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Principal Subject

PHYSICS **9792/02**

Paper 2 Part A Written Paper **May/June 2013**

INSERT

The question in Section B of this paper will relate to the subject matter in this Insert. You will have received a copy of this booklet in advance of the examination.

The extracts on the following pages are taken from a variety of sources.
University of Cambridge International Examinations does not necessarily endorse the reasoning expressed by the original authors, some of whom may use unconventional Physics terminology and non-SI units.

You should draw on all your knowledge of Physics when answering the questions.

This document consists of **16** printed pages.

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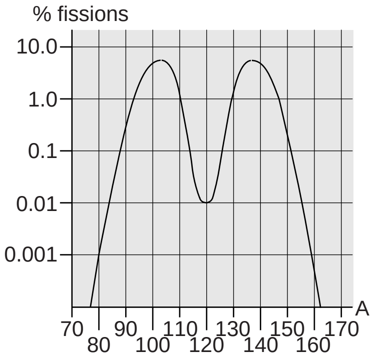
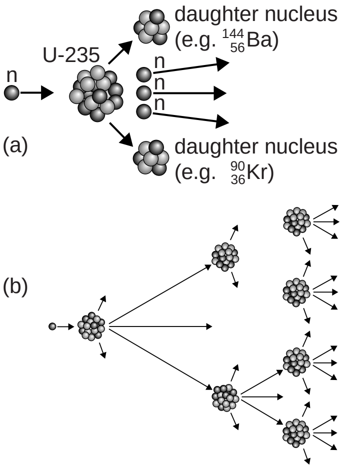
Extract 1: Nuclear Fission

The first indication that it was possible to split the nucleus came in 1938, just before the outbreak of World War 2. Two German physicists, Otto Hahn and Fritz Strassmann, discovered traces of light elements present in a sample of uranium that had been irradiated by neutrons. This was explained by Otto Frisch and Lise Meitner, who suggested that the uranium nucleus had absorbed a neutron and deformed to such an extent that it had split in two. The lighter elements detected by Hahn and Strassmann were **daughter nuclides** formed by the fission (splitting) of uranium. The following year John Wheeler and Niels Bohr analysed fission using the **charged liquid drop model** and concluded that:

- The isotope uranium-235 (which accounts for just 0.7% of all natural uranium) is readily fissionable, especially with **slow** neutrons (i.e. those with low kinetic energy).
- Uranium-238 (99.3% of natural uranium) is more likely to absorb neutrons than to undergo fission (see below).
- There is no single way that a uranium nucleus splits, so many different pairs of daughter nuclei are possible.
- Daughter nuclei are likely to be beta emitters because they retain the ratio of *N* to *Z* from uranium and this is bigger than the stable ratio for lighter nuclides.
- One or more fast neutrons will be emitted along with the daughter nuclei in most fissions.



U-235 can split many ways in a fission reaction. This graph shows the percentage yield (on a logarithmic scale) versus nucleon number of daughter nuclei. Why is the graph symmetric?



(a) Induced fission. (b) A chain reaction.

If fission is brought about by the absorption of a neutron it is called **induced fission**. If a nucleus simply splits in two it is called **spontaneous fission**. Both processes are important in nuclear reactions. The equation below shows one possible mode of induced fission.

$$^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \longrightarrow {}^{144}_{56}\mathrm{Ba} + {}^{90}_{36}\mathrm{Kr} + 2\,^{1}_{0}\mathrm{n}$$

Atomic masses:

$^{1}_{0}\mathrm{n}$	1.009 u
$^{235}_{92}\mathrm{U}$	235.044 u
$^{144}_{56}\mathrm{Ba}$	143.923 u
$^{90}_{36}\mathrm{Kr}$	89.920 u

Using these values, we find that $\Delta m = 0.192\,\mathrm{u}$. The energy equivalent of this is 179 MeV.

This is an enormous amount of energy. The energy released per atom in a chemical reaction is measured in tens of electronvolts, not millions. Physicists soon realized that nuclear fission could release about a million times more energy per kilogram of fuel (or explosive) than conventional chemical resources. But how could they make sure that the neutrons hit the rare uranium-235 nuclei and did not get swallowed up by uranium-238?

The development of nuclear weapons took place during World War 2 at Los Alamos, a top secret research site in the New Mexico desert. There Robert Oppenheimer (pictured here, centre, inspecting the Trinity test site) was in charge of a group of physicists and engineers drawn from the Allied countries and occupied Europe. At the time physicists thought that Germany, which had led the world in fission research before the war, was close to producing its own atomic bomb. After the war it was discovered that this had not been the case.

A chain reaction

The key to getting energy from fission is to use the neutrons emitted in fission to induce more fission reactions. As long as more than one neutron per fission goes on to induce another fission, the reaction rate and power generated will rise. This is called a **chain reaction**. There are two major problems, both of which prevent neutrons from inducing fission.

- Uranium-238 absorbs neutrons.
- Neutrons are lost from the surface of the assembly.

On top of this, the neutrons emitted in fission are fast neutrons (high energy), but fission is more likely to occur if the neutrons have low energies. (In a reactor, slow neutrons are called **thermal neutrons** because they have kinetic energies comparable to the thermal kinetic energy of particles in the reactor core, approximately kT).

There are three main ways in which these problems can be overcome:

- Use pure uranium-235, or else highly enriched uranium (that is, natural uranium in which the proportion of uranium-235 has been artificially increased).
- Mix the uranium with a material that does not absorb neutrons, but slows them down – this increases the ratio of neutrons that continue to induce fission compared to those that are absorbed by the uranium-238.
- Control the shape and size of the assembly (reactor core or explosive) to reduce the surface area-to-volume ratio so that the proportion of neutrons lost from the surface is reduced.

The assembly of fuel must reach a certain **critical size** before a self-sustaining chain reaction is possible. With a subcritical assembly, too many neutrons are lost from the surface. As the size of the assembly increases its surface area-to-volume ratio falls, so the ratio of lost neutrons (which depends on the surface area) to total number of neutrons released (which depends on volume) also falls. When a fission bomb (often misleadingly called an ‘atom bomb’) is detonated it becomes a **supercritical** assembly – more than one neutron per fission goes on to induce more fissions. The trick with a nuclear reactor is to keep the assembly balanced in a critical state so that, in normal operation, an average of one neutron per fission induces another fission and the reaction rate and power output stay at a steady level.

Mass and energy

Applying a force to a particle that is already travelling near the speed of light has very little effect on its velocity, but increases its mass. Electrons in the Large Electron–Positron (LEP) collider at the European Laboratory for Particle Physics (CERN – for Conseil Européen pour la Recherche Nucléaire) are travelling so fast that their mass is increased more than 100 000 times. Where does the extra mass come from? All that has been supplied to the particle is energy by the work that has been done accelerating it. Perhaps energy itself has mass? Einstein showed that all forms of energy have a mass given by:

$$E = mc^2$$

This means a particle of rest mass m_0 has a rest energy $E_0 = m_0c^2$. This may well be the most famous equation in physics, and it applies not just to photons but to all energy and mass transfers. Unfortunately its meaning is often misunderstood. It tells us that energy *has* mass, not that it can be converted to or from mass. *Every* energy transfer involves a mass transfer (this includes striking a match or standing up, not just nuclear explosions!).

From: *Advanced Physics* by Steve Adams and Jonathan Allday; ISBN 0-19-914680-2; Chap. 8.29

Extract 2: The Oklo Natural Nuclear Reactor

By Andrew Alden

Today we run reactors by taking uranium and enriching it in the one isotope, U-235, that fissions the most, so that an energy-producing chain reaction can take place. Without enrichment, you can pile up tons of uranium and it won't make any heat. Nevertheless, in 1972 the remains of a natural, spontaneously-formed uranium reactor were found in ancient rocks of the African nation of Gabon, in the Oklo uranium mine. The site is shown in Fig. E2.1.

Fig. E2.1

What made such a thing possible was that in the distant past, naturally-occurring uranium was more enriched in U-235. Less U-235 had decayed away and so its atomic abundance was larger than it is now.

The atomic abundance ratio of an isotope is defined as

$$\frac{\text{number of atoms of isotope}}{\text{number of atoms of element}}$$

(it can be expressed as a percentage).

A natural deposit of uranium ore was radioactive enough to generate about 100 kilowatts of heat, off and on, for more than a million years.

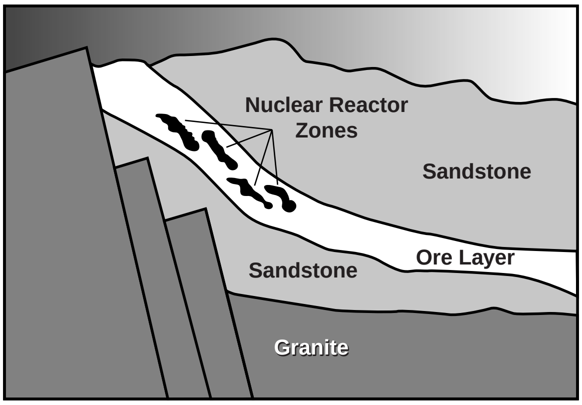


Fig. E2.2

Geologic forces gathered the uranium together. First a layer of sandstone was infiltrated by uranium-bearing groundwater, leaving a relatively thin sheet of uranium-oxide ore. Then the rocks were tilted, and as they eroded downward the groundwater concentrated the uranium minerals, sweeping them downward within the sandstone until a thick stripe of ore was built up. Fig. E2.2 shows the geological structure.

That's when things heated up.

To understand what happened next, you need to know a little about nuclear reactors. The nuclei of uranium atoms normally decay with the release of energetic neutrons – so energetic that they fly away without interacting with other uranium nuclei. The neutrons need to be slowed down before they can start splitting other uranium nuclei, which release more neutrons and start a feedback cycle. Something needs to moderate the neutrons. The first artificial reactor, built in 1942, used balls of enriched uranium spread out inside a large pile of graphite blocks, which served as a moderator.

But water acts as a moderator, too. At Oklo there was a lot of water, probably a river flowing above the buried ore. The water allowed the nuclear interactions to reach the critical point, and the reactor began to work. But as it heated up, the water turned to steam and flowed away. With the moderator gone, the chain reaction stopped and did not start again until the ore cooled and the water returned. This simple feedback cycle kept the Oklo reactors (there were at least a dozen of them) active until the U-235 was depleted. That took about a million years. When the Oklo mine was producing ore in the 1970s it was that tell-tale depletion of U-235, unheard-of in nature, that tipped scientists off.

A remarkable thing about the Oklo reactors is that the highly radioactive waste products stayed put without the elaborate containment we use today on nuclear power plant waste. More than a billion years later, everything is contained within a few metres of its source.

Recently a team of scientists took advantage of this excellent preservation and studied the isotopes of xenon gas – a product of uranium decay – trapped in phosphate minerals at Oklo. Led by Alex Meshik of Washington University of St. Louis, they reported in 2004 that the reactor went through eight cycles a day, running for 30 minutes then shutting down for two and a half hours. The whole thing is reminiscent of geysers.

Why was uranium so much more radioactive then? That is a deep question that points to the very origin of the solar system. The formation of the planets (and the Sun) from an original cloud of dust and gas apparently was triggered by the explosion of a nearby supernova. Only a supernova can manufacture elements heavier than iron, such as uranium. With a half-life of just over 700 million years, U-235 started out making up nearly half of all uranium when the solar system began some 4.5 billion years ago. Many shorter-lived radioisotopes that existed in the beginning, like aluminium-26, have become extinct. We know of their former existence by the presence of their decay products in ancient meteorites, so-called nuclear fossils.

Adapted from: http://geology.about.com/od/geophysics/a/aaoklo.htm
Fig. E2.1 from: http://oklo.curtin.edu.au/
Fig. E2.2 from: http://www.worldalmanac.com/blog/2007/01/the_oklo_fossil_reactors.html

Extract 3: Radioactive Decay

Discovery

Radioactivity was discovered by Henri Becquerel in 1896, when he noticed 'fogging' of photographic plates that were placed in a drawer in close contact with uranium salts.

Emissions

Radioactivity is simply the spontaneous disintegration of nuclei to move from an unstable state to a stable one.

There are three types of radiation emitted in radioactive decay: **alpha particles**, **beta particles** and **gamma rays**.

Alpha Particles (α)

These are helium nuclei, and therefore consist of two protons and two neutrons.

Beta Particles (β^+ β^-)

There are two types of beta particle: beta-plus and beta-minus. The beta-plus is sometimes called an anti-electron. Each can travel up to 98% the speed of light. A beta-minus particle is released as a result of a neutron changing into a proton, while a beta-plus particle is released as a result of a proton changing into a neutron.

Gamma Rays (γ)

Gamma rays are high-energy, short-wavelength photons of electromagnetic radiation. Gamma rays are emitted because the atom is usually in a high energy state after emission of alpha or beta particles. This unstable state is made stable by emission of gamma ray photons.

Balancing equations

The effect of radioactive emissions can be summarised as follows:

alpha decay:
atomic mass decreases by 4
atomic number decreases by 2

$^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$

$^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$

beta-minus decay:
mass number unchanged
atomic number increases by 1

$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$ (antineutrino emitted)

beta-plus decay:
mass number unchanged
atomic number decreases by 1

$^{11}_{6}\mathrm{C} \longrightarrow {}^{11}_{5}\mathrm{B} + {}^{0}_{+1}\mathrm{e}$ (neutrino omitted)

The Radioactive Decay Equation

The rate of decay (activity A) is proportional to the number of parent nuclei (N) present.

$$A \propto N$$

$$A = -\frac{\mathrm{d}N}{\mathrm{d}t}$$

$$\frac{\mathrm{d}N}{\mathrm{d}t} \propto N$$

$$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$$

λ (lambda) is a positive constant called **the decay constant**. It has the unit s^{-1}.
The minus sign is included because N <u>decreases</u> as the time t in seconds (s) <u>increases</u>.

Half-Life

The half-life of a radioactive substance is the time taken for half the nuclei present to disintegrate.

$$t_{½} = \frac{0.6931}{\lambda}$$

λ (lambda) is the decay constant.
The half-life curve illustrates that the number of nuclei halves whenever the time increases by $t_{½}$. The half-life is a constant for a particular radio-nuclide.

Here is a list of half-lives of radio-nuclides from the Uranium series.

nuclide	half-life
uranium 238	4.51×10^9 years
thorium 234	24.1 days
protactinium 234	6.75 hours
uranium 234	2.47×10^5 years
thorium 230	8.0×10^4 years
radium 226	1620 years

Radioactive Equilibrium

Radioactive equilibrium is when the rate of decay of a nuclide is approximately the same as its rate of production.

This happens to products of the Uranium Series. We start off with the production of thorium exceeding its rate of decay. Then as the amount of thorium increases, the activity increases. Eventually the rate of production of thorium equals its rate of decay. So the amount of thorium in the sample is constant.

This continues down the series with constant amounts of each product being formed in a sample. This being the case, all the rates of decay are equal.

$$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$$

$$\frac{\mathrm{d}N_1}{\mathrm{d}t} = \frac{\mathrm{d}N_2}{\mathrm{d}t} = \frac{\mathrm{d}N_3}{\mathrm{d}t} = \ldots$$

and

$$\lambda_1 N_1 = \lambda_2 N_2 = \lambda_3 N_3 = \ldots \qquad \textbf{(i)}$$

since $\lambda = \frac{0.6931}{t_{½}}$, where $t_{½}$ is the half-life

$$\lambda_1 = \frac{0.6931}{T_1},\ \lambda_2 = \frac{0.6931}{T_2},\ \lambda_3 = \frac{0.6931}{T_3}\ \ldots$$

substituting for $\lambda_1\ \lambda_2\ \lambda_3\ \ldots$ into **(i)**

$$\therefore\quad \frac{N_1}{T_1} = \frac{N_2}{T_2} = \frac{N_3}{T_3} = \ldots$$

Adapted from: http://www.a-levelphysicstutor.com/nucphys-radioactivity.php

Extract 4: Uranium Enrichment

- Most of the 495 commercial nuclear power reactors operating or under construction in the world today require uranium ‘enriched’ in the U-235 isotope for their fuel.
- The main commercial process employed for this enrichment involves gaseous uranium in centrifuges. Fig. E4.1 shows a bank of centrifuges at an enrichment plant. An Australian process based on laser excitation is under development in the USA.
- Prior to enrichment, uranium oxide must be converted to a fluoride so that it can be processed as a gas, at low temperature.
- From a non-proliferation standpoint, uranium enrichment is a sensitive technology needing to be subject to tight international control.

Fig. E4.1

Uranium found in nature consists largely of two isotopes, U-235 and U-238. The production of energy in nuclear reactors is from the ‘fission’ or splitting of the U-235 atoms, a process which releases energy in the form of heat. U-235 is the main fissile isotope of uranium.

Natural uranium contains approximately 0.7% of the U-235 isotope – its atomic abundance ratio is approximately 0.007. The remaining 99.3% is mostly the U-238 isotope which does not contribute directly to the fission process (though it does so indirectly by the formation of fissile isotopes of plutonium). Most reactors are Light Water Reactors (of two types – PWR and BWR) and require uranium to be enriched from 0.7% to between 3% and 5% U-235 in their fuel.

Uranium-235 and U-238 undergo identical chemical reactions and cannot be separated by chemical means. They differ, however, in their physical properties, notably 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.

The difference in mass between U-235 and U-238 allows the isotopes to be separated by their physical behaviour and makes it possible to increase or “enrich” the percentage of U-235. All present enrichment processes, directly or indirectly, make use of this small mass difference.

Some reactors, for example the Canadian-designed Candu and the British Magnox reactors, use natural uranium as their fuel. (For comparison, uranium used for nuclear weapons would have to be enriched in plants specially designed to produce at least 90% U-235.)

Enrichment processes require uranium to be in a gaseous form at relatively low temperature, hence uranium oxide from the mine is converted to uranium hexafluoride in a preliminary process, at a separate conversion plant.

Adapted from: http://world-nuclear.org/info/inf28.html
Fig. E4.1 from: http://world-nuclear.org/info/inf28.html

Extract 5: Fukushima's Impact on Nuclear Power

Even as crews continue their heroic efforts to stabilize Japan's troubled Fukushima Dai-1 Nuclear Power Station, the effects of the crisis are rippling through the global nuclear industry. The industry might not shrink, but the emergency has put on pause many countries' nuclear power revival plans.

Fig. E5.1

After two decades of decline sparked by Three Mile Island and Chernobyl, nuclear power had been on its way back in recent years. Burgeoning energy use and concerns over climate change and energy safety had prompted governments to recognize nuclear as a source of safe, clean electricity. Even countries that had banned nuclear power or halted new reactor construction had been rethinking their policies. But Japan's nuclear emergency has reignited the nuclear debate, especially in Europe.

Most clearly hit are the nuclear revivals in Germany and Switzerland. On March 14, German chancellor Angela Merkel temporarily shut down the country's seven oldest nuclear power plants. Just last year, the government had made the highly unpopular decision to keep all of its 17 plants operating for another 12 years. Officials now say the decision will be held off until at least June while safety checks are carried out.

Switzerland has suspended its plans to build and replace nuclear plants. Authorities there had approved three new plants, but Swiss energy minister Doris Leuthard announced on March 14 that the approvals won't be granted until experts have reassessed the safety standards at existing plants.

Italy has also put on hold its plans to build new nuclear plants. Ten per cent of Italy's electricity comes from nuclear, all imported. In May 2009, Silvio Berlusconi's government revoked the country's nuclear moratorium, but voting for a referendum on construction of four new power plants is set for sometime between April and June. Italy's strong anti-nuclear movement, bolstered by the country's regular seismic activity, might not bode well for the industry.

Sweden and Finland are abiding by their nuclear policies, but are thinking twice about their long term plans for nuclear expansion. Sweden ended its nuclear ban in June 2010, and Prime Minister Fredrik Reinfeldt has said in a press conference in Lithuania that the decision still stands. Finland, which is building its fifth reactor and has approvals for two more, plans to continue with these projects.

In the UK, where nuclear power faces considerable public opposition, Energy and Climate Change Secretary Chris Huhne ordered an official investigation to determine what London can learn from the Japanese nuclear crisis.

Most anti-nuclear sentiment in Europe is coming from countries that were already hesitant about nuclear energy and didn't rely on it too much. Germany, for example, gets only a quarter of its electricity from nuclear; Italy has no nuclear power plants of its own. By comparison, France gets 75 per cent, Slovakia 53 per cent and Belgium 51 per cent. There has been no outcry against nuclear energy in these countries. Poland, Lithuania, Slovakia, the Czech Republic, Bulgaria, Romania, and Turkey all intend to build new nuclear power plants.

In Asia, which is today the centre of nuclear growth, the big players seem determined to carry on with their nuclear ambitions albeit with caution. China, which has 27 units under construction and has plans to build 50 reactors by 2020, issued a statement on March 14 reaffirming its nuclear ambition. On March 16, the country announced that it was suspending new plant approvals and stepping up safety inspections at existing plants.

India and South Korea, which are both constructing five reactors, also plan to forge ahead. At the same time, the Indian Nuclear Power Corporation's chairman told Bloomberg News that Japan's emergency could be a “big dampener” on his country's nuclear program. And in South Korea, anti-nuclear voices are getting louder. Russian Prime Minister Vladimir Putin signed an agreement with Belarus on March 15 to build Belarus's first nuclear plant.

Here in the United States, Obama still sees nuclear power as a part of the country's energy future. The country's 104 operating nuclear plants generate 20 per cent of its electricity and nuclear power is making a strong comeback after a slump in the late 1990s. Some members of Congress, though, are now advocating a reassessment, and the industry faces some uncertainty.

Japan's disaster has clearly brought to light that nuclear power is a divisive issue. But it has also shown that most everyone agrees on one thing: a high standard for nuclear safety. At the European Energy Council meeting in Brussels yesterday, ministers decided to develop a “stress test” for nuclear power plants in the EU.

From: http://spectrum.ieee.org/tech-talk/energy/nuclear/fukushimas-impact-on-nuclear-power

Extract 6: There are Advantages of Nuclear Energy and there are Challenges

Are advantages of nuclear energy such that it could be part of the solution to global warming? Or is nuclear radiation an even greater problem?

The debate about whether to build nuclear energy reactors is again in full swing. It is necessary, as we become more aware about the magnitude of the climate change through the global warming phenomenon.

So identifying significant advantages of nuclear energy would be important.

Most scientists agree that we are seeing the effects of global warming already and that the imminent future looks dire. We must reduce the emissions that cause global warming. Therefore alternative energy must be employed.

Some think this means a wholesale adoption of nuclear energy, some see no advantages of nuclear energy, some believe in a mix of nuclear energy with renewable energy.

Now even garden-shed size “neighborhood nuclear power plants” are a reality.

Nuclear energy provides between 11% and 18% of world electricity needs.

But the USA has not built any nuclear reactors since 1978 because of public opinion which does not identify many advantages to nuclear energy.

Eight of its reactors have been decommissioned since then, leaving it with some 130 reactors. Of course the USA is also the greatest contributor to greenhouse gases through burning of fossil fuel.

Currently there are some 442 nuclear reactors in the world with at least another 12 under construction in Asian countries, Brazil and Finland.

Australia with its abundant uranium ore supplies has recently entered into uranium contracts with economically fast growing giants India and China, also two major contributors to greenhouse gases.

These countries are also among those that have decided on the advantages of nuclear energy and are building nuclear reactors.

Energy demands are growing fast everywhere and we cannot afford to continue to meet them with finite and polluting fossil fuels.

During the last decade in the previous century world energy use grew by 20% and has been at around 3% per year and growing.

James Lovelock, of Gaia fame, is supporting nuclear energy as the only way to minimise serious harm from global warming. Something he says is now inevitable as he forecasts a debilitated physical and social world.

We can now only minimise the impacts.

So … the stakes are high whichever way you look at it.

If there are advantages to nuclear energy it makes sense to hear them despite nuclear radiation risks from accidents, weapons proliferation and so on.

So what are advantages of nuclear energy?

Fissile atoms contain vast amounts of energy

Nuclear fission, the splitting of a heavy atom's nucleus, releases great amounts of energy. For example the energy it releases is 10 million times greater than is released by the burning of an atom of fossil fuel. Besides it would take many hectares of land covered with solar collectors, wind farms or hydro-electric dams to equal this power.

No greenhouse gases are released by nuclear power plants

According to some, even when accounting for the fossil fuel used in mining uranium, processing it, building and decommissioning of the nuclear plant, the picture remains good from this perspective. Less than one-hundredth of carbon dioxide gas is produced by nuclear power plants compared to coal or gas-fired energy plants. This means nuclear energy also emits less greenhouse gas than renewable energy sources such as hydro, wind, solar and biomass. Of course, others have contrary views to these claims about the advantages of nuclear energy.

Cost

The major costings in building nuclear power plants are usually those of construction and operating the nuclear plant as well as that of waste disposal and cost of decommissioning the plant. The end product, useable energy, has been estimated to be around 3–5 cents (US) per kilowatt-hour. However there are many variables, including type of reactor, cost-over runs in construction and decommissioning, and loan interest rates.

In the American nuclear power industry the cost of producing electricity has fallen from 3.63 cents per kW-hr in 1978 to 1.68 cents per kW-hr in 2004.

Again, there are opposing views as to the cost and other aspects of advantages of nuclear energy.

Availability of uranium

Uranium is obtained from open-cut mines and is not expensive to mine. World reserves are estimated to last anywhere between 6 to 150 years, to even hundreds of centuries, depending on who is the commentator, and depending on the type of reactor they have in mind.

Present reactors only use some 1% of the energy available in uranium, but in future fast-breeder reactors could recycle spent fuel rods at a 99% efficiency rate. The potency and quantity of radioactive waste material from such reactors is much less than that of current thermal reactors.

In the US alone, with just under a third of nuclear reactors worldwide there are 43 000 metric tonnes of accumulated nuclear waste stored at reactor sites. This is useable fuel for fast-breeders, however, their construction is at least 15 years off.

These are some of the advantages of nuclear energy, but of course, apart from the first advantage, they are contested.

Other advantages of nuclear energy

- nuclear fuel is inexpensive
- waste is highly compact, unlike carbon dioxide
- the compact fuel is easy to transport.

Major challenges of nuclear energy

Nuclear radiation accidents

Although only one serious nuclear accident has ever occurred, in Chernobyl in 1986, such an accident affects many thousands of people, livestock and agricultural production over a large geographical area. In the case of Chernobyl in the Ukraine, nuclear fall-out reached as far as areas of the UK.

Supposedly, poor reactor design at Chernobyl allowed the emission of radioactivity and this has not been repeated elsewhere. However one accident is too many.

Nuclear weapons proliferation

It is not easy to handle the highly toxic plutonium that is needed to produce a nuclear bomb. So, for terrorists this is nigh impossible. Constructing a ‘dirty’ nuclear bomb for instance is much easier.

However some governments of nuclear states may now, or in the future be regarded as terrorist in their willingness to use nuclear weapons or sell uranium to states that have not signed the International Nuclear Non-Proliferation Treaty.

Other disadvantages

Capital cost

Nuclear power requires a large capital cost, involving emergency, containment, radioactive waste and storage systems

Long-term storage of nuclear waste is difficult.

Not only from a geological standpoint. Where to store it is difficult in a world where political stability cannot be guaranteed for 50 years, let alone for 10,000. No-one can predict who will access this waste in future generations and for which purposes. Ground-water contamination would be a deadly nuclear legacy.

Take Germany, where its previous Social-Democrat/Greens government resolved to phase out nuclear energy and its present Conservative government has put it back on the agenda. But nuclear waste is now a big headache.

126,000 rusting containers of atomic waste are buried 750 metres down in a disused salt mine in Asse, Lower Saxony. They contain low-grade radioactive waste from nuclear reactors, buried between 1967 and 1978. The waste comprises some 100 tonnes of uranium, 87 tonnes of thorium and 25 kg of plutonium. Water is leaking into the mine at a rate of 12,000 litres a day and geologists have warned that the mine could collapse. It now needs to be brought back to the surface to try and stop ground water contamination.

Further advantages of nuclear energy?

Among the further advantages of nuclear energy against the backdrop of climate change, is that we are forced to look at ourselves.

What have we done to get us here? Any promise of unlimited energy, nuclear or otherwise, is deceptive in a world that exists because of tensions, limitations, dependency and vulnerability.

We may have to adjust to that reality and use less energy than we actually think we need. You and I will need to review our priorities. Inevitably we will need to use more of the energies of relationship and genuine care for each other and our environments to be a success at that.

Adapted from**:** http://www.alternate-energy-sources.com/advantages-of-nuclear-energy.html

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