”only nuclear power can now halt global warming”

The English environmentalist James Lovelock (2004)

Chapter 14

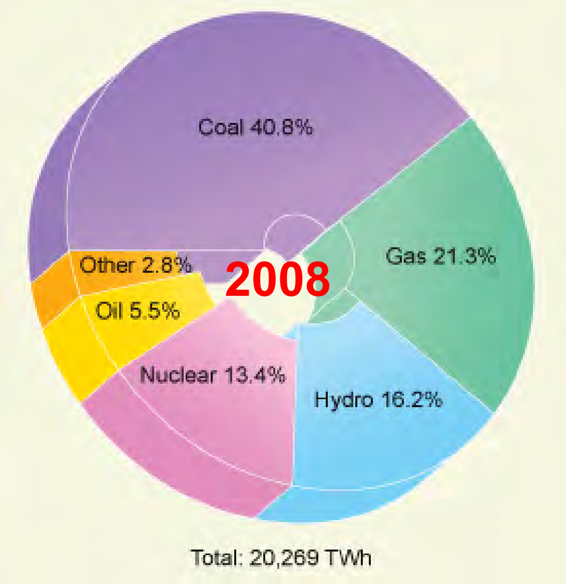
Nuclear power – Environment – Climate

The time is ripe for increased use of nuclear energy

The climate debate as well as the demand for more energy to sustain and improve the living for an increasing world population, has called for a new discussion on nuclear energy.

Today, about 85 % of the worlds total energy production is from fossil energy sources, which result in an increase in the atmospheric CO_2 content of about 2 ppm per year. If this increase in CO_2 content continues, it will result in climate change and a warmer world. The main part of the discussion (at least the political) have been concerned about CO_2 capture and storage. The problems are enormous and up to now the CO_2 release has only increased.

The world energy use has increased exponentially during the last 150 years. Today the increase is 1.8 % per year. One possible solution is to use other energy sources with small or none release of CO_2. This implies that the new power plants, as far as possible, should not be based on fossil fuel.



In the illustration to the right we give you a glimpse of the world electricity production in 2008. Of the renewable energy sources, hydroelectricity is the most significant, and contribute with about 16 % of the production. Wind energy is increasing by almost 30 % per year and contributed (in 2010) to about 2.5 % of the world electricity production. Solar energy contribute very little, at least up to now.

In the illustration for 2008 the nuclear reactors contribute with about 13.4 % of the electricity production. Nuclear power has got a bad reputation, mainly because of the fear for radioactivity and its radiation. Nuclear power give waste and include also the risk for reactor accidents. The public and political lack of knowledge in radiobiology have resulted in fear for cancer and other detrimental health effects from radiation. This is the main reason for turning the “thumb down” for nuclear power.

For all those who have read this book, in particular chapters 12 and 13 may have a different view on radiation and its effects. Thus, we have learned that small amounts of radiation would stimulate our defence mechanisms and protect us against cancer. In fact, the results of the last 20 years of research within radiation biology is a large stimulation to new enthusiasms for nuclear power compared to fossil fuels.

The beginning of nuclear power


Enrico Fermi

The Italian physicist Enrico Fermi started the first nuclear reactor on December 2. 1942 in Chicago. He then opened for a completely new energy source. The first day, the reactor operated for 4 minutes with an intensity of half a watt.

Since this successful start, reactors have been built, for the production of plutonium used in atomic bombs, for research (like the Kjeller reactor in Norway in 1951), and for electric power. And power generation is the subject for this chapter.

During the first years after the war, the optimism was large for using nuclear power for boats, in particular submarines since a reactor does not require oxygen that is particularly important for a submarine.

Nuclear reactors have been built for electricity production. Different design and protection schemes have been used. Today an ordinary reactor very often has a power of up to about 1300 – 1500 MW. With full drift through the year, a reactor with this power may give about 10 – 13 TWh, which is a significant contribution..

In January 2012, 435 nuclear reactors in 31 countries contribute with a net electric capacity of about 368 GW. Furthermore, 63 plants with a capacity of 61 GW are under construction. The contribution from nuclear power to the electricity production varies largely from one country to another with France on the top. Nuclear power increased up to about 1986 (the Chernobyl accident), and has for the last 25 years contributed by 14 – 16 % of the world electricity production.

Before we embark on the basic physics for nuclear power, we shall stop for a moment on climate ideas and compare the energy resources for nuclear power with the renewable sources such as wind power.

Nuclear power and climate

Nuclear power does not release CO_2 – and will not contribute to climate change. This fact must be a dream to most environmentalists and the famous English environmentalist James Lovelock (known from the book «Gaia») express his view in 2004 as follows: ***"only nuclear power can now halt global warming".***
In his view, nuclear energy is the only realistic alternative to fossil fuels that has the ***capacity*** to both fulfill the large scale energy needs of humankind while also reducing greenhouse emissions.
Another well known scientist James Hansen (former director of NASA Goddard Institute for Space Studies, GISS) strongly support research and use of nuclear energy.
However, the large majority of environmentalists and politicians do not support Lovelocks and Hansens view. The downward trend for nuclear energy started with the reactor accidents; "Three Mile Island" in 1979, Chernobyl in 1986 and Fukushima in 2011.
During the last 25 years environmentalists, and the general public have considered the negative effect of radiation to be too large, and nuclear energy has not been considered in the climate debate.

We know that radiation is a carcinogen in large doses. However, in the case of the radium workers (particularly the dial painters we discussed on page 274– 276) cancer occurred only for doses above 10 Gy. A large amount of information exists on the benefits of living in high dose areas in Iran, Brazil and the dramatic effect for the Taiwan cohort (page 281). Also the clean up workers after Chernobyl seem to benefit form the extra radiation (page 166).
However, the radiation authorities in all countries follow the guidelines from ICRP, assuming a linear correlation between radiation dose and cancer (the LNT-model). These false guidelines have hampered the use of nuclear power for many years. Most people consider nuclear power to be too risky – and would rather use other energy sources like fossil fuels, and of course the renewable sources, like wind and solar power.

Wind and solar energy is very popular – however, the drawback is that they both contribute, very little. Both the capacity is small and the fact that you can not turn on and off these sources after demand makes it so far difficult. Thus, in Norway, wind power contributed with 0.98 TWh in 2010 (less than 1 % of the electricity production).
The countries with the highest contribution from wind is (in 2010) Denmark (21 % of the electricity production), Portugal (18 %), Spain (16 %) and Germany (9 %). The total installed capacity in the world (2010) was 196 GW. According to the plans this will increase to 1500 GW in 2020.

A few words are necessary in order to give a correct picture of the wind power and the relation between installed capacity and power output, which of course is extremely dependant upon the wind speed (the average wind speed through the year). Let us therefore compare wind power with nuclear power in the following way.

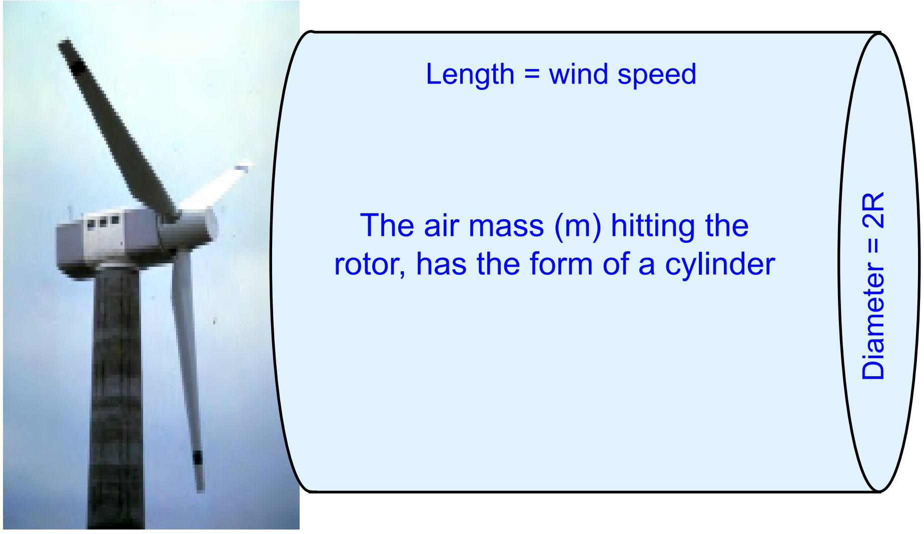
Wind power versus nuclear power

Nuclear. We assume a modern nuclear reactor with the power of 1500 MW. The reactor can run at this power almost the full year and produce 12 – 13 TWh. Furthermore, a nuclear reactor can be turned on and off according to demand.

Wind. The power in the wind is converted to electric power in a mill. We must have a large windmill park in order to give the power of the reactor mentioned above. Wind power depend on the wind speed and the size of the rotor.
The power production from a wind mill is calculated in the following way using the figure below for explanation: The energy available is the power of the airmass (m) hitting the rotor with the speed v (wind speed). The energy is given by $E = \alpha(1/2\ mv^2)$. Here α indicates which fraction of the total energy passing through the rotor disk that is transmitted to the rotor. According to Betz' law it cannot become larger than 0.59. Modern turbines reach 70 – 80% of this limit – and α is 0.40 – 0.45.

Using the figure we see that the mass hitting the rotor per second is the air in the cylinder with the area πR^2 and the length v (R is the rotor radius and v is the wind speed).
We get the following expression:

$$E = (\frac{1}{2}\pi R^2 \cdot \rho \cdot v^3) \cdot \alpha$$



An illustration which shows the airmass hitting the rotor of the mill per second. The air mass has the form of a cylinder with the lengt equal to the wind speed – and the diameter is equal to the diameter of the rotor.

We can use the formula to calculate the capacity of a windmill. In the formula ρ is the density of air (at sea level it is 1.23 kg/m^3).
The efficiency factor of the windmill, α, is set to 0.45 (about 75 % of the theoretical maximum). The energy increases with the cube of the windspeed. We can use a windmill for windspeeds from 4 m/second up to a maximum of 14 – 15 m/s. Higher wind speeds will not increase the power and the mills are stopped for wind speeds above 20 m/s.

The "capacity" of a mill is calculated for a wind speed of 12 – 15 m/s. The rotor diameter has increased in the recent years from 60 to about 100 m. The maximum diameter (2012) is 123 m and the height of the mill is 135 m. The capacity of this mill is therefore approximately 9 MW.
For a rotor of 100 meter diameter, the capacity is about 6 MW. If we have a wind speed of 12 – 15 m/s through the year, the annual energy output of the mill, running all the time, would be 52 GWh (0.052 TWh). However, we have to assume normal wind speeds which are much smaller and of course variable. Consequently, the annual power output is of the order 20 – 40 % of the theoretical value.

An example. Smøla wind park consists of 68 windmills with a capacity of 150 GW and produces annually 356 GWh, whereas the theoretical maximum is 1314 GWh (a factor 3.6 larger). The average wind speed in Smøla is 8 m/s. The same holds true for Hitra with another wind park. The wind speed is measured 50 meter above ground.

For offshore wind parks the wind speed is of the order 10 – 12 m/s – and would probably be a better choice. On the west coast of Norway the pilot project with Hywind consists on a windmill with rotor diameter of 82 m. in diameter. The capacity is 2.3 MW and in 2010 the producyion was 7.3 GWh – somewhat better than the Smøla windmills.

If we compare the windmills with a nuclear reactor we can conclude that we must have at least 1000 Hywind mills or extent Smøla windpark to include more than 1600 units to give the same annual energy production.

In order to prevent disturbances in the wind field the mills must be placed about 3 rotor diameters (or more) from each other. This implies that Smøla wind park must increase to about 450 km^2 – double the area of Smøla (214 km^2)!

Wind energy has also another problem – you attain energy only when the wind blows – you can not turn a knob when you need energy. Furthermore, we would like to have a system to save energy when the production is larger than the use.

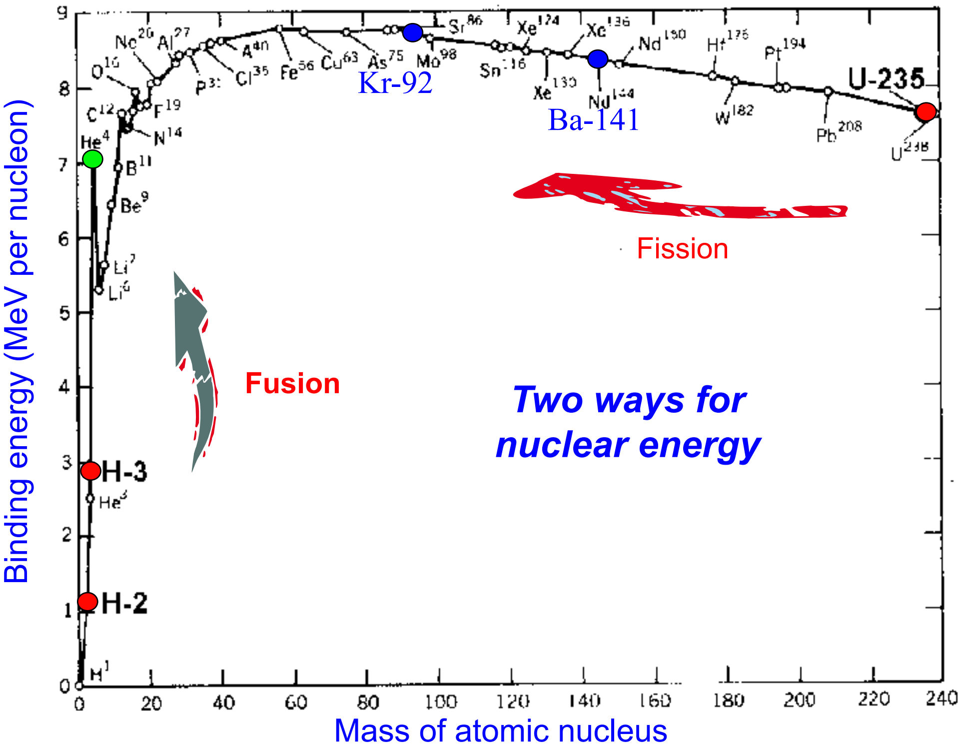
In conclusion. It is possible to use wind power. However, we need systems for storing. Even though new windparks are constructed more and more, it would take time before wind energy represents a solution to the energy demand in the future.

Energy from the atom

Fission - Fusion

Some of this is also presented in Chapter 4 (page 38–42) and in Chapter 8.

Nuclear power is based on the two physical processes called fission and fusion. Today only the fission process is used for energy production, but hopefully fusion may be used in the future.



The two processes can be explained using the figure to the left. The figure gives the binding energy in the atomic nucleus. Energy can be gained if we can transform a nucleus with a small (or at least lower) binding energy into a nucleus (or nuclei) with a larger binding energy.

Protons and neutrons are kept together by strong forces in the atomic nucleus. Along the vertical axis is given the binding energy per nucleon (mass unit). The figure says that the binding energy increases from about 1.1 MeV (for deuterium) to about 8.8 MeV (for iron). It decreases again toward heavier atoms such as U-235.

Along the vertical axis is given the "binding energy" per nucleon, and along the horizontal axis is given mass number. You gain energy by going from a nucleus with low binding energy into one with a larger binding energy.

It is possible to gain energy by transforming a nucleus with a small binding energy to another with a larger binding energy.
Thus, the gain is about 24 MeV when two deuterium atoms combine to form helium (He-4) or about 17 MeV by a fusion of H-2 (D) with H-3 (T). Upon a fission of uranium into Kr-92 and Ba-141 the gain is approximately 203 MeV (the red U-235 into the blue nuclei in the figure).

In conclusion: There are two possibilities for energy production from the nucleus:

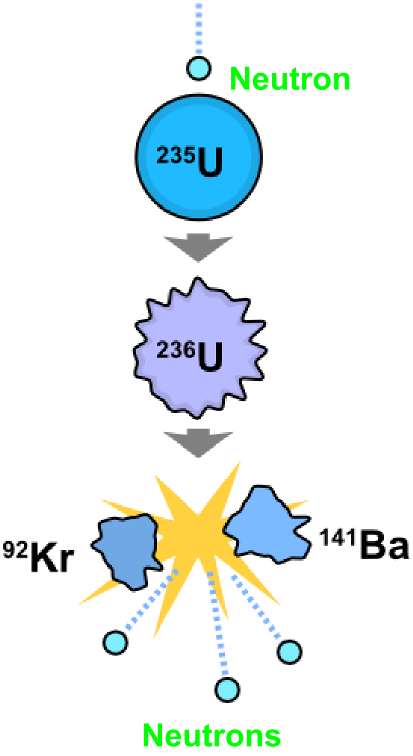
1. Fission. A large atomic nucleus is split into smaller units. From the curve above it requires that a heavy nucleus (to the right) be fissionable. Atoms that are fissile are the isotopes U-233, U-235 and Pu 239. We shall return to these isotopes and the use of them. The energy released in the process is about 200 MeV – and about 170 MeV goes into kinetic energy that can be used for power generation.

2. Fusion. Energy is gained in a fusion process. The requirement is that light atoms with a low binding energy are used. Hydrogen, deuterium and helium are all atoms that can be used for fusion. The fusion process requires a very high temperature (several million degrees) and is the main energy source for the sun.
So far, a controlled fusion process with gain of energy has not been achieved. In order to reach the high temperatures, high energy lasers have been used. At present, an international cooperation has started to build a tokamak in Provence, France called ITER (International Thermonuclear Experimental Reactor) which hopefully will be tested in about 2019. The plans are that the reactor will give an output of about 500 MW for an input of 50 MW.

Fission and fissile material

The reader should also consult the pages 125 – 126 in chapter 8.

The power reactors used today are based on fission and thermal neutrons. Even though, we shall not go through the technical aspects, we can explain some of the basic principles. In the illustration to the right the fissile element U-235 fissionate into two new elements; Kr-92 and Ba-141. A slow (thermal) neutron initiate the reaction. The reaction also gives 2 – 3 new neutrons with an energy of about 2 MeV (fast neutrons).



Fissile elements

The fuel for fission reactors is the fissile atoms; U-235, Pu-239 and U-233. Only U-235 is found naturally. The two other fissile elements must be produced. In the table below we see some of the properties for the fissile elements and for the fertile elements U-238 and Th-232.

Isotope	Half-life in years	% Abundance
U-235	$7.13 \cdot 10^8$	0.72
U-233	$1.62 \cdot 10^5$	0
Pu-239	24400	0
U-238	$4.51 \cdot 10^9$	99.27
Th-232	$1.39 \cdot 10^{10}$	100

If nuclear energy should be based only on U-235 the resources are rather limited. However it is possible to start with the fertile elements and convert them into fissile ones. The following nuclear reactions are necessary:

Pu-239

$$^{238}_{92}U + ^{1}_{0}n \Rightarrow ^{239}_{92}U + \beta \Rightarrow ^{239}_{93}Np + \beta \Rightarrow ^{239}_{94}Pu$$

$t_{1/2}$ = 23.5 minutes $t_{1/2}$ = 2.35 days

U-233

$$^{232}_{90}Th + n \Rightarrow ^{233}_{90}Th + \beta \Rightarrow ^{233}_{91}Pa + \beta \Rightarrow ^{233}_{92}U$$

$t_{1/2}$ = 22.4 minutes $t_{1/2}$ = 27 days

Conclusion

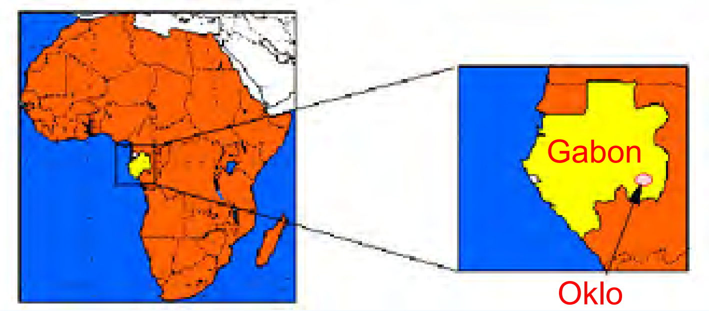
Three different isotopes are fissile. As you see in the table above only U-235 can be found in nature. In order to use the nuclear resources for power production we must enrich U-235 and/or transform the isotopes U-238 and Th-232 into the fissile ones.

Enrichment of U-235

Most power reactors with U-235 are based on enrichment of U-235. We have "*Slightly enriched uranium*" with a U-235 concentration of 0.9% to 2%, "*Low-enriched uranium*" which has a U-235 concentration lower than 20% and finally "*Highly enriched uranium*" with a U-235 concentration greater than 20%.
Nuclear weapons usually contains 85% or more of U-235. The Hiroshima bomb contained U-235 to a concentration of 80 %.
The different isotopes are, of course, chemically equivalent and the separation methods are based on the physical differences such as the weight. Gas diffusion and gas centrifugation are used.

The Oklo reactors – a result of a higher U-235 concentration

When Enrico Fermi started the first man-made reactor under Stagg Stadium in Chicago in 1942, everybody assumed that this was the first reactor. However, in 1972 the French physicist Francis Perrin discovered that nature itself had beaten Fermi by approximately 2 billion years. They reported that in Gabon in Africa there was, once upon a time, *natural fission reactors* that operated for several thousands of years.



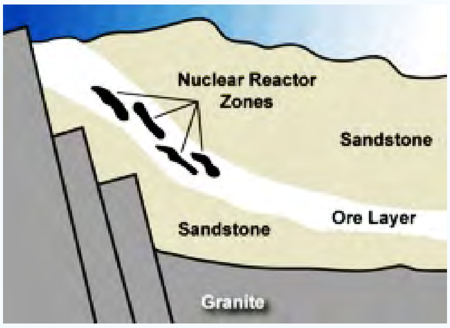
Some exciting work led to the discovery of the Oklo phenomenon. In the samples from Oklo the amount of U-235 was smaller than the expected 0.72 %. In some samples, hardly more than 50% of that expected, was found. The conclusion, after a long series of tests, was that U-235 had been "burned up" in the same way as in an ordinary fission reactor.

The reactor in Oklo was formed about 2 billion years ago. At that time the amount of U-235 was about 3.6 % (today it is only 0.72 %). Using the data on the half-lives in the table above you can calculate the U-235 concentration to any time you want. If you choose $2 \cdot 10^9$ years ago the concentrations of the two isotopes were 3.6 % U-235 and 96.4 % U-238. Consequently, the amount of U-235 was approximately like that found in an enriched reactor.

Franciss Perrin
(1901 – 1992)

In order to maintain the fission the energetic neutrons formed must be slowed down to thermal energies. In Oklo the moderator was water bound to the minerals.

About 15 reactors were buried in the Oklo uranium mine. They generated about 100 kilowatts for about 150,000 years. Groundwater evaporation and condensation kept them on a cycle that prevented meltdowns!



Fission products were formed, but the radioactive isotopes disappeared a long time ago. The stable end products can still be found. A very interesting result, with regard to storage of radioactive waste, is that the fission products have not moved significantly in the course of 2 billion years.

The plutonium (Pu-239) formed in the Oklo-reactor was slowly transformed to U-235 (α-decay), which then went into the burning cycle.
Today the occurrence of U-235 is too small for any new natural fission reactors. The Oklo-phenomenon will not reappear, but the uranium mines in Gabon have yielded a number of interesting facts.

Formation of the fissile isotopes Pu-239 and U-233 (reactor fuel)

Whereas U-235 exists in nature and can be used after enrichment – the two other fissile elements have no natural sources and can not be gained by enrichment. However, the other possibility is to form (or breed) these isotopes. ***The requirements are the fertile materials, U-238 and Th-232, and a strong neutron source.***

A strong neutron source is available in a reactor. The fission process liberates 2 – 3 neutrons with high energy. In average one of these neutrons can be used for a sustained fission process and the rest can then be used to produce new fissile elements. If a neutron is absorbed by U-238 the result may be Pu-239. Consequently, Pu-239 is all ways formed as a byproduct in a reactor. We can use this Pu-239 as fuel in a fission reactor.
We have also the possibility to increase the formation of both Pu-239 and U-233 in a reactor – such as a "***breeder reactor***". In a breeder reactor the neutron economy is high enough to breed fissile from the fertile materials U-238 and/or Th-232. This would increase our energy sources and satisfy our energy needs for as long as we can see into the future.

Breeder reactor

We have two types of traditional breeder reactors:
1. ***Fast breeder reactor*** or FBR. Here the neutrons are not slowed down – they are fast. The initial fuel is enriched U-235 (enrichment of about 20 %) and Pu-239. The core has a "fertile blanket" of depleted uranium (U-238), and this is where much of the Pu-239 is produced. Neutron activity is very low in the blanket, so the plutonium produced there remains almost pure Pu-239 - largely not burned or changed to Pu-240. The blanket can then be reprocessed and the plutonium recovered for use in the core. Fast reactor concepts being developed for the Generation IV program will simply have a core so that the plutonium production and consumption both occur there. Many interesting plans exists and new reactors will be built in the years to come. India is now on the point to try out a fast breeder reactor and use thorium for this purpose.

2. ***Thermal breeder reactors.*** The excellent neutron capture characteristics of U-233 make it possible to build a moderated reactor that, after its initial fuel charge of enriched uranium, plutonium or MOX, requires only thorium as input to its fuel cycle. Th-232 produces U-233 after neutron capture and beta decay.

ADS. Another possibility to form fissile U-233 is the "***accelerator driven system***" as suggested by Carlo Rubbia.
In this case accelerators are used to produce neutrons from heavy elements by spallation. A beam of high-energy protons (usually >500 MeV) is directed at a high-atomic number target (e.g. tungsten) and neutrons are formed by spallation.

An ADS can only run when neutrons are supplied to it because it burns material which does not have a high enough fission-to-capture ratio for neutrons to maintain a fission chain reaction.
Therefore we have a nuclear reactor which could be turned off simply by stopping the proton beam, rather than needing to insert control rods to absorb neutrons and make the fuel assembly subcritical. Because they stop when the input current is switched off, accelerator-driven systems are seen as safer than normal fission reactors

Carlo Rubbia

The Nobel Prize in Physics 1984 was awarded jointly to Carlo Rubbia and Simon van der Meer:
"for their decisive contributions to the large project, which led to the discovery of the field particles W and Z, communicators of weak interaction".

Conclusion

We do not intend to go into reactor technology – you can find all the principles and problems on internet. ***World Nuclear Association*** publish information and updates on the following address:

http://www.world-nuclear.org/infomap.aspx
and
http://www.world-nuclear.org/info/inf62.html

Resources

The resources for fission energy is uranium and thorium. Let us first mention a little about the history of these two elements.

Uranium

Martin H. Klaproth
(1743 – 1817)

The element was discovered in 1789 by the German chemist Martin Heinrich Klaproth. The name is from the planet Uranus. Uranium is element 92 and has altogether 14 isotopes, all radioactive.
Due to the half-lives only U-238 and U-235 can be found in nature.
Today U-238 accounts for 99.27 %. It is not fissile, but can be transformed to Pu-239 and used for reactor fuel. Uranium is a relatively common element, approximately as common as tin or zinc, and it is a constituent of most rocks and even of the sea.
As we know it today the largest sources are found in Australia (31%), Kazakhstan (12%), Canada (9%), Russia (9%). South Africa, Namibia , Brazil and Niger has about 5 % each.

Since only 0.72 % is U-235 the resources are not too large. Some estimates indicate that with the present use the resources would last about 100 years. However, if U-238 can be used in future reactors the resources would last several thousand years.

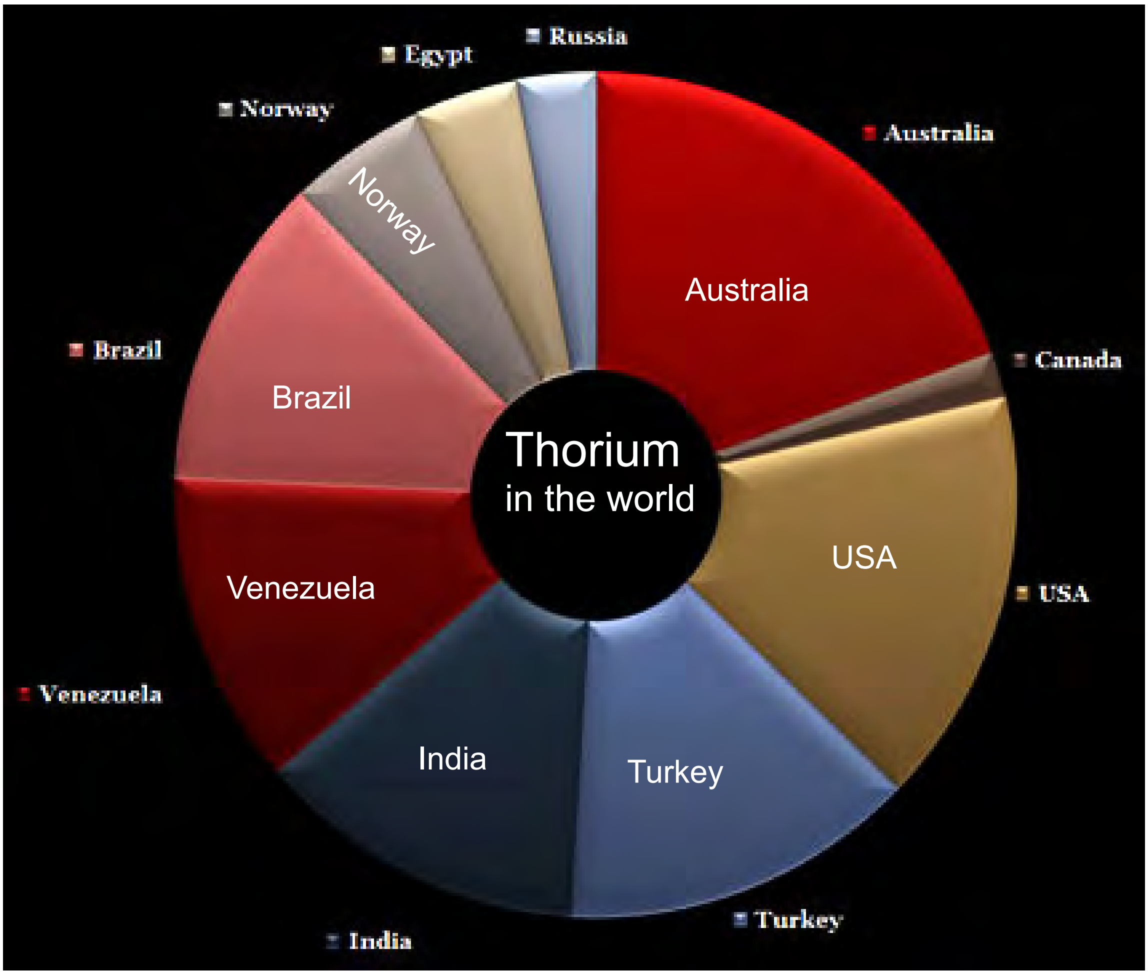
Thorium

Jöns Jacob Berzelius
(1779 – 1848)

Thorium was discovered in 1828 by the Swedish chemist Jöns Jakob Berzelius. The name is from the god Tor. Thorium is element 90 and has 13 isotopes – all radioactive. Only Th-232 is found in nature. The isotope is not fissile, but can, as shown above, be transformed into the fissile isotope U-233.

The resources are very large (three times larger than uranium) and would last for thousands of years.

The most common source of thorium is the rare earth phosphate mineral, monazite, which contains up to about 12% thorium phosphate, but 6-7% on average. Monazite is found from rocks of molten magma and other rocks, but the richest concentrations are in sand deposits, concentrated by wave and current action with other heavy minerals. World monazite resources are estimated to be about 12 million tonnes, two-thirds of which are in heavy mineral sands deposits on the south and east coasts of India.
Thorite ($ThSiO_4$) is another common mineral.



In this illustration is given the distribution of the world resources of thorium (explored so far). Only the sources that are cheapest for thorium production are taken into account. The limit is that thorium should be recovered at a price of less than 80 dollar per kg (2007).

Thorium in Norway

As seen in the illustration above Norway has a considerable resource of thorium. Most of it is found in the Fen Complex in Telemark. It is assumed that the thorium resources have a potential energy content which is about 100 times larger than all the oil extracted to date by Norway, plus that of the remaining reserves.

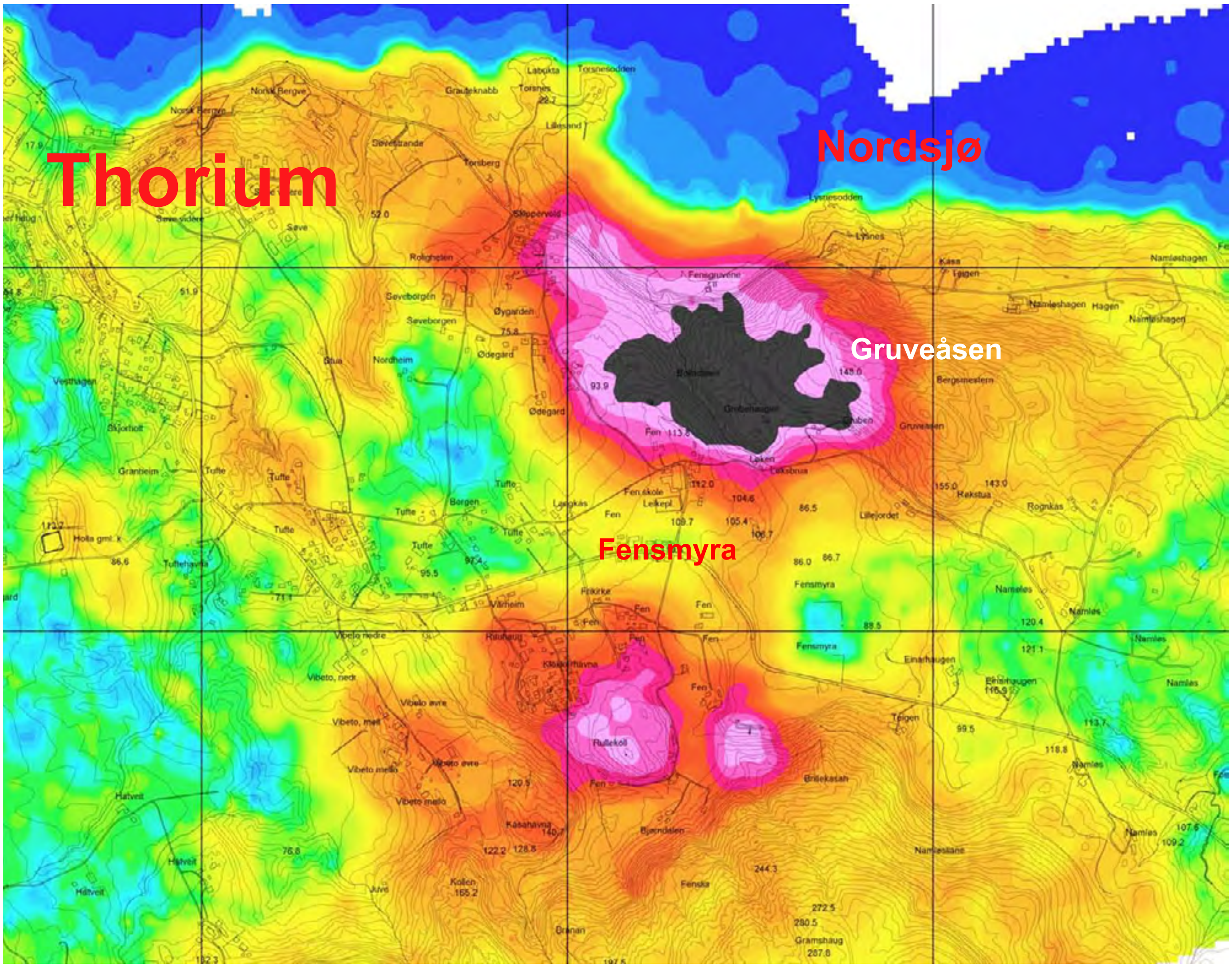
The interesting Fen complex originate from a vulcano about 500 million years ago. The field is almost cylindrical and the crystallization occured 2 – 3 km below surface. It has been found a lot of "*rare earth elements*" and it has been mining in the area for iron (period 1657 – 1927) and niobium (1953 – 1965). Furthermore, the radioactivity is quite large and demonstrates both thorium, uranium and potassium.

Several geological investigations has been perfomed in recent years. Here we would like to mention the studies on thorium.

The search for radioactivity in the air and on the ground are based on the γ-radiation. Thorium and uranium are pure α-emitters whereas a number of the daughter elements yield γ-radiation. With a good γ-spectrometer with high energy resolution it is possible to sort out the isotopes. A nice example is shown on page 76 where the isotopes from the Chernobyl accident were identified in a grass sample outside the Physical institute in Oslo. In order to identify thorium and uranium based on radioactivity the isotopes in table below is used.

Compound	Isotope used	Half-life	Gamma-radiation
Thorium	Tl-208	3.1 min	2.61 MeV
Uranium	Bi-214	19.7 min	0.61 MeV
K-40	K-40	$1.27 \cdot 10^9$	1.46 MeV

In 2007 an area of about 20 km^2 of the Fen Complex was observed with a γ-ray spectrometer with a sodium iodide detector connected to a helicopter. To ensure a uniform and dense data coverage, the measurements were performed along parallel lines with a narrow line spacing of 50 m. The average flying altitude during the measurements was 45 m. Maps of the three elements were produced. The thorium map is shown below.



The field map showing the thorium density in the Fen complex. The concentration is given by colors – the more red and violet the larger concentration of thorium. Large areas of the field is covered by sediments that varies from centimetres to several meters which effectively absorbs the γ-radiation. Consequently, the measurements in this area (Fensmyra) may be considerable larger than shown by the helicopter measurements.

Nuclear power – Climate

We shall discuss a few points concerning nuclear power and climate. The discussion include energy resources, waste disposal (CO_2 release versus radioactivity), accidents and consequences for the landscape. We shall not include economy since this factor will change with time.

Energy

First of all we would like to mention the very large content of energy in the atomic nuclei that can be released by fission and fusion. We mentioned above that a splitting of a fissile nucleus yield about 200 MeV – and about 170 MeV is available for electricity production.

Today about 80 % of the world energy production comes from fossil fuel. The resources of oil is limited and with the present use it will last for about 100 years at an increasing cost. Coal sources are larger and will last for a long time.
Let us now compare nuclear energy with fossil fuel. The energy produced from burning 1 kg wood, coal and oil can be compared to the energy produced by the fission of 1 kilo of the fissile atoms such as U-235 or U-233. Included in the table below is also the energy content by fusion of 1 kg hydrogen (the energy production in the sun).
The data are given in the following table.

Source	Method	Energy in kWh
1 kg wood	Burning	5.3
1 kg Coal	Burning	7.8
1 kg Oil	Burning	10.7
1 kg U-235	Fission	$20 \cdot 10^6$
1 kg Hydrogen	Fusion	$190 \cdot 10^6$

The table show that burning 1 kg of wood is equivalent to run an electric heater of 1000 watts for 5.3 hours. Coal and oil have more energy. However, using 1 kg of fissile materials is equivalent to use the 1000 watt heater for 20 million hours or about 2283 years.

Nuclear energy from fission has been used during the last 50 years and has accounted for about 14 – 16 % of the world electricity production during the last 25 years. Now the time is ripe to increase the use of nuclear energy.

Arguments in favor of nuclear energy

1. No release of CO_2 which is the main argument against fossil fuel.

2. The large amount of research during the last decade which show that small doses of radiation given at a low doserate have a beneficial effect on the cells defence mechanisms. This show that small doses of radiation is necessary for life. Our fear for nuclear accidents and nuclear waste are strongly exaggerated.

3. The use of thorium and fast breeder reactors can give waste with a shorter halflife.

Fossil fuel waste. CO_2 capture and storage

In the case of fossil fuel the waste such as CO_2 is not harmful for living organisms. In fact CO_2 is a necessary component for photosynthesis as well as for living cells.

However, **all climate models show that the greenhouse effect increases with the CO_2 content** (not linearly, but rather in a logarithmic way). Consequently, environment-organisations and the political establishment in the industrialized countries have for some years now explored the idea of capture and storage of CO_2. If this would be possible it would require a significant reduction of the energy produced and available for use, because some part of the energy must be used for CO_2 capture and another part for storage.

Since CO_2 is stable the storage must be permanent – with no leakage.

Nuclear waste

The storage of nuclear waste has very strong regulations. Today all regulation authorities assume that the detrimental effects of radiation follow the LNT model – and all countries have implemented an extremely conservative system for nuclear waste.

Throughout this book we have questioned the LNT-hypothesis and the research during the last 5 years have clearly shown that it is not valid. These research data will sooner or later change our view on the danger with radioactivity and change the rules and regulations used today.

Accidents

Nuclear energy is very safe compared to coal, oil and even hydroelectricity. All opponents to nuclear energy talk about the accidents and the late effects of the released radiation. It seems to be enough only to mention the name Chernobyl. We have through this book treated the Chernobyl accident several times and the conclusion is as follows:

1. Approximately 135 were hospitalized with acute radiation syndrome and 28 died within 96 days.

2. More than 300 000 were permanently replaced. This evacuation was a great mistake and this cohort had a lot of psychological problems including suicide and cardiovascular diseases.

3. It appears that the cleanup workers (at least the group from Russia) that got measurable radiation doses have less cancer and appear to be healthier than the other Russian groups. This would be in line with the new results in radiation biology.

4. Experiments within a region with a large fallout indicate that the ecological half-life for Cs-137 was 3.6 years during the first 6 years after the accident and then increases to almost the physical half-life after 20 years (see the data on page 154). It would be of interest to observe similar results from other regions.

We can conclude that the detrimental health effect is very small – whereas the psychological effects were extremely high and initiated by the LNT-model and supported by environment organizations and lack of knowledge among politicians.

Terror actions

From time to time terror actions against nuclear power stations have been mentioned as an argument against nuclear power. It is possible to carry out terror actions to all systems, but the danger for pollution by radioactive isotopes is extremely small. Terror actions against hydroelectricity dam-projects would be far more dangerous.

Closing Remarks

The purpose of this book is to provide information about ionizing radiation, its use and its consequences. We have provided information about the applications of radiation that benefit society and the different parameters that must be considered for the use of radiation technology in medicine, research, and industry.

For the years to come it would be very important with education and research. It would be a great job to give information about the positive effect of ionizing radiation – but not impossible.

Most people not only accepts the use of radiation within medicine and are eagerly interested in new methods such as CT and PET. Most people accepts the use of radiation in cancer therapy. However, LNT and the radiation authorities have scared the people to be afraid of radon in houses, radioactivity in the drinking water and of course nuclear power.

In this book we have given some information on the positive use of radiation. We have identified risk factors for radiation and it should be possible to establish new rules and regulations to limit detrimental effects and enhance the positive effects both to the individual and to the society.