What is a Nuclear Reaction?

A nuclear reaction takes place when the nucleus of an atom undergoes some kind of change. This made be a spontaneous change, which happens during radioactivity, or induced through bombarding the nucleus with particles or rays.

Here is an example of natural radioactivity, the decay of the most common isotope of uranium:

$$^{238}U \rightarrow {}^{234}Th + {}^{4}He$$

The reaction releases an α particle in the form of the Helium nucleus. The new isotope of Thorium is also radioactive, but in this case releases a β particle in the form of an electron:

$$^{234}Th \rightarrow {}^{234}Pa + {}^{0}e^{-} + \text{neutrino}$$

Particles can be used to bombard the nucleus of one isotope to create a different isotope. Charged particles, such as α or β particles, must have very high energy to penetrate the nucleus. In contrast, neutral particles such as neutrons are very effective at low energies as projectiles for inducing nuclear reactions.

In most isotopes the neutron is absorbed by the nucleus, and excitation energy appears as a γ ray.

How are Nuclear Reactions used to create energy for human use?

When certain heavy element isotopes absorb a neutron, there is a different result. In elements such as Uranium and Plutonium, the absorption energy causes a distortion of the nucleus, and it flies apart in two pieces. This is called *fission*, and isotopes that have this characteristic are called *fissile*. The two pieces have a large amount of kinetic energy, and begin to lose electrons and energy as they interact with surrounding atoms. This thermal energy can be recovered if the reaction takes place in a nuclear reactor, and can be then transformed into electricity.

The only isotope of Uranium that is fissile is ^{235}U. It takes about 1.3g to produce 1MW/day of power using present reactors.

$$^{235}U + {}^{1}n \rightarrow {}^{90}Kr + {}^{144}Ba + {}^{2}n + \text{Energy}$$

The resulting isotope by-products are unstable, and decay naturally to stable forms. The result is radioactive waste, which must be disposed of. It is the decaying process that gives off radioactive material – not the material which is left over and used.

Another by-product of fission is fast moving neutrons, which result in an on-going chain reaction. The nuclear reactor is carefully designed to monitor the speed of this chain reaction, and has a number of safety things in place. Extra neutrons can also be used to be "breed" new fuel to replace the amount that is already used up.

How much is Nuclear Energy presently used?

Nuclear energy presently accounts for 16% of worldwide electricity production.

The top ten nuclear energy consuming nations are the United States, France, Japan, Germany, Russia, South Korea, UK, Ukraine, Canada and Sweden. (Source: United Nations Statistical Division). Note that these statistics are by use, rather than per capita. Around 30 nations use nuclear energy (2003), which presently accounts for approximately 16% of total production.

It is important to also look at the percentage of nuclear use compared with different sources of energy. For example, in the United States nuclear is approximately 20% of the energy, while in France it is 80%.

What are the UK policies on Nuclear Energy?

In 2003 the UK government released a white paper on its energy policy, which promised to reduce CO_2 emissions by 60% by 2050. Nuclear power was cited as an "unattractive option" to the energy crisis, although the lack of carbon emissions from the technology was noted. It stated clearly that "before any decision to proceed with the building of new nuclear power stations, there would need to be the fullest public consultation and the publication of a white paper setting out the Government's proposals." (Energy Act, 2004)

The 2004 Energy Act erected a framework for the Nuclear Decommissioning Authority (NDA) with a budget of 2£ billion/year. The Act put a large emphasis on tackling the "energy crisis" with increased dependence on renewable energy.

A following report from the House of Lords Science & Technology Committee questioned both the practicality and cost of the government's emphasis on wind as a source for renewable energy. It commented that the government might need to support the building of new nuclear plants to secure affordable electricity for the UK.

Nuclear Accidents

Part A: Three Mile Island

The incident occurred at the Three Mile Island Unit nuclear power plant near Middletown, Pennsylvania, on March 28, 1979. It did not lead to any deaths or injuries to plant workers or anyone in the community.

How did it happen?

The causes of the accident are still debated to this day. The following description is most often cited as the events that led to the accident.

At about 4:00 am the cooling water pumps stopped working, and the steam generators were no longer able to remove heat from the system. Pressure began to change in the system, and the relief valve (that would have stopped the pressure from rising to a dangerous level) did not work. The emergency water system was also not working. After about 8 minutes, the emergency water was turned on, but by this point there were empty sections in the pipes without any water in them.

Without enough water, the nuclear fuel overheated and its casing began to react with the water and release hydrogen into the containment building in a big bubble. This hydrogen was released into the reactor containment building. By March 30, two days after the start of the problems, some hydrogen remained within the primary coolant system in the vessel surrounding the reactor, forming a "hydrogen bubble" above the reactor core.

A large amount of the fuel reacted, and radioactivity in the reactor was high. Small leaks released some of the materials into the environment. The emergency teams arrived and evacuated everyone from the plant. Xenon gas was still leaking and many people were scared there would be a large explosion. People in the community, especially children, were evacuated to other areas or told to stay indoors until the situation was under control.

Long term Effects

Very detailed scientific studies were done in the area and it was found that people were not exposed to high levels of radiation. Scientists tested the air, the water, plants and food and concluded that there were no harmful long term effects on people in the area.

Nuclear Accidents

Part B: Chernobyl

The incident occurred on April 26th, 1986 at Chernobyl in the former USSR (now the nation of Ukraine).

What happened?

The Chernobyl nuclear power plant had 4 reactors and on April 25th Reactor 4 was turned off for maintenance. The workers decided to run a test on the reactor, to see it would have enough electricity when it was turned off to run the emergency equipment.

A mistake was made and it was turned off at a very low power level. The operators tried to fix the problem by taking out all of the control rods – which are used to control the number of nuclear reactions that occur within the reactor. The reactor became very unstable and the steam pressure dropped. The operators reduced the amount of water, which created a huge amount of steam and rise in temperature and energy.

The rise in temperature caused part of the fuel to break off and react with the water. There was a steam explosion that destroyed the reactor core, and two minutes later, another explosion.

There was a significant delay in evacuating people from the area, and people were explosed to high levels of radioactive exposure.

Long Term Effects

Some long term health effects were attributed to the accident, including a rise in the amount of certain cancers (eg thyroid cancers).

30 lives were lost during the accident or within a few months after it. The Ukraine Radiological Institute says that over 2,500 people died because of the accident.

There were also many other problems in the community, including depression and anger. Many people felt that the government and nuclear managers did not give enough answers about what had actually happened or how radioactive the environment was.

The Nuclear Energy Debate

What are the major arguments supporting Nuclear Energy?

- Limited supplies of fossil fuels – nuclear energy as a sustainable electrical source.
- Nuclear power plants burn less fuel than traditional plants for energy production. One ton of uranium produces more energy than is produced by several million tons of coal or several million barrels of oil.
- Nuclear power plants do not pollute the environment with carbon dioxide and other contaminants.

What are the major arguments against Nuclear Energy?

- Nuclear proliferation - ^{239}Pt and other isotopes can be used to create nuclear weapons, a major security concern for all peaceful nations.
- Biological and physiological harm from exposure to radioactive waste products.
- A nuclear accident (such as the ones that occurred at Three Mile Island or Chernobyl) can have devastating implications. In a major accident, the fission reaction goes out of control, leading to a nuclear explosion and the emission of great amounts of radiation.