be granted licence extensions from 40 to 60 years. This justifies

significant capital expenditure in upgrading systems and components, including building in extra performance margins.

Some components simply wear out, corrode or degrade to a low level of efficiency. These need to be replaced. Steam generators are the most prominent and expensive of these, and many have been replaced after about 30 years where the reactor otherwise has the prospect of running for 60 years. This is essentially an economic decision. Lesser components are more straightforward to replace as they age. In Candu reactors, pressure tube replacement has been undertaken on some plants after about 30 years operation.

A second issue is that of obsolescence. For instance, older reactors have analogue instrument and control systems. Thirdly, the properties of materials may degrade with age, particularly with heat and neutron irradiation. In respect to all these aspects, investment is needed to maintain reliability and safety. Also, periodic safety reviews are undertaken on older plants in line with international safety conventions and principles to ensure that safety margins are maintained.

Load-following capacity

Nuclear power plants are essentially base-load generators, running continuously. This is because their power output cannot readily be ramped up and down on a daily and weekly basis, and in this respect they are similar to most coal-fired plants. (It is also uneconomic to run them at less than full capacity, since they are expensive to build but cheap to run.) However, in some situations it is necessary to vary the output according to daily and weekly load cycles on a regular basis, for instance in France, where there is a very high reliance on nuclear power.

The ability of a power reactor to run at less than full power for much of the time depends on whether it is in the early part of its 18 to 24-month refueling cycle or late in it, and whether it is designed with special control rods which diminish power levels throughout the core without shutting it down. Thus, though the ability on any individual reactor to run on a sustained basis at low power decreases markedly

as it progresses through the refueling cycle, there is considerable scope for running a fleet of reactors in load-following mode. See further information in the Nuclear Power in France paper.

Primary coolants

The advent of some of the designs mentioned above provides opportunity to review the various primary coolants used in nuclear reactors. There is a wide variety - gas, water, light metal, heavy metal and salt:

Water or heavy water must be maintained at very high pressure (1000-2200 psi, 7-15 MPa) to enable it to function above 100°C, as in present reactors. This has a major influence on reactor engineering. However, supercritical water around 25 MPa can give 45% thermal efficiency - as at some fossil-fuel power plants today with outlet temperatures of 600°C, and at ultra supercritical levels (30+ MPa) 50% may be attained.

Helium must be used at similar pressure (1000-2000 psi, 7-14 MPa) to maintain sufficient density for efficient operation. Again, there are engineering implications, but it can be used in the Brayton cycle to drive a turbine directly.

Carbon dioxide was used in early British reactors and their AGRs. It is denser than helium and thus likely to give better thermal conversion efficiency. There is now interest in supercritical CO₂ for the Brayton cycle.

Sodium, as normally used in fast neutron reactors, melts at 98°C and boils at 883°C at atmospheric pressure, so despite the need to keep it dry the engineering required to contain it is relatively modest. However, normally water/steam is used in the secondary circuit to drive a turbine (Rankine cycle) at lower thermal efficiency than the Brayton cycle.

Lead or lead-bismuth eutectic in fast neutron reactors are capable of higher temperature operation. They are transparent to neutrons, aiding efficiency, and since they do not react with water the heat exchanger interface is safer. They do not burn when exposed to air. However, they are corrosive of fuel cladding and steels, and Pb-Bi yields toxic polonium (Po-210) activation products. Pb-Bi melts at a

relatively low 125°C (hence eutectic) and boils at 1670°C , Pb melts at 327°C and boils at 1737°C but is very much more abundant and cheaper to produce than bismuth, hence is envisaged for large-scale use in the future. The development of nuclear power based on Pb-Bi cooled fast neutron reactors is likely to be limited to a total of 50-100 GWe, basically for small reactors in remote places. In 1998 Russia declassified a lot of research information derived from its experience with submarine reactors, and US interest in using Pb or Pb-Bi for small reactors has increased subsequently.

Molten fluoride salt boils at 1400°C at atmospheric pressure, so allows several options for use of the heat, including using helium in a secondary Brayton cycle with thermal efficiencies of 48% at 750°C to 59% at 1000°C , or manufacture of hydrogen.

Low-pressure liquid coolants allow all their heat to be delivered at high temperatures, since the temperature drop in heat exchangers is less than with gas coolants. Also, with a good margin between operating and boiling temperatures, passive cooling for decay heat is readily achieved.

The removal of passive decay heat is a vital feature of primary cooling systems, beyond heat transfer to do work. When the fission process stops, fission product decay continues and a substantial amount of heat is added to the core. At the moment of shutdown, this is about 6% of the full power level, but it quickly drops to about 1% as the short-lived fission products decay. This heat could melt the core of a light water reactor unless it is reliably dissipated. Typically some kind of convection flow is relied upon.

Primitive reactors

The world's oldest known nuclear reactors operated at what is now Oklo in Gabon, West Africa. About 2 billion years ago, at least 17 natural nuclear reactors achieved criticality in a rich deposit of uranium ore. Each operated at about 20 kW thermal. At that time the concentration of U-235 in all natural uranium was 3.7 percent instead of 0.7 percent as at present. (U-235 decays much faster than U-238, whose half-life is about the same as the age of the Earth.) These natural chain reactions, started spontaneously by the presence of

water acting as a moderator, continued for about 2 million years before finally dying away.

During this long reaction period about 5.4 tonnes of fission products as well as 1.5 tonnes of plutonium together with other transuranic elements were generated in the orebody. The initial radioactive products have long since decayed into stable elements but close study of the amount and location of these has shown that there was little movement of radioactive wastes during and after the nuclear reactions. Plutonium and the other transuranics remained immobile.

Task. Translate into English

Атомний реактор, пристрій для одержання енергії за рахунок керованої реакції поділу ядра. Існує кілька типів атомних реакторів, усі вони використовують ядерну ланцюгову реакцію поділу. Перший реактор був запущений у США в 1942 (в СРСР в 1946). Розпад ядер відбувається в активній зоні реактора, у якій зосереджене ядерне паливо, і супроводжується вивільненням значної кількості енергії.

Реактори розрізняють:

- за енергією нейтронів, що викликають розпад (реактор на теплових, швидких і проміжних нейтронах)
- за характером розпаду ядерного палива (гомогенні і гетерогенні)
- за використовуваним сповільнювачем (графітові, водо-водяні та ін.)
- за призначенням (енергетичні, дослідницькі).

Реактор на швидких нейтронах - ядерний реактор, в якому ланцюгова реакція поділу ядерного палива здійснюється на швидких нейтронах. Нейтрони високих енергій обумовлюють відносно високий вихід нейтронів поділу. Поглинання частини швидких нейтронів ізотопами, що не діляться, з подальшим перетворенням їх в ті, що діляться (наприклад, ^{238}U в ^{239}Pu) приводить до утворення вторинного ядерного пального

(коефіцієнт відтворення може досягати 1,6). «Зона відтворення» оточує активну зону в корпусі реактора. У енергетичному швидкому реакторі теплоносієм (головним чином рідкий натрій), нагріваючись в цих зонах, віддає тепло в теплообмінниках робочому пароводяному середовищу. У разі натрієвого теплоносія реакторний і парогенеруючий контури розділяються проміжним, також натрієвим, контуром в цілях запобігання попаданню радіоактивного натрію в контур турбіни. Застосовуються і інші варіанти відведення тепла. Розширене відтворення ядерного пального в швидкому реакторі принципово дозволяє використовувати всі наявні уранові ресурси, зокрема ^{238}U , що залишається в значних кількостях невикористаним в реакторах, які працюють на теплових нейтронах.

При наявності в Україні п'яти атомних електростанцій потужністю 11800 МВт (на 01.01.2000), уран відіграє значну роль у забезпеченні країни електроенергією. Його частка у виробництві електроенергії, в порівнянні з іншими енергоносіями, постійно зростає.

Task. Look at the picture № 1 and learn all the elements of the reactor.

