Bundesministerium
für Verkehr,
Innovation und Technologie

NACHHALTIGwirtschaften
konkret

A Future for Nuclear Power?

P. Biermayr, R. Haas

Berichte aus Energie- und Umweltforschung

3/2010

Dynamik mit Verantwortung

Imprint:

Owner and Publisher:
Austrian Federal Ministry for Transport, Innovation and Technology
Radetzkystraße 2, A-1030 Vienna, Austria

Responsibility and Coordination:
Division for Energy and Environmental Technologies
Head: Michael Paula

This publication is available on http://www.nachhaltigwirtschaften.at

A Future for Nuclear Power?

Dipl. Ing. Dr. Peter Biermayr
a.o. Univ. Prof. Dipl. Ing. Dr. Reinhard Haas

Vienna University of Technology
Energy Economics Group

Vienna, November 2009

Translated from German by Matthew McCarthy-Rechowicz

Original title: „Aspekte der zukünftigen Kernenergienutzung“
published in the series „Berichte aus Energie- und Umweltforschung“, 53/2008

Supported by the Austrian Federal Ministry for Transport, Innovation and Technology

[1]

The half-life of human memory is damned short -
that one of plutonium amounts to 24,000 years.

Peter Biermayr

[1] The nuclear mushroom over Hiroshima, photograph from the Enola Gay, a B29 bomber, which dropped the world-wide first nuclear bomb used in a conflict. Source: US archive ARCWEB.

1. Abridged version

1.1 Motivation

The media coverage surrounding nuclear power has recently been increased by the current discussion about the reduction of greenhouse gases, and of the industrialised nations' dependence on oil and gas imports. After a period of many years characterised by silence and amnesia, which followed the Chernobyl catastrophe, voices are now to be heard which advocate nuclear power as a solution to the looming crises regarding climate change and resource shortages.

1.2 Method and data

Against this background, the study at hand presents a fact-based account of the key dimensions of the global use of nuclear power. The historical development, and the status quo, as well as questions relating to the development of the future diffusion of technology, will be discussed. This discussion will be accompanied by a structured presentation of controversial aspects regarding the use of nuclear power, and by a development of problem areas.

The content of the present study has resulted, on the one hand, from workshops with internationally recognised scientists who are experts in the field, and who have dealt with the topic over many years; and on the other hand from the analysis and evaluation of current literature and data on the subject. Both supporters and opponents of nuclear power were involved in the workshops. The literature and data sources were selected for their reliability and lucidity; they originate both from supporters of nuclear power and the nuclear power industry, and from NGOs which campaign for the abandonment of nuclear power stations.

1.3 Results

Numerous dimensions of nuclear power need to be considered in order to comprehensively analyse and evaluate the technology, if we wish to be able to make conclusive statements about the sustainability of this technology, and about its importance for the development of sustainable energy and social systems. The fundamental questions which arise in this context have been thoroughly reviewed in this study:

I. Can the use of nuclear energy be extended quickly enough to allow it to make a relevant contribution to the reduction of greenhouse gas emissions?

The historical market diffusion of nuclear power took place between 1967 and 1988. In 1989, a global total of 423 reactors were in operation with a total installed output of 328 GW_{el}. The following collapse of the diffusion of the technology can be traced back to the catastrophe in Chernobyl (1986), and to the incipient liberalisation of the energy markets and the accompanying reappraisal of the exorbitant capital requirements and of the financial risks. 17 years later, in 2006, 442 reactors with an installed output of 368 GW_{el} were in operation – only slightly more than in 1989. In 2004, these reactors produced around 16% of the world's electricity. In the past 10 years, 43 new plants worldwide went on stream. The majority of these replaced old plants which had been taken out of operation. In 2008, the world's nuclear power stations had already been in use for an average of 24 years. The average lifetime of the 110 plants, which had previously been shut down, was 21 years. It is increasingly the case that plants are seeing a longer period of use before they are shut down.

In the next 10 to 20 years, we should not expect to witness a medium-term, global expansion of nuclear power which would exceed the mere replacement of the plants which are being closed. In this sense, the use of nuclear power cannot make any further contribution to the protection of the environment. Currently, two plants are under construction in Western Europe (Finland and France). A few plants are being built in Eastern Europe, North and South America, and South Africa. It is only Asia which is witnessing more prolific construction with a total of 19 new plants. In view of the lengthy building process of often 10 to 20 years, and even having taken account of all the projects in planning, it is to be concluded that no more than four or five new plants per year will be put into operation worldwide over the next decade. In the medium term, in view of the age distribution of the current working plants, the result will thus be a decline in the number of nuclear power stations.

In 2005, the use of nuclear power stations lead to a decrease of CO_2 emissions of 2,500 million tonnes worldwide (nuclear substituting natural gas steam plants), or 7.4% of the total emissions. These values increase when one includes the substitution of coal-powered energy. Due to the diffusion of technology and the increase of emissions in other areas (e.g. traffic), the future role of nuclear power will decrease in the medium term. Above all, however, nuclear power is unsustainable due to limited fuel resources (uranium). Moreover, nuclear power is by no means carbon-neutral, as the extraction of the fuel is linked to energy-intensive processes. Furthermore, this energy use will increase in the future as the quality of the uranium ore deteriorates. The extraordinarily lengthy planning and building phases, as well as the enormous capital required, preclude any noteworthy, short-term expansion. This, however, is indispensable for effective measures protecting the environment.

II. How economically viable is the use of nuclear power in the long term?

When talking about the economic viability of nuclear power stations, it is necessary to differentiate between two different cases:

1. The extension of the operational lifespan of nuclear power stations which have been written off. An extension of this kind is exceedingly attractive for the operators of such plants. On the one hand, in view of the financially

draining cost structure of nuclear power plants, it is possible to make tremendous profits if the lifespan of a plant is extended. On the other hand, the enormous costs which are incurred by the decommissioning and decontamination of the plant, can be delayed or, if the operator should become insolvent in the meantime, be made the responsibility of the taxpayer.

2. Due to the extremely large capital requirements and the high financial risk it presents, the construction of new nuclear power plants under ancillary free market conditions is not attractive for investors. In the USA, no investors have been attracted by governmental incentives. In Western Europe, it has taken 25 years for a new nuclear power station outside France (the nuclear power plant in Olkiluoto, Finland) to be commissioned from the nuclear power industry (mainly AREVA and Siemens). Even this commission has only been made possible by large-scale industry dumping (a guaranteed fixed price of €3bn) and a state-subsidised, billion Euro loan from the Bayrische Landesbank (interest rate: 2.6%). An attempted further commission under the same conditions has already been rejected by the atomic industry.

   In the past, the actual construction costs of nuclear power plants have always dramatically exceeded the estimates. In the USA, the minimal historical construction cost overrun amounted to more than 100%; that is, in a best-case scenario, a nuclear power plant cost twice the estimated price. The cost data for numerous other power plant sites outside the USA are either unavailable, or so unclear that it is not possible to conduct a serious analysis. The unavoidable construction cost overruns are a result of: overruns in the construction time, which are also unavoidable and which are associated with increased costs of capital; the changing safety-related requirements; changes on the capital market (exchange rates, interest rates); and many other factors.

III. How much longer will the uranium reserves last?

According to market analysis carried out by the IAEA and the IEA, there are 4,47 million tonnes of ‘cheap’ uranium available worldwide, based on a price level of US$130/kg of uranium. Accordingly, if consumption remains at the 2004 level, the nuclear fuel resources should last a calculated 70 years. Other studies do not concur as to the length of time that resources will last, and the statistics given always vary by several decades. In recent years the price of uranium has been very volatile and, in 2007, it exceeded the level of US$130/kg by more than 100%. The once long-term price stability of this fuel is no longer reckoned with.

According to the potential cost curves, it will in future be necessary to exploit ever more expensive deposits which will have decreasing concentrations of uranium. Mining in these areas will cause increasingly serious environmental problems, as it will be necessary to excavate larger and larger amounts of ore per kilo of uranium. It is possible, by means of reprocessing burned out fuel rods and breeder technology, to preserve remaining reserves of reactor fuel. However, even in the face of rising uranium prices, fuel rods from reprocessed raw materials are not a competitive alternative; nor has breeder technology, due to technological, safety-related, and economic considerations, yet been able to assert itself.

IV. Has the problem of the permanent disposal of radioactive waste been solved?

The problem of permanently disposing of nuclear waste has still not been resolved, and is hardly taken into account when looking at nuclear power plants from a business management perspective. After around 50 years of non-military nuclear power use, there is no market price for the permanent disposal of nuclear waste, due to a lack of permanent, non-military disposal sites with practice-oriented capacity. In the calculations of atomic power stations, the costs of permanently disposing of burned up fuel which will arise in the distant future, and of the decontamination of the radioactive parts of the reactor, are disregarded by the deduction of accrued interest which is usual in feasibility studies. It is a fact that the nuclear waste which is produced by the operation and subsequent decommissioning of nuclear power plants will cause problems for humanity for geological eras. Future generations will have to carry the costs of keeping radioactive waste, which annihilates all higher life forms, away from the biosphere.

V. How are the safety risks linked to the use of nuclear power to be seen today?

At the latest, we became aware of the risk of the catastrophic release of radiation from nuclear power stations after the maximum credible accident at Chernobyl in 1986. A further accident is possible at any time, despite the noticeable improvement of safety precautions – in terms of both technology and staff – at nuclear power stations. The likelihood of such an accident is dependent on the number of plants in use, as well as on their condition. This, in turn, places the economically attractive extension of the life-span of plants in a critical light. The terrorist attacks of the 11th September 2001 have added an additional dimension to the risks which accompany the operation of nuclear power plants. Any area which houses a nuclear power plant runs the risk of becoming the object of a terrorist attack, or, in the event of war, a strategic target. Further risks can result from the release of radioactive material during the regular use of nuclear power stations, particularly from: the mining of uranium; the after treatment of fuel; and the temporary storage and permanent disposal of nuclear waste.

It is not possible to differentiate between the military and the non-military apects of nuclear technology. In principle, every nuclear power station, and even every experimental reactor, can serve as the source of material which can be used to produce nuclear weapons, despite the large qualitative and quantitative differences between the types of reactor. It is not for nothing that the atomic programmes of some states (historically Iraq, currently Iran, for example) are viewed internationally with great concern. The ability to produce nuclear weapons is also increased by plants which are involved in the life cycle of fuels. Reprocessing and enrichment plants can be used just as much for non-military as for military purposes. The risk of weapons-grade fissile material and nuclear weapons being proliferated further increases due to the amount of nuclear matter, nuclear fuels, and nuclear weapons which are sold worldwide. The necessary bases for the construction of nuclear weapons are freely available, e.g. on the internet, and, with the congruent engineering capabilities, it is consequently possible to produce nuclear weapons for states or organisations which possess the requisite fissile materials. This problem will become considerably more serious in the future, due to the intensification of breeder technology and the resulting plutonium economy.

VI. Can any of the cost risks of nuclear power stations be covered?

The operation of nuclear power stations can only be partially insured. Without limitation of liability, it would not be possible to operate a nuclear power station, as no insurance company in the world is prepared to insure a nuclear power station. It is international treaties which regulate the limits of liability. In the case of a serious nuclear accident, the sum insured would, to some extent, be unable to cover the damages. In such an event, it is not the (private) operator of the plant who bears the risk, but society, even though it is the operator who siphons off any profits from the plant. It is also society which bears further cost-related risks, such as the unknown costs of the final disposal of atomic waste for thousands of generations, or the costs incurred in the decommissioning and decontamination, should the operator declare insolvency.

VII. How should the democratic relevance be assessed?

Even in many countries which use nuclear power, a low percentage of the population endorses the operation of nuclear power plants. As such, the democratic relevance of nuclear power can be regarded as critical. In promoting such projects, the atomic industry always bypasses the public, and addresses itself directly to the highest political committees in a country. If the atomic industry's proposals meet with a positive response, it is usually the government which tries to convince the public of the value of the relevant projects. In this case, it is again the public which carries the associated propaganda costs. This is necessary in democracies as it is society which, on the one hand, foots a large percentage of the bills, and, on the other hand, bears the majority of the risk. That is why, on the whole, new nuclear power projects are carried out (with the exception of Japan) in countries with undemocratic decision-making processes (China, Russia).

VIII. Is the new generation of nuclear power stations different?

A new generation of nuclear power stations, the so-called 'Generation IV', is being created under an expensive development programme. This programme should produce sustainable nuclear power technology. Above all, however, the atomic industry wants to regain people's trust, in order to be able to realise new projects. The aim of developing 'sustainable' technology is being hindered by the lifecycle of the fuel. Starting with production, through to the problem of disposal, the mere existence of these nuclear fuels in the various stages of their use will cause massive problems for future generations. These problems are not compatible with the basic principles of sustainability. Fast breeder reactors, which are strongly represented among 'Generator IV' reactors, and which should, above all, lead to a better fuel utilisation, cause additional problems due to the intensification of the plutonium economy. These problems represent a threat to human existence because of the tremendous toxicity of plutonium, as well as its particular suitability for nuclear weapons.

IX. Are the human capacities (experts, engineers) necessary for the expansion of nuclear power use available?

After the diffusion of nuclear power technology collapsed in 1988, the demand for experts in this field has sunk. The appeal of professional training relating to the planning, operation and disposal of nuclear power plants has been constantly decreasing, due to the Chernobyl catastrophe and the failure of this technology to develop into a sustainable option. The abandonment of nuclear power, which has been announced by large countries such as Germany, brings with it a further depression in the field of education. Specific training courses are often unappealing for young people, although even the planned decommissioning of plants in the next decades should create a high demand for experts. Aggressive diffusion of nuclear power will have a long lead time, possibly of many decades, due alone to the necessary redevelopment of human capacities. The appeal of corresponding, mostly protracted, professional training would have to be increased, and appropriate incentives would have to be offered.

1.4 Conclusions

Can we call the current situation the renaissance of nuclear power?

It is not possible to call the current situation the 'renaissance of nuclear power'. The current construction of new nuclear power stations does not even suffice in the medium term to replace the plants which have been decommissioned due to age. In the face of such a situation, the atomic industry is taking pains to repudiate the image of a technology which is becoming obsolete. Its argumentation includes contemporary issues, such as climate protection. On closer inspection, however, this argument is untenable. On the one hand, nuclear power is by no means carbon-neutral, and on the other, the slow diffusion of the technology prevents effective climate protection. In democracies acting within the market economy, it is only in exceptional circumstances that a new nuclear power station is built. Due to the exorbitant capital requirements, the cost structure of nuclear power stations is incompatible with the ancillary conditions of liberalised energy markets. Conversely, extending the lifetime of plants which have been written off is appealing from a market economy perspective. This, however, does not only bring large profits for the operators, but, due to the operation of antiquated plants, carries a heightened risk for society. Because of international liability limitations, without which nuclear power would not be possible, the risk arising from nuclear power stations must be borne by society. The risk is multi-faceted: the release of nuclear radiation in the course of the regular operation of plants (uranium mining, reprocessing, temporary storage and permanent disposal), and as a result of catastrophic accidents (e.g. Three Mile Island in 1979, and Chernobyl in 1986); and the threat to plant locations in the event of terror attacks or war.

Nuclear power projects only become appealing when a large part of the costs is borne by the taxpayer. This starts with governmental propaganda aiming to ‘shape public opinion’, which is necessary for the execution of the respective projects and is made possible by government-funded loans, governmental liability in the event of plant failure, industry dumping, and making the public liable should an accident occur. Not least, the problems and costs related to the disposal of nuclear waste, which will affect thousands of future generations, are ignored.

The motivation of countries which are still committed to nuclear power can, after all economic, maintenance-related, and ecological aspects have been taken into account, only lie in: strategic military interests; the demonstration of power; or a lack of alternative modes of energy production. In special cases, for instance France, which has a large number of power stations and an influential industry lobby, many mechanisms are in place which maintain the system and prevent the abandonment of nuclear power at the present time.

As with the use of fossil fuels, the use of nuclear power is tied to a lack of available resources (uranium ore). If these resources continue to be consumed at the present rate, it is estimated that they will last between 60 and 70 years. Should nuclear power be expanded, these resources will last for a proportionally shorter time. Breeder technology, which should allow resources to be exploited more effectively, has not yet been able to assert itself and, due to the related plutonium economy, harbours a high risk to society.

In terms of the development of sustainable energy and social systems, the use of nuclear power is not an option. On the contrary. The use of nuclear power ties up large amounts of capital which would be desperately needed for the further development of sustainable energy sources and energy efficiency. Additionally, the mere daily non-military operation of reactors and the accumulation of atomic waste are creating a monstrous legacy. As such, the use of nuclear power is incompatible with the demands for sustainable energy and social systems, and must be repudiated as a sustainable approach to the problem of energy production.

2. Table of contents

3. Introduction

Against a background of sharply rising energy use in industrialised nations, several important problem areas stand out both nationally and internationally. These problem areas will, in the foreseeable future, be of crucial importance for the affected economies, and have been labelled future challenges by the European Commission.[2] The following key points, arranged in no particular order, are of interest:

- Meeting rising energy demand in an international (e.g. European) context.
- Guaranteeing supplies (short-term: with regard to system stability; long-term: with regard to the availability of the primary energy in use).
- Reducing dependence on foreign countries, which results from turning imported fossil fuels into electricity, or from the import of electricity.
- Striving to reduce greenhouse gas emissions.
- Providing cheap electricity to ensure a competitive economy and further economic growth.

In this context, diverse approaches to solving the problem are raised within the framework of the international discussion. The future status of nuclear power is taken on as a theme of this discussion. The atomic industry experienced a boom between the 1960s and the 1980s, but in recent years has faced, and continues to face, a considerable reduction in the number of orders. The industry, however, continues to spot new market potential, and this has lead to a discussion about a forthcoming 'renaissance of nuclear power'.

The present study will examine the extent to which increased use of nuclear power can contribute to solving upcoming problems, and the societal effects which could be caused by an intensification of the use of nuclear power. This will be done on the basis of a comprehensive study of literature, and of the appraisal of the expert workshops which were held for this purpose. These workshops were held in Vienna on the 11th October 2006 and 23rd January 2007, and both international supporters of nuclear power, as well as its international opponents were invited. A list of those who participated in the workshops can be found in Appendix A. An event called 'Renaissance of Nuclear Energy in Europe?' ('Renaissance der Atomenergie in Europa?'), held within the framework of the 'Energy Talks' ('Energiegespräche'), at the Technisches Museum, Vienna, on the 10th October 2006, was the prelude to these workshops. The events at the Technical Museum were also able to reach a wide and interested audience.

This final report is constructed in the following manner: Chapter 4 presents a short overview of the development of the use of nuclear power. Chapter 5 illustrates, both as a basis and as a definition for further observations, the various types of reactor and their practical relevance. Chapter 6 is concerned with the historical diffusion of nuclear technology, and foreseeable further diffusion in the future.

---

[2] Commission of the European Communities (2006)

4. The historical development of the use of nuclear power

The following section shows how the use of nuclear power has developed, with a special focus on Germany using the key milestones of this technology. This historical development covers a period of more than 110 years, from research into the physical phenomenon to the present day. The current state of technological development, as well as the present proliferation of technology, are presented in detail in the following chapters.

1896 Antoine Henri Becquerel discovers the phenomenon of radioactivity

1898 Marie and Pierre Curie discover the decay of radium in other elements, and in doing so observe ionising radiation.

1911 Ernest Rutherford develops his theory regarding the structure of the atom and of radioactive decay. Niels Bohr later develops his model of the atom on the basis of these theories.

1938 Otto Hahn and Fritz Straßmann succeed in documenting the fission of uranium atoms.

1939 Joliot, Halban and Kowarski detect the release of neutrons during nuclear fission. These neutrons set a chain reaction in motion. Liese Meitner and Siegfried Flügge calculate the order of magnitude of energy amounts released during nuclear fission.

1941 The ‘Uranium Club’, under the leadership of Werner Heisenberg and Walther Bothe, builds an experimental reactor. No self-sustaining chain reaction has been induced by the end of the war (1945).

1942 Enrico Fermi and his team build the first experimental nuclear reactor. Chicago Pile 1 (CP-1) is used to initiate the first controlled chain reaction.

1945 6^{th} and 9^{th} August: the first atomic bombs to be used during a conflict kill 265,000 people in Hiroshima and Nagasaki. 155,000 people die immediately, another 100,00 die in the following weeks as a result of injuries and radiation exposure. In the subsequent years, uncountable numbers of people die as a result of medium-term and long-term radiation exposure.

1951 Idaho, USA: electricity is produced for the first time by nuclear power in the experimental reactor EBR 1.

1955 The German Federal Government, under Federal Chancellor Konrad Adenauer, creates the Federal Ministry for Nuclear Energy. Franz-Josef Strauß is appointed as the first Federal Minister for Nuclear Energy.

1959 The Atomic Energy Law is proclaimed in the Federal Republic of Germany. It is the future legal basis for the construction and operation of nuclear power plants.

1967 The experimental programme for the storage of nuclear waste in the salt mine at Asse is initiated.

1971 Nuclear waste is deposited for the first time in the nuclear waste dump at Morsleben. This dump is planned as permanent nuclear waste storage site.

1971	Construction work begins on Austria's first nuclear power plant in Zwentendorf.
1972	Germany's first commercial nuclear power plants, Stade and Würgassen, begin supplying electricity.
1974	The world's first 1,200 MW block is put on stream in Biblis, Germany.
1977	Following various experimental set-ups, the first German fast breeder reactor goes on stream in the Nuclear Research Centre in Karlsruhe.
1978	As a result of the referendum regarding the activation of the nuclear power station in Zwentendorf, the Law Banning the Use of Atomic Power is enacted.
1979	On 28th March there is a serious accident on Three Mile Island, Pennsylvania, USA. A combination of malfunctioning machine parts and operational errors made by the staff, caused the breakdown of the cooling system, which in turn lead to a partial core meltdown and the release of 90 TBq of radioactive gases. To this day, this is the worst accident to have occurred in a commercial reactor in the USA.
1979	The heads of German federal and state government enact the 'Principal Precautions of Nuclear Waste Disposal'.
1982	The foundation stone for the Federal Republic of Germany's first large-scale uranium enrichment plant in Gronau is laid.
1986	The most serious accident yet in the history of peaceful nuclear power use happens on April 26th in block 4 of the Soviet nuclear power plant at Chernobyl. The IAEA Convention regarding early warning in the event of a nuclear accident, as well as the German Bundestag's law regarding precautions against radiation, come into effect.
1988	Commencement of the archetypal deconstruction of the nuclear power plant at Niederaichbach. Nuclear technology celebrates its 50th birthday.
2000	An agreement between the Federal Government and energy providers regarding the future operation of German nuclear power plants is initialled. These energy providers agree to produce only a certain amount electricity in nuclear plants, and in return the government guarantees their undisturbed operation. On December 15th, block 3 at Chernobyl, which had been in operation until this point, is decommissioned. Block 3 was the last to be taken out of operation.
2003	In November, the nuclear power station at Stade is taken out of operation.
2005	In May, the nuclear power plant at Obrigheim is decommissioned.

5. The state of technological development

In principle, the plant-specific rough concept of a nuclear power station can hardly be differentiated from that of a coal-fired power station or any other type of calorific power station (Figure 5.1). In a nuclear power station, the reactor is the source of heat, and it is hence necessary to differentiate between the various types of reactor. Due to the potential nuclear threat, it is not possible to compare the necessary plant-specific and constructional measures in a nuclear power plant with the demands of a traditional, calorific power plant. The safety measures and the dimensioning of all safety-related components in a nuclear power station are installed with regard to the destructive effects which a serious accident could have on society. This risk also finds expression in the investment costs, construction periods, and the politically explosive nature of the technology.

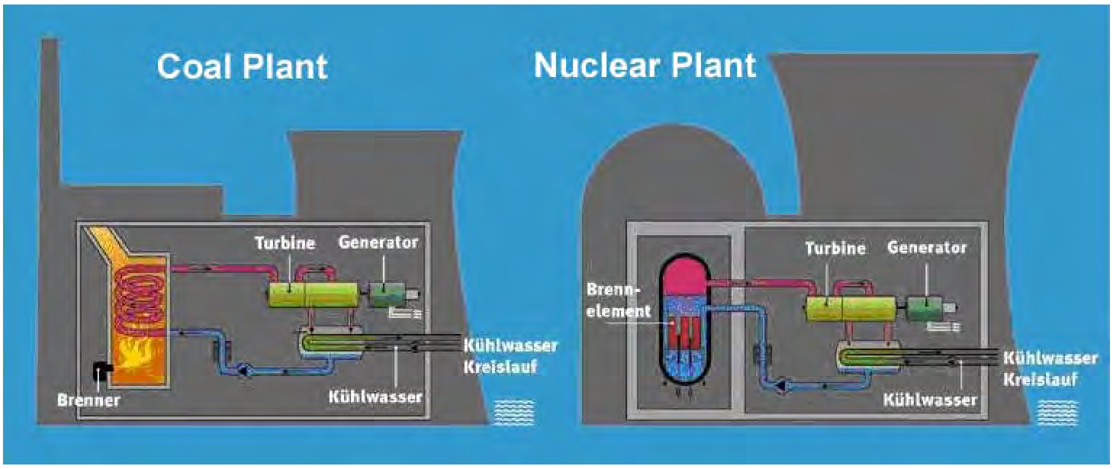


Figure 5.1: Comparison of the rough concept of a coal fired power station and a nuclear power plant with a boiling water reactor.

The representational section presents the technical concepts of the main reactor types, without regarding reactor safety, economic viability, or strategic aspects, such as the extraction of weapons-grade fissile materials. In this sense, Section 5 is also to be understood as providing definitions of various terms for the following chapters.

5.1 Reactor types

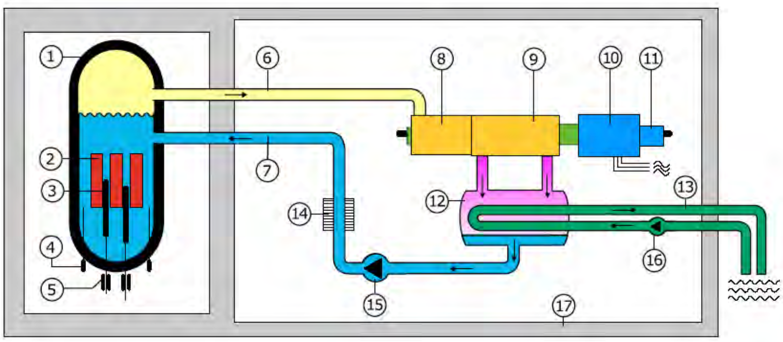
A great assortment of reactor types has emerged in the course of the development of nuclear power. The boiling-water reactor, pressurised-water reactor, high-temperature reactor and the fast reactor are particularly noteworthy. As a parallel to this concept-oriented classification, it is also possible to classify reactors, according to their primary goal, as power reactors (for energy production), production reactors (for the creation of weapons-grade fissile materials), and research reactors. In most cases, uranium oxide is used as nuclear fuel. The uranium oxide is enriched with c. 3% Uranium-235. A moderator is necessary to control the course of the chain reaction; depending on the reactor type, the moderator can be light or heavy water, or graphite. To illustrate the technology, the following sections will explain the principles of water-cooled, high-temperature, and fast reactors.

5.1.1 Water-cooled reactors

The majority of commercial power reactors are water-cooled. Water-cooled reactors can be realised either as boiling water reactors, or as pressurised water reactors. In Germany, for example, 11 pressurised water and 6 boiling water reactors are in operation. World-wide, 61% of all reactors are pressurised water reactors, and they produce 66% of nuclear power; the percentages for boiling water reactors are 21% and 23% respectively.

The technological trend we have just described is being set forth by the European Pressurised Reactor (EPR), which has been commissioned by energy providers and is currently in development in Germany and France. The developers hope to make improvements to safety features and economic viability. The EPR is designed for an electric output of 1,525 MW.

Boiling water reactors (BWR) are light water reactors, in which 'light' water, i.e. normal water (H_2O), is used as a moderator and coolant. The heat produced by nuclear fission is absorbed and conveyed by this water. The reactor's pressure vessel, in which water boils at a temperature of around 290^{o}C, is at a pressure of approximately 70 bar. The steam is used to drive a turbine which is linked to a generator. The steam is then cooled in a condenser and turned back into water. This water is then fed back into the cooling circuit. Figure 5.2 is a diagram of the technical concept.



1. reactor vessel
2. fuel rods
3. control rods
4. circulation pumps
5. control drive
6. steam line
7. feed water
8. high pressure turbine
9. low pressure turbine
10. generator
11. pilot exciter
12. condenser
13. cooling water
14. preheater
15. feed pump
16. cooling water pump
17. concrete screen

Figure 5.2: Concept of a boiling water reactor. Source: Kernenergie.de (2007).

Pressurised water reactors (PWR) are another type of light water reactor. 'Light' water (H_2O) serves, as with the BWR, as the moderator (neutron moderator) and coolant, as well as the heat conveyer. The reactor's pressure vessel is at a pressure of 150 to 160 bar. This high pressure prevents the water boiling at the working temperature of around 320 ^{o}C. A self-contained main cooling circuit, the primary circuit, transfers the heat produced in the reactor to the steam generators, where the water in the secondary circuit is vaporised. The steam turbine and, subsequently, the generator are found in the secondary circuit. A condenser cools the processed steam in the secondary circuit. Figure 5.3 shows the technical concept.

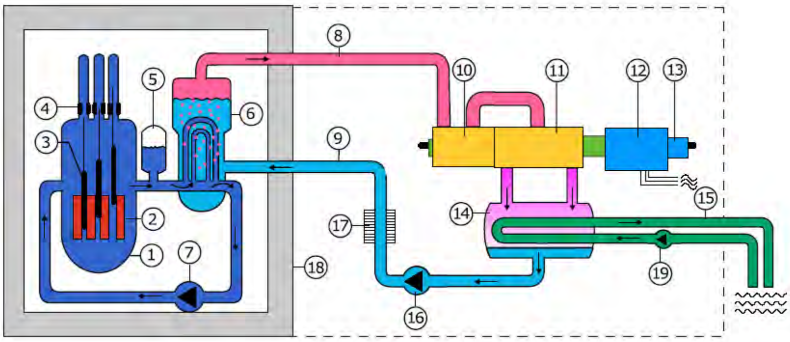


Figure 5.3: Concept of a pressurised water reactor. Source: Kernenergie.de (2007).

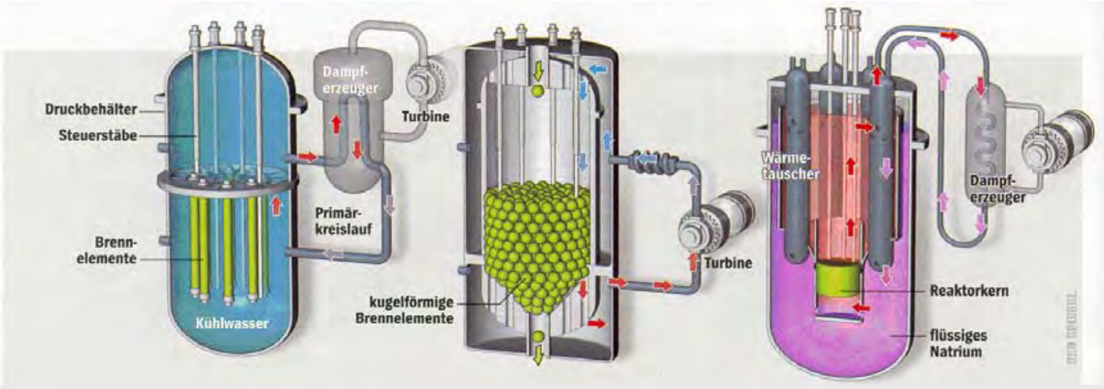
1. reactor vessel
2. fuel rods
3. control rods
4. control drive
5. pressure vessel
6. steam producer
7. circulation pumps
8. steam line
9. feed water
10. high pressure turbine
11. low pressure turbine
12. generator
13. pilot exciter
14. condenser
15. cooling water
16. feed pump
17. preheater
18. concrete screen
19. cooling water pump

5.1.2 High temperature reactors

The high temperature reactor was developed as a pebble-bed reactor. The reactor core consists of ballast made from round fuel elements. This is surrounded by a cylindrical graphite structure which serves as a blanket. The round fuel elements, which have a diameter of 60mm, are made of graphite, in which the fuel, in the form of many small, coated particles, in embedded. The fuel is charged continually during use. The noble gas helium is used as a coolant, which, on passing the ballast, is heated to a temperature of 700 to 950^{o}C. Each component of the primary helium circulation is enclosed in a reactor pressure vessel. The high temperature reactor is a universally deployable energy source which can provide heat at very high temperatures of up to 950^{o}C. In addition to producing electricity, this type of reactor can also be deployed in the production of process heat, as is necessary in the gasification of coal, for example. Illustration 5.4 shows this technical concept.

5.1.3 Fast reactor

The fast reactor, also known as the ‘fast breeder’, is a nuclear reactor whose chain reaction is maintained by fast neutrons, and which produces more fissionable material than it uses. By means of neutron capture and two following beta decays, the fertile material U-238 is converted to the fissile material Pu-239. Nuclear fission occurs almost exclusively with fast neutrons, with the aim of obtaining a high breeder effect. Water is not a suitable coolant due to its braking effect, as the neutrons should be slowed down as little as possible. For technical reasons, sodium, which is liquid at temperatures above 98 ^{o}C, is particularly well suited. Fast breeders are up to 60 times more effective than light water reactors, as far as uranium exploitation is concerned. Figure 5.4 shows this and the previously discussed technical concepts.



water cooled reactor **high temperature reactor** **fast reactor**

Figure 5.4: Comparison of the basic concepts of the different reactor types water cooled reactor, high temperature reactor and fast reactor. Source: Spiegel Spezial (1/2007).

5.2 The sustainability of reactor types

From a long-term, strategic point of view, the problem with the water cooled and high temperature reactors described above is that they will exhaust a limited resource, namely uranium, in a foreseeable length of time. This also currently applies to crude oil and natural gas. Long-term, strategic considerations must, hence, disregard this technology as unsustainable. In accordance with the historical technological development, the related reactor concepts are referred to as ‘Generation 1’ to ‘Generation 3’.

The term ‘Generation 4’ reactor is often used in the course of the development of innovative reactor concepts. The campaign ‘Generation 4’ was launched by the US Department of Energy in 2000 and institutionalised in the organisation ‘Generation 4 International Forum (GIF)’. This initiative is supported by ten countries, as well as by EURATOM. The aim of this initiative is to develop sustainable reactors which will be fully functional by 2030. The goals of Generation 4 are subdivided into four categories, namely:

- sustainability;
- economic viability;
- safety and reliability;
- obstacles to proliferation and physical protection.

Experts from the GIF have defined six reactor concepts which should be studied in future. The chances of actually realising these six concepts have been rated differently, although the GIF has never claimed that all concepts must be realised. Roughly characterised, the following approaches are important:

1. Gas-cooled Fast Reactor (GFR)
2. Lead-cooled Fast Reactor (LFR)
3. Molten Salt Reactor (MSR)
4. Supercritical Water-cooled Reactor (SCWR)
5. Sodium-cooled Fast Reactor (SFR)
6. Very High Temperature Reactor (VHTR)

The strategic approach of the initiative is demonstrated by the very choice of reactor concepts. It is fast reactors, thus breeder reactors, which are seen as a way of approaching the problem of fuel shortages. It is also a question of coming closer to a hydrogen concept (high temperature approach), through which the fuel, hydrogen, could be produced directly in the reactor.

The discussion around Generation 4 has yet to produce any conclusive or convincing approaches to solving the problems which accompany the non-military use of nuclear power: the established risk of accidents; the susceptibility in the event of war or terrorist attacks; and the unsolved problem of permanently disposing of nuclear waste.

6. Technological diffusion and plants currently in operation

Not least due to extensive media coverage and the controversial discussion surrounding it, non-military nuclear power gives the impression of being a quantitatively significant global energy source. This section has two aims: to give an objective analysis of the actual significance of this technology; and to work out the critical parameters of the technology which will limit its possible future contribution to global energy production.

6.1 The *status quo* in technological diffusion

Figure 6.1 shows the global diffusion of power reactors used to produce electricity. The bars indicate the number of reactors in operation in each year, while the line through them shows the installed electrical output of these plants.

The number of reactors increased continually, from the beginnings of technological diffusion (in the 1950s) to the first years of the 1970s. Between the 1970s and the trend reversal in 1988, a surge in the intensification is to be observed. From this trend reversal, which was brought about by many factors, up to the present day, there has been only a very limited further increase in the number of plants and in the installed electrical output.

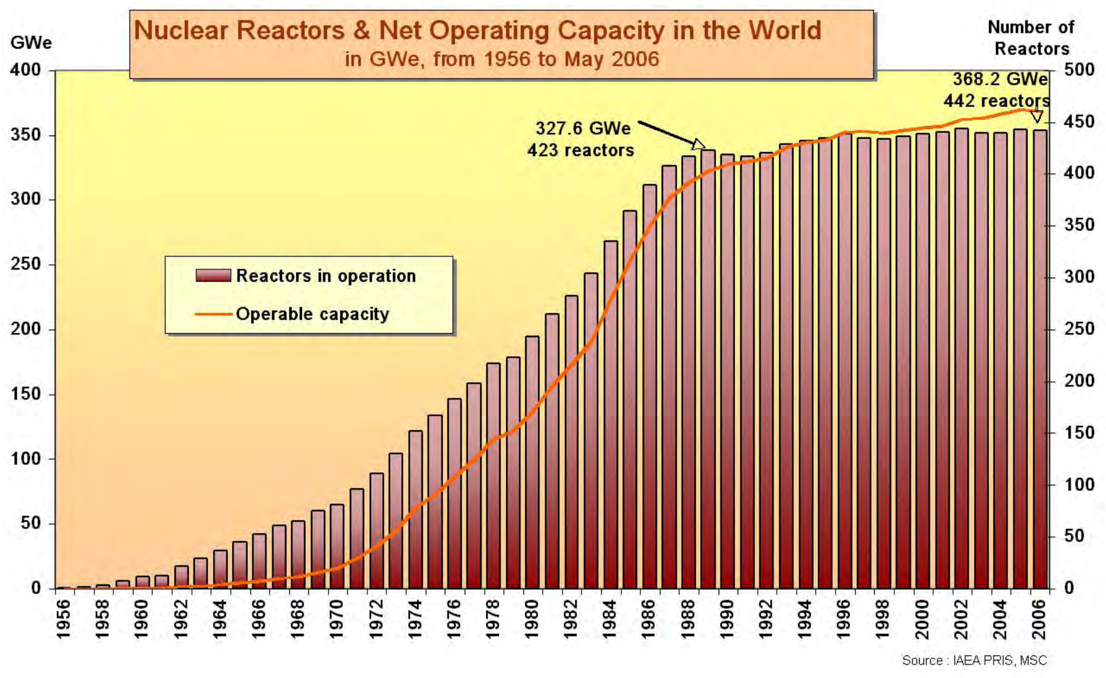


Figure 6.1: Diffusion of nuclear power reactors and installed capacity from the year 1956 on. Source: Mycle Schneider 2006.

The increase in diffusion in the 1970s and early 1980s can be mainly attributed to the periods of high energy costs. The follow-up time after these periods is also to be ascribed to the very long interludes which occur between the decision to invest in a nuclear power plant and the plant's activation. The trend reversal in the diffusion of nuclear power stations was caused by the Chernobyl catastrophe,[3] constantly decreasing energy prices, and the restructuring (liberalisation) of the electricity markets, which was slowly taking place. It was, above all, the alterations to, and privatisation of, the electricity markets which stabilised the trend reversal, as nuclear technology was not, and is not, attractive for private investors, due to the large investments required and the high risk.

Due to the course of diffusion, which was displayed in Figure 6.1, there is an inhomogeneous age distribution among the power reactors which are in operation today. Figure 6.2 shows the actual age distribution of the reactors. In 2006, reactors had a mean age of 22 years (in 2008, if the distribution remains the same, the mean age will be 24), and most are older than 16 years. 43 plants have come on stream in the last decade (1996-2006), which means that an average of 4.3 plants worldwide has come on stream each year.

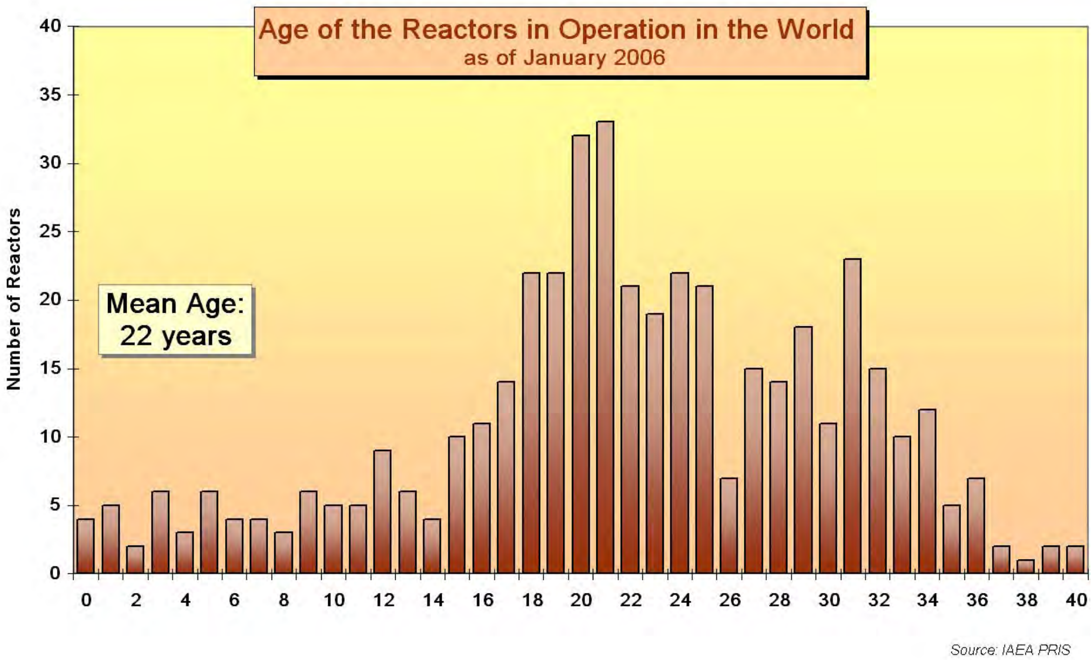


Figure 6.2: Actual age distribution of the reactors in operation 2006. Source: Schneider (2006).

From a strategic (medium-term and long-term) point of view it should be noted that, given the current age distribution, many plants will reach the end of their maximum operational life span in the next ten to 30 years. It is possible, even, that as a result of future development, the majority of plants will reach the end of this life span. From an economic point of view, it is particularly attractive to operate old plants which have already been decommissioned, although the risk increases. This has become a contentious matter, which even today can

[3] See also: Appendix A

be seen in the discussion around the extension of the operational periods of plants. Next to the economic interest of plant operators, who wish to enjoy a very profitable operational phase after the plant has reached the end of its life span, in the medium and long term we can also expect increased political pressure, due to the reduction of energy production. All these factors represent inducements to extending the life span of plants, which can result in increased safety-related problems.

Figure 6.3 shows the current distribution of plants in operation, plants under construction, and plants in planning. We can see the inhomogeneous global distribution, on the one hand, of plants currently in operation, and, on the other hand, of plants currently under construction or in planning. In Western Europe, there are currently 130 plants in operation. Conversely, only two plants are under construction (Finland and France), and one more is in planning. This situation and the prospects for the future will lead, at least in the medium term, to technological equipment which is steadily aging, and could result in the abandonment of the technology.

The situation is Eastern Europe is similar, with the exception that, in the medium term, 14 nuclear power plants are in planning. Currently, 66 plants are in operation and 4 under construction, mainly in Russia, Ukraine, and the Czech Republic. Most of the plants in planning will be built in Russia or Ukraine.

The conditions in North and South America are similar to those in Western Europe. South Africa is the only African country to possess nuclear power plants. The situation is somewhat different in Asia. 100 plants are currently in operation, 19 under construction, and 43 in planning. Most of the operational plants are located in Japan, South Korea, India and China; most of those under construction in China and India; and most of those in planning will be built in China, Japan and South Korea.

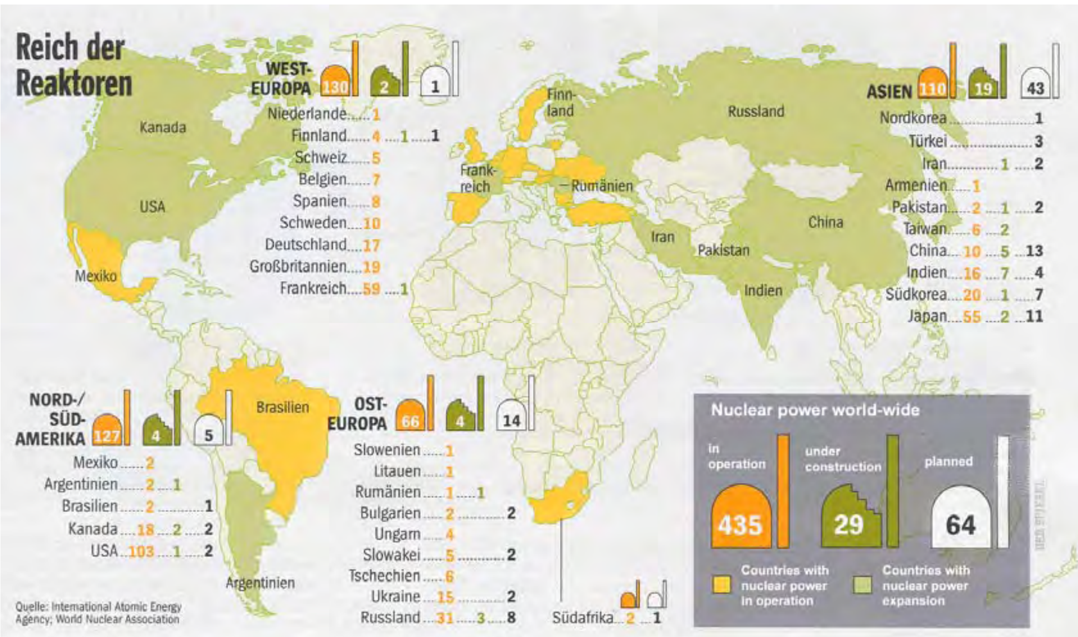


Figure 6.3: Nuclear power plants world wide. Source: Data from International Atomic Energy Agency (IAEA) and World Nuclear Association. Figure: Spiegel Spezial 1/2007.

In a nutshell, the statistics show that, in 2006, 435 plants worldwide were in operation, 29 under construction, and 64 further plants were in the planning stages. Taking the normal construction periods into account, the distribution shown encourages the assumption that it will be possible to continue the current construction trend of four to five new plants worldwide each year over a considerable period of time. A change in the trend visible in Illustrations 6.1 and 6.2 should not, however, on the grounds of current development, be expected in the foreseeable future.

Figure 6.4 shows the historical development of the installed electrical output of nuclear power stations in the four world regions: North America, Eastern Europe and the CIS, OECD nations, as well as Asia. With the exception of Asia, the diffusion curves demonstrate the above mentioned course with a noticeable trend reversal starting around 1988. It is only in Asia, where the growth of installed nuclear power output can still be seen, that the development has taken a different course.

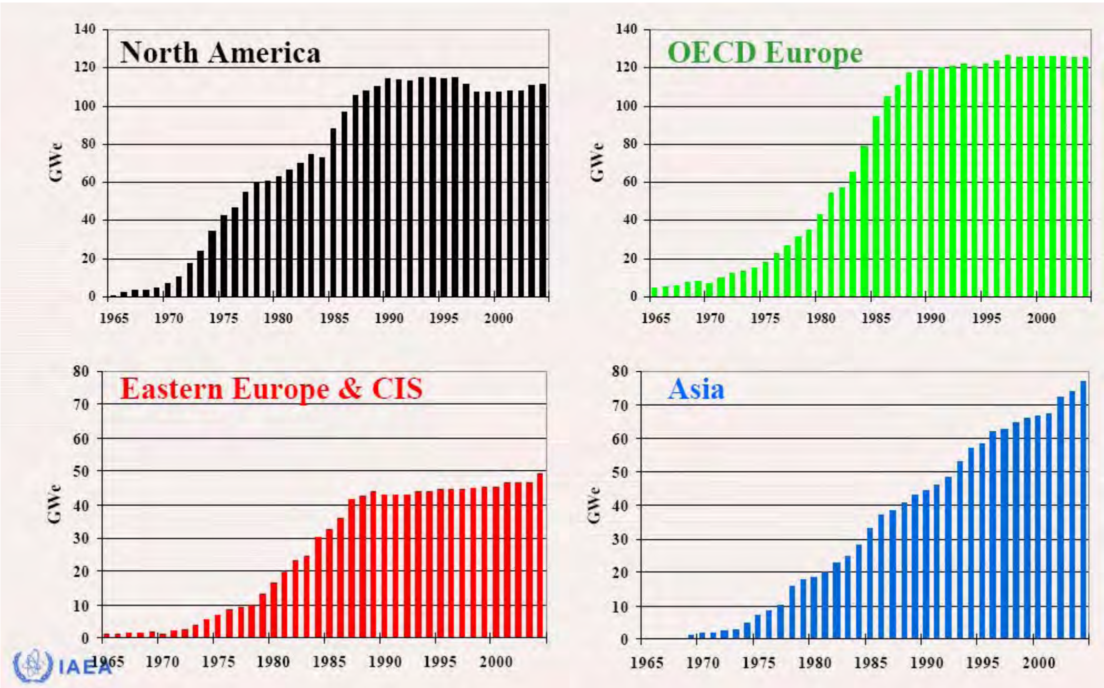


Figure 6.4: Development of the installed nuclear power plant capacity in the four world regions. Attention, scales differ. Source: IAEA, Rogner (2007).

Figure 6.5 shows a breakdown of global electricity production in 2007. Pro-rata, with a share of just over 41%, coal is the world's leading producer of electricity. Both brown and hard coal are included. The illustration shows the amount of energy produced. If the primary energy required were factored into the illustration, it would significantly increase the dominance of coal, due to the difference in efficiency between the various types of power station. Natural gas is the second strongest sector, with a share of approximately 21%, followed by hydroelectricity (around 16%), and finally electricity produced by nuclear power, with a share of just under 14%. Oil and renewable energies (excluding large-scale hydropower) are further, considerably smaller sectors.

During a later discussion regarding the reduction of CO_2 emissions through nuclear power, the question will arise as to which fuels at which levels of power station efficiency should be replaced by nuclear power at the particular time.

Global electricity production in 2007: 19,771 TWh

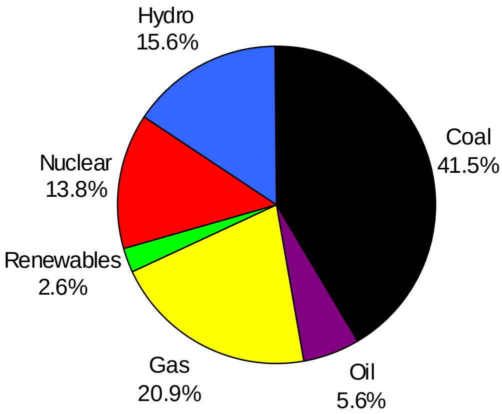


Figure 6.5: Global electricity production in 2007. Source: IEA (2009).

6.2 The future diffusion of nuclear power

We have already documented, in Section 6.1, the statistics relating to nuclear power plants currently under construction around the world, and those which are still in the planning stages. According to Figure 6.1, there are currently 29 reactors in construction worldwide, while 64 further reactors are under consideration. It is likely that the plants currently being constructed will be finished and put into operation, but uncertain whether those still in planning will be realised.

Figure 6.2 showed the age distribution of the reactors currently in operation. The IAEA and reactor manufacturers like to give reactors a life span of between 40 and 60 years, as this operational period is of crucial importance when considering economic viability (depending on the calculation method). The actual life expectancy of nuclear power plants diverges considerably from this unrealistic notion. Illustration 6.6 shows the actual age at which the nuclear power stations, which have already been decommissioned, were finally taken out of operation. By 2006, 110 nuclear power plants had been taken out of operation for good. The average age on being taken off stream was 21 years. The current reality is hence far from the proclamations of various supporters of nuclear power. In future, the average life span may well extend, especially as numerous incentives to lengthening this are offered. Plant operators have an economic interest in using the plants for as long as is possible, politicians must think about meeting demand for energy, which is growing swiftly, and the atomic industry sees an increase in life spans, and the accompanying necessary investment, as an economic way out in collapsing markets such as Western Europe.

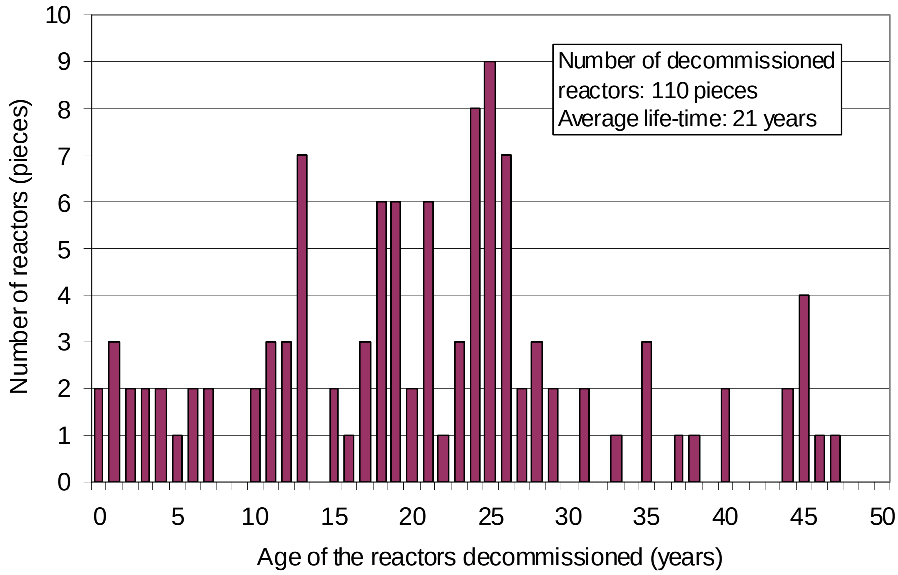


Figure 6.6: Distribution of the age of the reactors decommissioned until 2006. Source: Schneider (2006), EEG (2007).

Even if the life spans of all suitable plants can be extended considerably, all plants currently under construction come into operation as planned, and construction starts on all planned plants in the foreseeable future, the next decades will see a considerable decrease in the number of plants in operation, due to the current age distribution of these plants. This will be particularly due to the fact that the construction of new plants is, in practice, subject to lead times lasting many years. Particularly in countries with democratic legal systems, lengthy internal procedures are followed by discussions as to the location. Conclusive positive decisions are required for concrete plans and, finally, the negotiation of tenders with respective contractors. This process takes years or decades, and eventually leads to the initiation of construction. It can again be years or decades before the plant is finally put into operation. Construction of specific plants can often take between ten and 20 years.

Some historic and current examples:

<u>Zwentendorf Nuclear Power Plant (Austria)</u>

A construction period of 14 years passed between the decision to start building the nuclear power plant in Zwentendorf in 1971, and the resolution to liquidate the still unfinished power plant in 1985. During this time, the project cost 14 billion Schillings in total, of which 600 million were dedicated to preservation. Even without political problems, the planned activation of the plant in August 1976 (i.e. after a planned construction period of five years) would have been completely unrealistic.[4]

[4] Appendix C includes a detailed discussion of the Zwentendorf project.

Temelin Nuclear Power Plant (Czech Republic)

According to the original plans, the first reactor block of the plant in Temelin should, after construction was begun in the mid-1980s, have already gone on stream in 1987. In 1993, it was estimated that Reactor 1 would be finished by 1995; later, 1997 was given as the date of completion. In the autumn of 1996, it was envisaged that the plant would go on stream at the end of 1999. The last governmental examination of the reasonableness of the project took place in 1998. An independent group of experts was supposed to re-evaluate the pros and cons of the project. Although the report, which was submitted in 1999, did not definitively suggest putting an end to construction, it did highlight numerous economic risks, as well as the reduction in energy use in the Czech Republic. As far as the operating company, CEZ, could see, there were two options: they could either take the Temelin plant into operation … or 'inflict a loss of nearly 100 billion Koruna on society, which, in all likelihood, would have caused the collapse of CEZ.'[5] On the 12th May 1999, the government of Miloš Zeman decided to complete the construction of the plant. **After 13 years' construction**, block 1 of the controversial Temelin power plant was activated for the first time on the 9th October 2000.

Olkiluoto Nuclear Power Plant (Finland)

The foundation stone of the Olkiluoto 3 reactor, which has an output of 1600MW, was laid on the 12th September 2005. Finland bought the ready-made atomic pile from AREVA/Siemens for a fixed price of €3 billion, whereby it was agreed that completion would happen in 2009. However, **after 16 months' construction, there was already a predicted delay of one and a half years**. The Bayrische Landesbank, half of which is owned by the Free State of Bavaria and half by the Sparkassenverband (Association of Savings Banks), is financing this power plant, which is the largest in the world, by means of a loan worth €1.95 billion at an interest rate of 2.6%. The fixed price itself has already proven to be a strategic dumping price, as a further order made by Finland under the same conditions was no longer possible.

Bushehr Nuclear Power Plant (Iran)

Iran has announced the construction of two further atomic power stations.[6] The plants will be built in Bushehr, where Russian engineers are currently constructing the country's first nuclear power station. According to statements, the two new plants should have an output of 1,000 and 1,600 MW respectively. They will cost between $1.4 and $1.7 billion each. **It has been estimated that construction will take between nine and 11 years**. The plant which has already been built in Bushehr with Russian help was originally intended to go on stream in September. Due to discrepancies in the payment, however, it is anticipated that a delay will occur.

[5] CEZ Homepage; http://www.cez.cz/en/home.html
[6] http://news.orf.at/, 11th December 2007

Angra 3 Nuclear Power Plant (Brazil)

After a 21-year standstill, Brazil now wants to complete construction of the controversial Angra 3 plant, with German help.[7] The plant is controversial due to nearby areas of natural beauty, and because experts have said that the area is prone to earthquakes and landslides, and has bad ground conditions. **The plant is supposed to go on stream in 2013** and have an output of 1350MW. Angra 3 will be constructed by the company Framatome, in which both Siemens and Areva have shares. According to official figures, around €2.9 billion have been earmarked for the completion of the project. Construction began in 1984 and was suspended two years later. The project is part of the 1975 nuclear agreement between the then Federal Government in Bonn and the former military dictatorship in Brazil. The Angra 2 plant, which has an output of 1275MW and was built with German assistance (Siemens/KWU), went on stream in 2000 **after 25 years' construction**. Angra 1, which has an output of 626MW, was built by the USA (Westinghouse). In 2004, the German-Brazilian Nuclear Agreement was extended for five more years.

Effects on the future use of nuclear power

If we look at the situation realistically, we should not assume that all plants which are currently under construction, or even in planning, will actually go into operation. Of the 29 plants which are currently under construction, a third, i.e. nine plants, has already been 'under construction' according to the statistics for between 18 and 30 years.[8] In practice, therefore, we are talking about abandoned construction sites, and we cannot assume that these plants will go on stream in the foreseeable future.

EIA (2007) is one of the documents showing a prognosis of the development of nuclear power up to 2030. Figure 6.7 shows the results for OECD Europe. Nuclear power will see a reduction by 2030, both in terms of absolute values, and even more so if we look at the percentages. There will be a considerable increase in total electricity use, and natural gas and renewable energy sources will increasingly make up the shortfall. Coal will also be substituted by natural gas.

[7] http://www.tagesspiegel.de/politik/international/Umwelt-Energie-Atomkraft;art123,2328680, 11th December 2007
[8] Schneider (2006b)

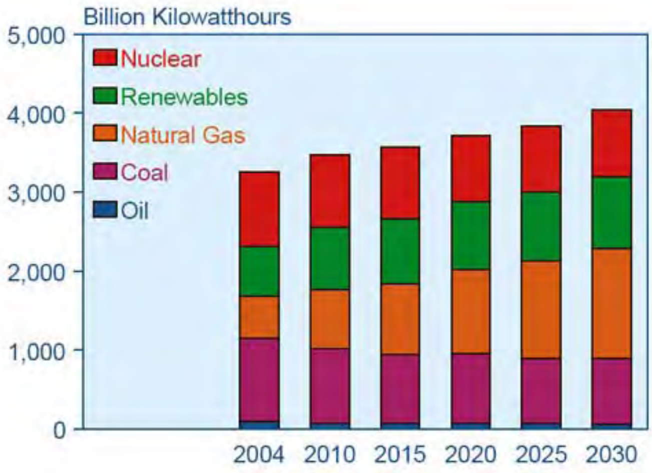


Figure 6.7: Forecast of the net electricity production in OECD-Europe from 2004 to 2030. Source: EIA (2007).

The above representation for OECD Europe is compatible with the extrapolation of the historic development of installed electrical output of nuclear power stations, which can be seen in Figure 6.8. This is also applies to the other regions of the world.

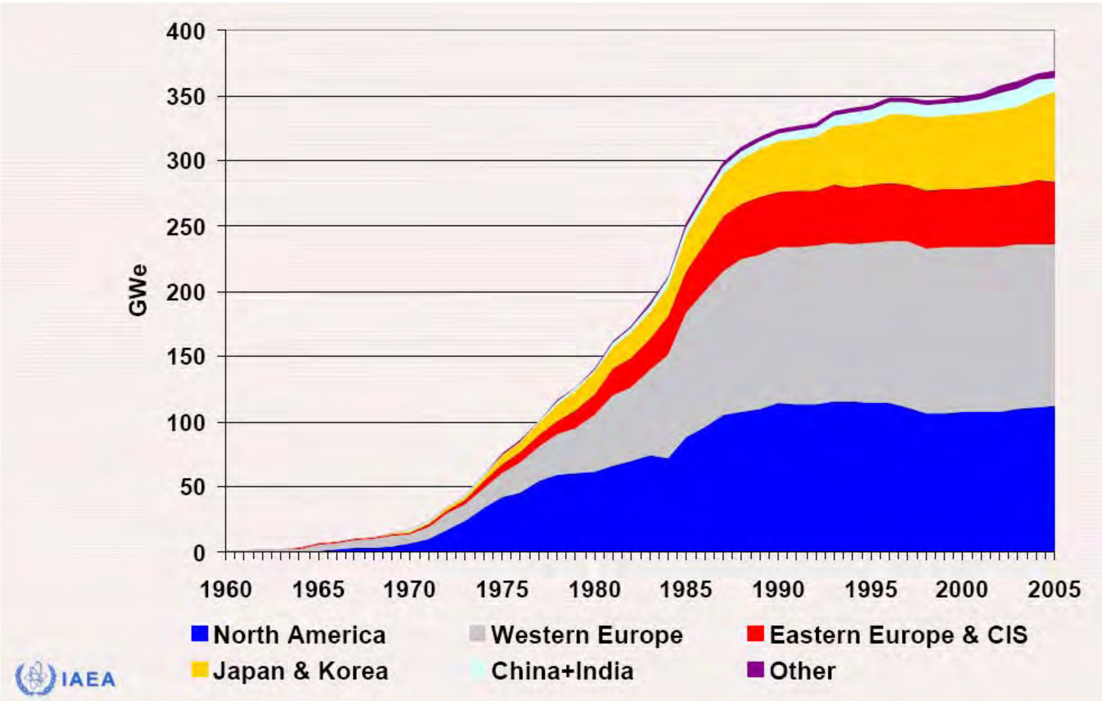


Figure 6.8: Development of the global installed electric power plant capacity. Source: IAEA, Rogner (2007).

6.3 Summary: Technological diffusion and plants currently in operation

Currently, 16% of the world's electricity is produced by nuclear power. This electricity is produced in 435 plants with an average age of 22 years. Between 1970 and the mid-1980s, there was a sharp upturn in the diffusion of nuclear technology, which collapsed around 1988. Decisive for this collapse were the changing economic parameters (liberalisation of the energy market, re-evaluation of the enormous capital expenditure, unbearable construction times, and burgeoning building costs) and the Chernobyl catastrophe in 1986. Most of the plants currently in operation are located in the USA (103), France (59), Japan (55), and Russia (31). The remaining plants are spread across 30 nations. Worldwide, there are currently 29 plants under construction; however, progress is being made in the construction of only 20 of these. At present, 4 plants worldwide are completed each year.

Due to the high average age of the plants currently in use and the low building rate, the next few decades will see a premature decrease in the number of functioning plants, as those in operation reach their maximum age. Even if there is an increased number of new projects, this effect will not be hindered, as plants have long lead times (up to ten years) and construction times (on average at least ten years). Representatives of the atomic industry assess plant life spans at between 40 and 60 years. In reality, however, the average age of the 110 plants which have, up to now, been permanently taken out of operation, was 21 years. Nevertheless, there is a definite trend towards extending the life spans of plants, as operators want to make the most of the profitable operation of plants which have been written off, and politicians are under increasing pressure with regard to meeting rising demands for electricity.

If we look to the future by extrapolating the historical course or by using a model showing the number of plants in operation, the number of plants will sink in the coming decades, while the production of energy from nuclear power will, at best, remain at the current level. This is because new plants have a considerably larger output than earlier ones. In any case, the diffusion process is characterised by a great tardiness (long time constants), which leads to the conclusion that this technology is not designed to solve the dynamic problems of the global energy system.

7. The economic viability of nuclear power plants

7.1 Introduction and case studies

If we disregard the hidden motivation for the use of nuclear power – such as the production of weapons-grade fissile material, the enhancement of prestige, or demonstrations of national power – which in reality is often decisive, then in today's economic world (ignoring all societal risks), and in the energy industry in particular, economic calculations alone would decide on the construction of new nuclear power plants.

It is here necessary to differentiate between two cases. The continued operation, or the extension of the operating period of a nuclear power plant, which for some time has been reliably producing electricity, can be very attractive from an economic point of view. This is because fuel expenditure accounts only for a small percentage of the total capital costs. It is thus clear that the operators of nuclear power plants want to make the most of this very profitable operational period, even if reinvestments are necessary. The rising technical risk, which results from the continued operation of ageing plants is not, as a rule, assessed monetarily, especially as it is not the operating company, but rather society in general which carries this risk.

The second case relates to the construction of new nuclear power plants. In this case, potential investors are confronted with the enormous investment sums involved in such a venture, as well as with the full financial construction risk (e.g. the dramatic overruns in terms of both construction costs and periods). No nuclear power plant would be built today solely on the basis of considerations related to the energy industry, without the influence of other factors such as the above cited strategic and military aspects, or the special conditions which result from the atomic industry's strategic interests (cross-subsidisation through dumping, special loan conditions, passing on the risks of the use of nuclear power on to society).

The conditions in the USA are a good example of this. On the whole, the American energy industry is subject to market-based ancillary conditions. No new orders have been placed with American reactor constructors since 1973, which have not subsequently been cancelled. The last nuclear power station, ordered in 1973, went on stream after 20 years' construction. As early as 2005, President Bush decided to promote the renewed development of nuclear power. According to Bush's vision, the companies constructing the first four new nuclear power stations would be insured, for millions of dollars, against delays occurring during the approval process. In addition, state credit guarantees for the atomic industry were implemented. As even such incentives could not bring any investors to the plan, it seems that investing in nuclear power plants in the USA makes no economic sense.

It was 25 years before the atomic industry received a commission for a new project outside France. This was the case with the Olkiluoto project in Finland in 2004, a strategic project and indication of the continued existence of the atomic industry, which is only being carried out thanks to a whole assortment of special conditions. Finland bought the ready-made atomic pile from AREVA/Siemens for a fixed price of €3 billion, whereby it was agreed that completion would happen in 2009. However, after 16 months' construction, there was already a predicted delay of one and a half years. The Bayrische Landesbank, half of which is owned by the Free State of Bavaria and half by the Sparkassenverband (Association of Savings Banks), is financing this power plant, which is the largest in the world, by means of a loan worth €1.95 billion at an interest rate of 2.6%. The fixed price itself has already proven to be a strategic dumping price, as a Finnish further order under the same conditions was no longer possible.

Economies with the highest growth rates, such as China, are of particular interest. In China, a new coal-powered power plant park with an output of 160GW was constructed between 2002 and 2005 to provide for the astounding rise in electricity consumption. By comparison, since 2000 the world's installed power station output has risen by approximately 150GW p.a. Nuclear energy represents only 2% of this worldwide growth (i.e. around 3GW). Even wind power, which at the time was only just starting to burgeon, contributed five times more to this growth, with a newly installed output of 15GW in 2006.[9] Although nuclear power plays a proportionally minor role in the supply of electricity in China (10 plants are in operation, 5 under construction and 13 in planning), China is cultivating this technology. In this case, the total contribution to meeting demand for energy is obviously meaningless, as is the economic viability of the plants; a much larger number of plants would need to be built for them to be competitive. China obviously has a strategic interest in not losing track of this technology, and also needs a certain nuclear infrastructure to produce weapons-grade fissile material.

7.2 The costs of using nuclear power

Figure 7.1 shows the various areas of expenditure linked to the use of nuclear power. Investment costs, which are determined by the high plant-specific and safety-related expenditure, make up about 60% of the total costs. Literature roughly portrays these costs as 2/3 of the total. Further cost centres include fuel (c. 20%) and operational and maintenance costs (c. 20%). Some cost centres, such as the permanent disposal of burnt out fuel rods, can only be calculated with difficulty, as the costs are unknown, and the necessary infrastructure does not yet exist.

Practical experience has often shown that, in the past, the estimated construction costs increased significantly during construction. The most important elements of uncertainty, which can derail construction costs, are:

- capital expenditure: this largest item of expenditure is the result of the repayment of loans. Changes on the equity market and/or changes in exchange rates can, depending on the relevant contracts, cause dramatic price increases.

[9] GWEC (2006)

- decommissioning costs: these costs should not be underestimated, yet, because of the long-term nature of the project, they are very difficult to estimate, especially as the actual technical, legal or political ancillary conditions cannot be known 40 to 60 years in advance.
- costs of maintenance and repair or servicing e.g. of the special safety equipment: the Chernobyl catastrophe initiated a phase, which was not foreseeable, during which plants were refitted with safety-related equipment. Should there be a further dramatic accident which did not result in the immediate general abandonment of nuclear energy, further incalculable costs would be incurred.
- fuel costs: although this cost centre is the most calculable of all, a certain uncertainty must be allowed for, given the long-term nature of the project. The demand for relevant fuels can, on the aforementioned grounds, be calculated over a period of decades, and fuel resources are guaranteed at least for longer than the operational period of a plant.

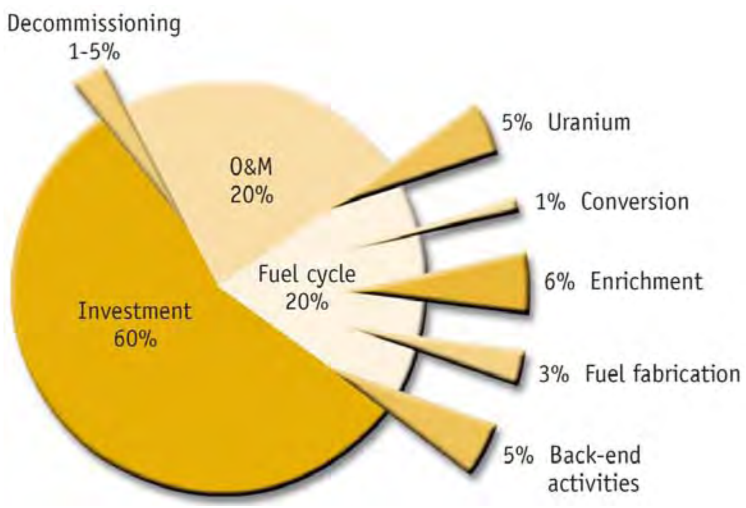


Figure 7.1: Distribution of the nuclear power costs. Source: Rogner (2007).

Historically, the high investment costs of nuclear power have not inhibited the diffusion of the technology in energy industries which are controlled by a state monopoly. Governments have invested these tremendous sums regardless of whether the population was in favour, and taxpayers have borne the decisions along with the economic costs. Ever since the energy markets were liberalised, private companies have suddenly found themselves confronted with the enormous investments necessary and with at least a part of the financial risk. Because of this, it has been a considerable time since a new nuclear power station was built in Western economies. New nuclear power stations cannot compete against other types of power station, due to the high capital costs and risk. The situation is of course different with respect to old plants which have already been written off. The operators of such plants have no capital costs to worry about, and can make large profits during the extended operational period.

Figure 7.2 shows the differing cost structures of nuclear, coal and gas power stations. It is evident that nuclear power stations have by far the largest proportion of capital costs. There is a correlation between capital costs and construction duration, which means that, comparatively, nuclear power stations take the longest to build. Conversely, coal power stations are characterised by proportionally low capital costs and quick construction. There is greater security of investment with gas power stations, despite the use of natural gas, which most countries have to import. This is because an amortisation is given within a short period of time, and because the risk linked to gas supplies is manageable beyond this short period. The short construction periods of gas power stations also answers the demands of a liberalised energy market, and the dynamic increase in use. In addition, gas power stations also have many advantages, from the point of view of operational management, part load behaviour, and possible dynamics in terms of the supply system as a whole, which nuclear power stations cannot offer.

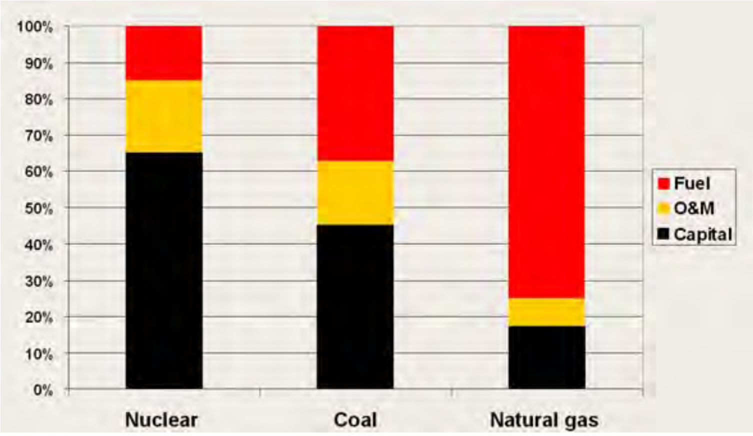


Figure 7.2: Comparison of the cost structures of different power plant types. Source: Rogner (2007).

Figure 7.3 shows the historical development of the specific construction costs of nuclear power stations, by means of the actual costs. The construction costs are shown relative to the installed electrical output of each plant. This makes the results even more interesting, because over the course of time, reactors have been produced with ever larger output capabilities, as a result of which economies of scale should have arisen in the specific costs. In reality, however, the opposite is true. Construction costs have constantly increased over the time period at hand.

The reasons for the price rises lie in the further development of reactor concepts, in the increased expenditure on safety-related equipment, and in the declining number of plants. Over time, there has been a significant drop in the number of plants commissioned annually (see previous sections), which has made the development of large-scale production impossible. The small quantity of plants commissioned in recent years has rendered efficient production lines, as well as the standardisation of individual components or even whole nuclear power plants, impossible. Nuclear power plants have increasingly become one-of-a-kind constructions, and as a result are extremely expensive.

The above mechanisms are just as effective for construction purposes, and the bottom line is that the length of construction decisively affects the construction costs. Due to the slow diffusion of nuclear technology, it should not be assumed that the specific cost tendencies will change quickly in the future.

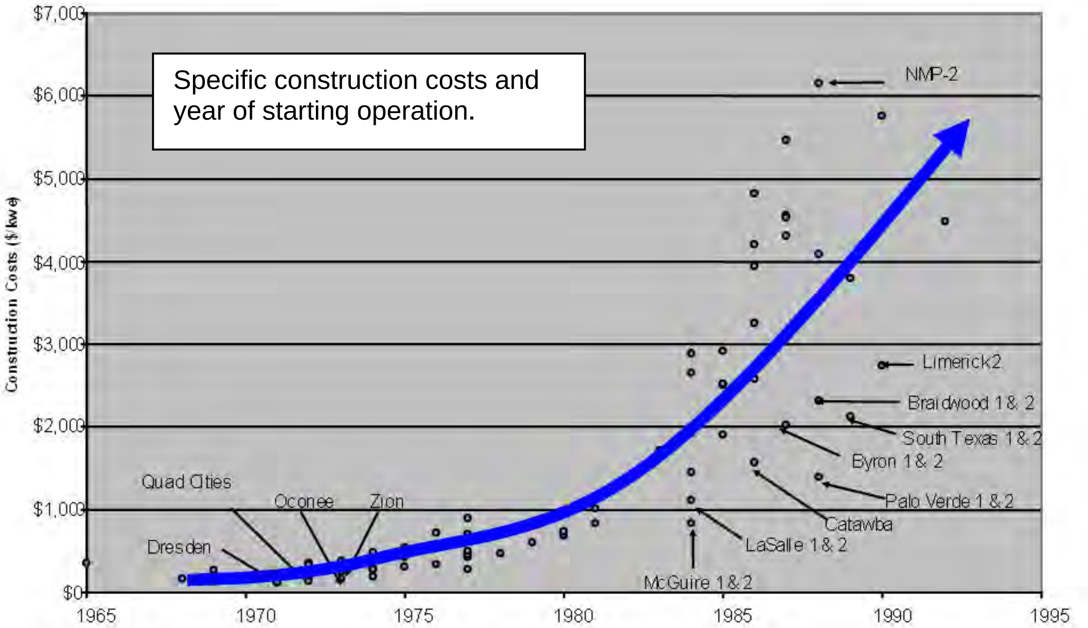


Figure 7.3: Specific construction costs of nuclear power plants and year of starting operation. Source: Harding (2007).

Even in the case of the Finnish nuclear power plant project, Olkiluoto, which has been made possible by unusually attractive economic ancillary conditions (strategic subsidisation from the industry and the capital market, see above), at commissioning, the statistical specific construction costs had been calculated at around US$2751/kW.[10] As Steve Thomas (2006) describes, the data for the actual construction costs of nuclear power plants are difficult to research, and only in the rarest cases can there be talk of verified, officially confirmed and traceable data. The most reliable data are those relating to US nuclear power plants. This is because the verified costs must be presented to the authorities if the according investments are to be passed on to the electricity bill. In most other cases it should be assumed that the published cost data are serving a strategic hidden agenda. Table 7.1 compares the costs of US nuclear power stations which were estimated before construction was begun, with the actual costs incurred after building had been completed.

Table 7.1 makes clear that the minimal overrun on construction costs was more than 100% (!), i.e. nuclear power stations constructed in the given

[10] Olkiluoto Nuclear Power Plant: 1600MW, € 3 billion, € 1875/kW; Dollar/Euro exchange rate on 12th December 2007: 1.4672 US$/ €, i.e. 2751 US$/kW

period cost, at best, double the estimated costs. In the worst period, there was an overrun of 381%, which means that the nuclear power stations cost almost four times more than was estimated before construction began.

Table elle 7.1: Difference between the estimated specific construction costs and the actual specific construction costs of nuclear power plants in the US. Source: Gielecki (1994).

Construction periode	estimated construction costs	actual construction costs	actual construction costs in % of estimated costs
1966-1967	$560/kW	$1170/kW	209%
1968-1969	$679/kW	$2000/kW	294%
1970-1971	$760/kW	$2650/kW	348%
1972-1973	$1117/kW	$3555/kW	318%
1974-1975	$1156/kW	$4410/kW	381%
1976-1977	$1493/kW	$4008/kW	269%

The period between the political decision to build a nuclear power station, and the actual commercial supply of electricity, is significantly longer than the construction period itself. In the lead time before construction can begin, lengthy public procedures regarding the location of the plant must be conducted. These procedures result in additional costs, which are, as a rule, borne by the public, and do not feature in the previously named construction costs.

The costs of the risk of using nuclear power (see Accidents in Nuclear Power Plants, Appendix A) cannot be insured. An international agreement[11] limits the liability of nuclear power plant operators to sums which would not cover the damages caused by a serious reactor accident. It was this limitation of liability which allowed non-military use of nuclear power to develop, and represents a large state subsidy for the atomic industry.

It is hardly possible to estimate the costs of decommissioning nuclear power plants, as we do not have enough experience. Additionally, the future legal ancillary conditions of decommissioning and decontaminating nuclear power plants are not yet known. If reserves for the decommissioning of a plant are put aside from the moment the plant goes into operation, then this cost item will only have a minor effect on the economic viability of the project as a whole. The decommissioning costs are only problematic if these costs were estimated too low from the very beginning, if internal reserves are liquidated, or if the plant operator declares insolvency before the plant has reached its minimum lifespan. In these cases, it is again the public who will bear the related costs.

The costs of permanently disposing of nuclear waste (burned out fuel rods or waste from the decommissioning) are unknown today, especially as there is no final storage site for non-military nuclear waste from nuclear power plants,

[11] 1963 Vienna Convention on Civil Liability for Nuclear Damage, amended in 1997

which means that no market price can be quoted. Also in this case possible reserves put aside by the plant operators are highly speculative, and it is uncertain if the costs incurred later will be covered.

7.3 A comparison of the costs of generating energy

When looking at figures given for the costs of generating nuclear electricity in various publications, one should be mindful of exactly which costs (see previous sections) have been taken into account. In many cases this is neither clear nor comprehensible. Cost factors are a further problem, as has been shown in Section 7.2. In principle, the costs of generating electricity in a nuclear power station can only be given after the whole power station has been decommissioned and decontaminated, and nuclear waste has been disposed of. This uncertainty does not exist in relation to conventional power stations, as the costs of deconstruction and decontamination are known, and the risk is manageable. Bearing in mind the risk to society, only a lower threshold for the costs of energy production can be quoted. How much did it cost to produce electricity at Chernobyl before the 26th April 1986, and how much afterwards? Have these costs ever been calculated, and which electricity consumers covered the costs of producing electricity at Chernobyl?

If the uncertainties and externalities mentioned are ignored, the costs of producing electricity can be determined. Table 7.2 gives an overview of the range of the specific costs of producing electricity in different types of power plant.

Table 7.2: Range of the specific costs of producing electricity in different types of power plant (without external costs). Source: Fritsche (2007), calculations on basis of GEMIS, EEG (2007).

Kraftwerkstyp	electricity costs[1] in Eurocent/kWh_{el}	
	von	bis
new nuclear power plant (in Germany)	4,5	5,5
coal power plant (imported coal in Germany)	4,0	5,0
coal combined heat and power (imported coal in Germany)	2,5	3,5
natural gas (gas and steam turbine)	4,0	5,0
natural gas co-generation (gas and steam turbine)	3,5	4,5
natural gas small co-generation	7,0	8,0
biogas small co-generation	6,0	8,0
wind power onshore	8,0	9,0
wind power offshore	6,0	8,0
hydro power	5,0	10,0
Photovoltaic	30,0	50,0
efficiency measures for the reduction of electricity consumption	3,0	6,0

[1] interest rate for the calculation in general = real 7%

As can be seen in Table 7.2, the costs of producing electricity in a nuclear power plant are on the same scale as those of producing electricity in a coal-powered plant or in a natural gas combined-cycle plant. Coal-powered combined heat and power stations and natural gas-powered combined-cycle heat and power stations are significantly cheaper. The sums given include the period from the construction of the plant.

Thomas (2005) has looked at the causes behind the varying information regarding energy production costs in nuclear power stations quoted in ten current studies. Table 7.3 compares the key assumptions and the core statements of this study. It is easy to see that all documented parameters vary considerably. This applies to the fundamental input variables, such as construction time, interest payable on capital, and the lifespan, as well as the results, such as the specific energy production or construction costs. The large differences in the decommissioning costs are very noticeable, as are the figures regarding the provisions made to cover these costs.

The results of the studies, all of which claim to be based on realistic assumptions in the scenarios calculated, quote energy production costs ranging from 1.81ct/kWh$_{el}$ to 9.06ct/kWh$_{el.}$ The mean value of all scenarios in the ten studies[12] is 4.9ct/kWh$_{el}$, in accordance with Fritsche's (2007) figures. However, the fluctuation range, from very low production costs to costs comparable with those of an onshore wind power plant, presents a problem.

A further current study by Hultman et al. (2007) investigates the electricity production costs of 99 US reactors. The findings are shown in Illustration 7.4, and display, on an empirical basis, large variations between the individual results. For the calculations, the interest due on the capital was estimated at a relatively low 6%. The lowest electricity production costs were around US$3.2 cent/kWh$_{el}$ (2004 basis), the highest around US$14.4 cent/kWh$_{el}$. The mean value for the electricity production costs of the 99 reactors investigated was US$6.0 cent/kWh$_{el}$. Even so, in 16% of the reactors the values are above US$8.0 cent/kWh$_{el}$, and in 5% they are above US$ 12.0cent/kWh$_{el}$. The authors noticed an increase in the capital and operational costs over the period, whereby improvements in efficiency and availability go hand in hand with these rising prices. The gradual increase in construction time is attributed to increasing safety-related requirements. The availability of reactors rose from 52.9% in 1982 to 87.4% in 2004.

12

Table 7.3: Costs of nuclear power – comparison of the results of different studies. Source: Thomas (2005), EEG (2007).

Study	construction costs (scenarios) (Euro[3]/kW$_{el}$)	construction periode (month)	capital costs (real)	power consumption (%)	operation and maintenance (ct/kWh)	fuel costs (ct/kWh)	planned operation periode (years)	plan for decommissioning	total electricity production costs (ct/kWh$_{el}$)
Sizewell B[1]	3.119 4.158	86	-	84	3,13	1,90	40	special funds und cash flow	9,06 ?
Rice University									7,55
Lappeenranta Univ.	1.802		5,0 %	91	1,36	0,54	60		2,42
Performance & Innovation Unit	1.155	-	8,0 % 8,0 % 15,0 %	>80			30 15 15		3,49 4,27 5,72
Scully Capital	693 832 - 970 1.109	60		90	1,51	0,76	40	393 million Euro savings over 40 years of operation	
Massachusetts Institute of Technology	1.540	60	11,5 %	85 75	2,27[2]	-	40 25		5,59 6,64
Royal Academy of Engineers	1.594	60	7,5 %	90	1,21	1,09	40	included in the construction costs	3,47
Chicago University	770 1.155 1.386	84	12,5 %	85	1,51	0,82	40	294 million Euro	4,38 5,13 5,89
Canadian Nuclear Association	1.478	72	10,0 %	90	1,33	0,68	30	funds 0,05ct/kWh	4,98
IEA/NEA	1.540 – 3.465	60–120	5,0 – 10,0 %	85	1,03 - 2,42	0,41 - 1,77	40	included in the construction costs	1,81-4,08 / 2,72 - 5,74
OXERA	2.252 first plant 1.594 later plants.			95	0,95	0,82	40	755 million Euro in funds after 40 years	

[1] The operation costs of Sizewell B correspond with the average of eight plants operated by British Energy.
[2] The operation and maintenance costs of the MIT-Study contain also the fuel costs.
[3] Exchange rates for the calculation (15.1.2007): 1 US$ = 0,77Euro; 1 Pfund = 1,51 Euro.

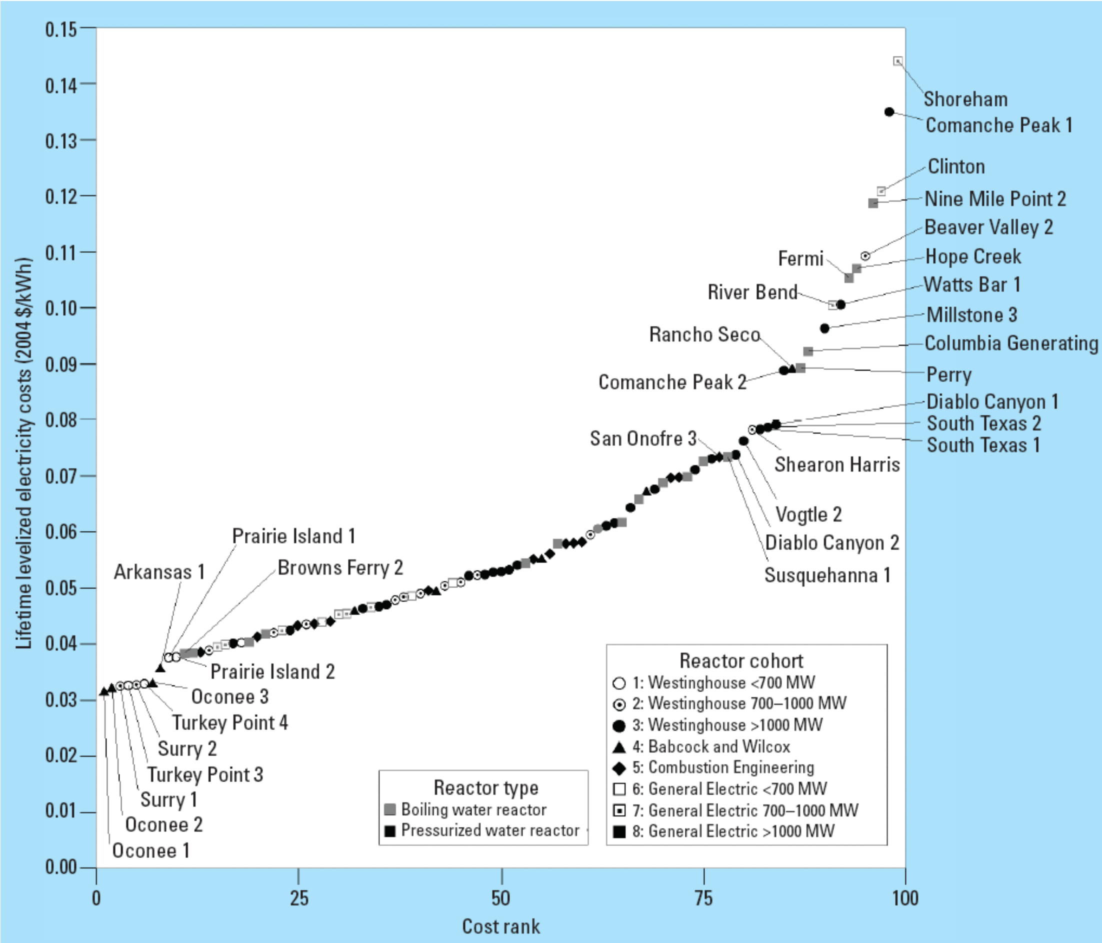


Figure 7.4: Distribution of the electricity production costs of 99 U.S. reactors. Source: Hultman et al. (2007).

7.4 Economic aspects of the use of nuclear power

When comparing the various technological options, the national economic effects of spending large amounts of public money should be of great relevance, at least for the politicians and economists concerned. Of interest are: the creation of value on a national scale; the creation of jobs in the country; social and structural effects (e.g. the effects of central vs. decentralised approaches); the acceptance or rejection of plans by the population; or the risk to society resulting from the use of nuclear power.

National value added:

The level of national value added is directly dependent on the extent of domestic vertical integration and provision of services. For countries, such as France, which manufacture nuclear power stations, the export or domestic installation of these, in view of the investments, is linked to a high national added value and a positive contribution to the foreign trade balance. As investments count for around 60% of the total costs of a nuclear power station (see Illustration 7.1), the related value added is very attractive for France. The situation is different for countries wishing to import this technology, but which have no atomic industry. In this case, the added value balance is negative, due to the investments. This is because it is a very specific technology, which only generates low added value through the creation of general jobs (e.g. in civil engineering).

The possibilities for creating national added value through further cost areas of the fuel cycle or the general operation should be distinguished from one another. The EU will always have to import fuel. The enrichment of fuel and the production of fuel rods can only happen in a few countries, such as France. Any politician or economist would gladly forego potential wealth creation from the temporary storage and final disposal of atomic waste, because this is such a controversial topic. The operation of a nuclear power plant creates wealth mainly from the sale of the electricity produced. This can be sold at home or exported.

The effects on the job market

Similar conditions exist regarding the job market as those regarding the national added value. Countries with an established atomic industry can point to jobs created by the construction and export of nuclear power plants. Countries which import nuclear power plants without having their own relevant industrial infrastructure can only create jobs through the operation of the plant. However, in the absence of any existing expertise, only a small number of jobs can be created, and the necessary human resources must also be purchased.

Social and structural effects

With a very large output of more than 1000MW (necessitated by economic considerations), a nuclear power station is a central system. It not only creates a geographical concentration of economic effects, but also represents a larger risk than localised systems in terms of supply guarantee.

Social risks

The risks to society are multidimensional, and, as a rule, are never converted into monetary values when assessing nuclear power stations. This is because the construction and operation of plants would not be possible if these aspects were taken into account.

The risks to society can be subdivided into the following categories:

- governmental guarantees associated with the construction of nuclear power stations: these guarantees should create incentives for investors. Depending on the composition of these guarantees, society takes on part of the investors' financial risk. Such guarantees were made, for example, by the Bush administration for investors in nuclear power (they were, however, unsuccessful).
- accident risk: the operation of a nuclear power plant can only be insured to a certain extent. International agreements regulate the limits of liability,

which would not even come close to covering the costs resulting from serious accidents in nuclear power plants. The risks are hence borne by the population (see the section on the catastrophe in Chernobyl).

- decommissioning: the economic risk of decommissioning a nuclear power plant, which it is not possible to calculate in advance, is borne as far as possible by society. Provisions for decommissioning are automatically reduced by conservative assumptions regarding the necessary procedures and the related costs. If the plant operator should declare insolvency, then the state must pay the full costs of the decommissioning.
- final disposal: the costs of disposing of nuclear waste, which we still cannot estimate, will have to be paid by future generations. This cost factor is hardly ever assessed, due to the deduction of accrued interest on future payments (a common procedure in aggressive accounting); future generations confronted with the problem of nuclear waste will certainly look at things differently.

7.5 Conclusion: the economic viability of nuclear power stations

Looking at the matter from a structurally qualitative and quantitative point of view, the economic viability of nuclear power stations is characterised, above all, by long periods of time (approval procedures, planning and construction periods), large capital requirements, and enormous uncertainty.

These characteristics alone explain why, under the ancillary conditions of liberalised energy markets, new power stations are only constructed in western industrialised nations in exceptional cases and under special conditions. Exceptions, such as the nuclear power station currently under construction in Finland, are only possible thanks to strategically motivated industrial price dumping (guaranteed low fixed prices), and highly subsidised loans (interest rate: 2.6%!). For the operators of nuclear power plants, however, it is very attractive to lengthen the operational period of old plants (which have been written off). From an economic point of view, the profits from such plants can be very high, due to the cost structure of nuclear power plants.

It is only possible to construct nuclear power plants because of the international agreement which limits liability in the eventuality of a nuclear incident. The risk and the related costs are borne by society. This represents a further large subsidy for the atomic industry.

Even economies which are experiencing rapid growth in energy consumption, such as China, are not opting for nuclear power. Only a small percentage of Chinese electricity is produced by nuclear power, even though the political structures would allow nuclear power plants to be constructed quickly and a possible different attitude to safety-related aspects would cause smaller construction costs than in Western Europe, for example. However, only a small number of plants are being operated and built in China. These plants were probably built for both technological and military reasons.

The risk factors for investors are the unreliable figures regarding the construction costs and duration, and the unavailable information about the costs of dismantling and decontaminating the plant and disposing of nuclear waste. The long construction period causes further uncertainties, as this period could see changes in the capital markets, exchange rates, the domestic political situation or the long-term development of energy consumption.

There are no economic learning curves to be seen for nuclear power stations. Successive intensifications in safety regulations (especially after the Chernobyl catastrophe), large decreases in the number of new plants, and continuous expenditure on development have caused plants to become ever more expensive. Throughout the history of nuclear technology, the atomic industry has not tired of continually announcing that learning curves have set in; in practice, however, these have never appeared.

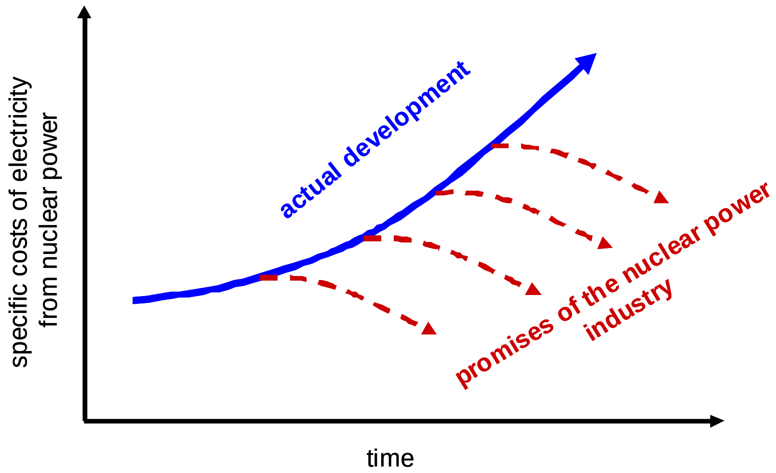


Figure 7.4: Qualitative development of the specific costs of nuclear power – promises of the nuclear power industry and actual development. Source: EEG (2007).

8. Can nuclear energy reduce greenhouse gas emissions?

This argument is used today by representatives of the atomic industry and by certain politicians to defend the operation, the extension of operational periods, and even the construction of new power plants. Some lobbyists for nuclear power even go so far as to say that the problem of greenhouse gases will, in the future, be solved by nuclear power. This, however, disregards two fundamental aspects:

1. If nuclear power is to make a meaningful contribution to the future reduction of greenhouse gases, there would have to be an unprecedented construction boom which is neither imaginable nor feasible from a technical or economic point of view.
2. The construction and operation of nuclear power plants are in no way carbon-neutral. Both the nuclear power plant and the nuclear fuel contain large amounts of grey energy. A thorough balancing of the facts shows that nuclear power would have a much smaller effect vis-à-vis the reduction of greenhouse gases than a naïve glance might suggest.

8.1 The status of nuclear power in the global energy system

The database for the following considerations is taken from the IEA's World Energy Outlook 2007 and refers to the reference scenario.[13] Table 8.1 shows the worldwide consumption of primary energy according to energy source.

Table 8.1: Primary energy consumption of the world in the reference scenario. Source: IEA (2007).

Energy carrier	Primary energy consumption in Mtoe					average groth rate in the periode 2005-2030
	1980	2000	2005	2015	2030	
Coal	1.786	2.292	2.892	3.988	4.994	2,2%
Oil	3.106	3.647	4.000	4.720	5.585	1,3%
Gas	1.237	2.089	2.354	3.044	3.948	2,1%
Nuklear	186	675	721	804	854	0,7%
Hydro power	147	226	251	327	416	2,0%
Biomass und garbage	753	1.041	1.149	1.334	1.615	1,4%
Other renewables	12	53	61	145	308	6,7%
Sum / average	7.227	10.023	11.428	14.362	17.720	1,80%

This scenario shows conservative development, with energy consumption growing uninterruptedly until 2030. The growth of total energy consumption in the period 2005 to 2030 is 1.8% p.a. The 'other renewable energies' will experience the greatest growth rates of 6.7% p.a. This sector encompasses

[13] The World Energy Outlook's reference scenario takes into account the realisation of all measures implemented by mid 2007. The assumptions regarding demographic development, the development of GDP and energy prices are plausible and moderate.

biogenic fuel, wind power, geothermal energy, solar heat, photovoltaics, and other renewable energy sources. Despite this high growth rate, the ‘other renewables’ will still only produce a small percentage (1.7% in 2030) of the world’s energy. This is due to the low initial values, and the continued growth of the other sectors during the given period. The largest section of growth by far will be covered by increased use of fossil fuels (coal, oil, gas).

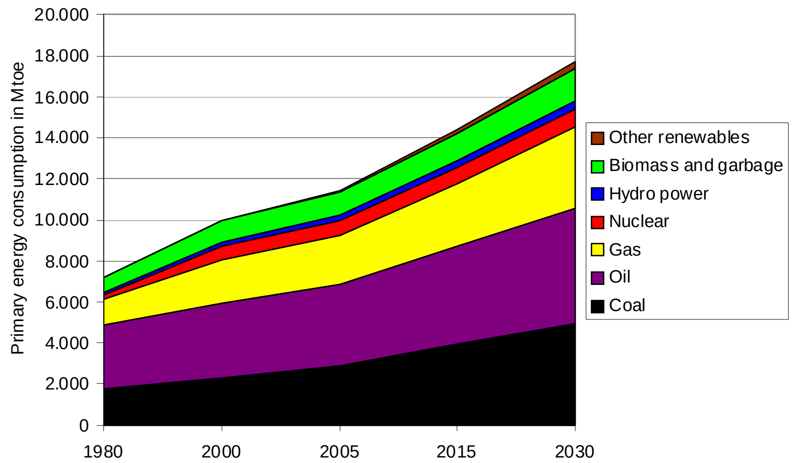


Figure 8.1: Development of the primary energy consumption of the world (reference scenario). Source: IEA (2007).

The role of nuclear power has been shaped by historic growth, which has been discussed in detail in previous sections, and a final stagnation. The energetic output from nuclear power will rise slowly until 2030. The growth rate of 0.7% is the lowest of all fuels. This result is particularly sobering from the point of view of nuclear power, as the scenario involved is very conservative. If we look at the growth of the individual fuels’ contribution to the total primary energy consumption, then the contribution of nuclear energy falls considerably (see figure 8.2). There is a further proportional decline for crude oil, while the use of coal and gas will see large increases.

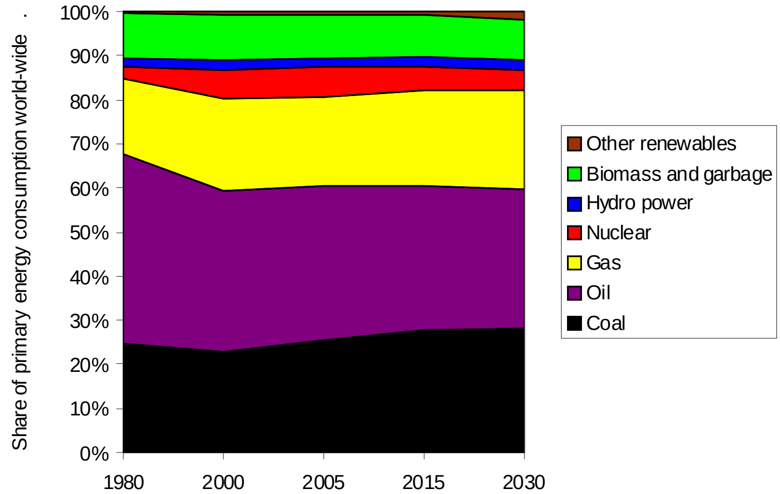


Figure 8.2: Development of the structure of primary energy consumption of the world (reference scenario). Source: IEA (2007).

Figure 8.3 shows the situation in 2007. In 2007, the world's total primary energy consumption was 12,029 Mtoe. Nuclear energy made up 710 Mtoe (i.e. 6.3% of the total consumption).

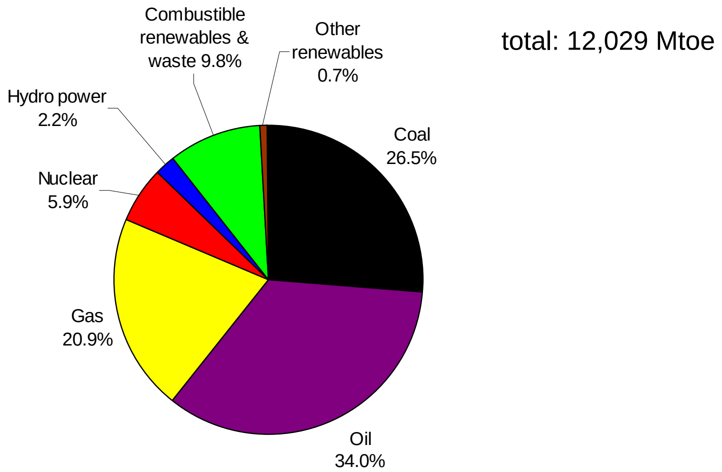


Figure 8.3: Total Primary energy consumption of the world in the year 2007. Source: IEA (2009).

When discussing the importance of nuclear power in reducing greenhouse gas emissions, two aspects are very significant:

1. When assessing the current role of nuclear power, there is the question of which fuels this technology should substitute, as this will determine the amount of CO_2 saved.
2. When assessing the future role, the future development of nuclear power is the main influencing variable. For background information, Table 8.2 shows the development of worldwide energy consumption by region. The large growth in energy consumption in developing countries is of particular note.

Tabelle 8.2: Electricity consumption of the world (reference scenario). Source: IEA (2007).

Regions	Electricity consumption in TWh					average growth in the periode 2005-2030
	1980	2000	2005	2015	2030	
OECD	**4738**	**8226**	**8948**	**10667**	**12828**	**1,5%**
North America	2385	4140	4406	5227	6390	1,5%
Europe	1709	2700	2957	3467	4182	1,4%
Pacific	645	1386	1585	1973	2257	1,4%
Emerging countries	**1098**	**1015**	**1099**	**1381**	**1729**	**1,8%**
Russia	-	607	647	792	968	1,6%
Developing countries	**958**	**3368**	**4969**	**9230**	**15180**	**4,6%**
China	259	1081	2033	4409	7100	5,1%
India	90	369	478	950	2104	6,1%
Rest of Asia	129	575	766	1306	1927	3,8%
Middle East	75	371	501	779	1228	3,6%
Africa	158	346	457	669	1122	3,7%
South America	248	626	734	1116	1700	3,4%
World	**6794**	**12609**	**15016**	**21278**	**29737**	**2,8%**
EU	-	2524	2755	3179	3786	1,3%

8.2 Balancing the use of nuclear power

A perfunctory glance will indicate that, once a nuclear power plant has been constructed and supplied with fuel, it will emit no greenhouse gases. That would, however, be neglecting two crucial points:

1. A nuclear power plant contains embedded energy. The buildings, and particularly the reactor containment, are made from large quantities of steel and concrete. These materials are produced in energy-intensive production procedures. The energy used in these processes is generated almost exclusively by fossil fuels, and hence represents a huge fossil ‘deposit’ into a nuclear power plant’s account.
2. The fuel used in the power station will have been won through complex mining activity, and further processed into a useable fuel by many different processes. Again, all steps in the production of fuel are powered by fossil fuels. Fuel production is a very energy-intensive procedure, which must also be taken into account when balancing CO_2.

Fritsche (2007), among others, has calculated the CO_2 equivalents for nuclear energy, which he lists as being 0.032 kg/kWh$_{el}$ for the uranium mix from Germany, or 0.065 kg/kWh$_{el}$ for uranium from Russia. A study by Bilek et al. (2006), gives a value of 0.065 kg/kWh$_{el}$ for Australia, where uranium ore containing 0.15% uranium is mined. This trend should generally be seen as increasing, as samples of processed uranium ore indicate sinking uranium content. This brings with it an increased processing effort. For further assessments, the CO_2 equivalent emissions coefficient of nuclear power of 0.050 kg/kWh$_{el}$ was adopted. This value, and the coefficients of the other primary fuels, is shown in Table 8.3.

Tabelle 8.3: Primary energy emission coefficients for the estimation of CO_2 relevance of nuclear power. Source: EEG (2007).

Primary energy carrier	kg $CO_{2äqu}$/kWh$_{primary}$
Coal (global mix)	0,349
Oil	0,279
Gas	0,202
Nuclear	0,050
Hydro power	0,040
Biomass and garbage	0,030
Other renewables	0,050

Table 8.4 compares three scenarios which illustrate the significance of nuclear energy in the reduction of greenhouse gas emissions. Global greenhouse gas emissions from the energetic sector are the basis. According to calculations, 31,206 million tonnes of CO_{2e} were emitted in 2005. If all nuclear power stations were replaced by modern natural gas and steam plants, an additional 2,501 million tonnes CO_{2e} would be emitted. In comparison with the natural gas scenario, this would conversely be equivalent to a 7.4% saving of greenhouse gases through nuclear power. If all nuclear power stations were replaced by coal-powered plants, then 6,084 million tonnes of additional CO_{2e} emissions would result. In this scenario, the use of nuclear power would cause a 16.3% saving of emissions. These two values demarcate the scale

within which the effect of nuclear power – depending on the fuel substituted – can move.

Table 8.4: CO_2-savings by the use of nuclear power. Source: EEG (2007).

Primary energy carrier	global $CO_{2äqu}$ emissions in 2005 in million tons		
	Nuclear (not substituted)	Nuclear substituted by natural gas η = 58%	Nuclear substituted by coal plants η = 45%
Coal	11.724	11.724	11.724
Oil	12.979	12.979	12.979
Gas	5.530	5.530	5.530
Nuclear	419	2.920	6.503
Hydro power	117	117	117
Biomass and garbage	401	401	401
Other renewables	35	35	35
Sum	31.206	33.707	37.290
Savings absolute		2.501	6.084
Savings relative		7,4%	16,3%

8.3 The potential future role of nuclear power in the reduction of greenhouse gas emissions

As we have demonstrated in Sections 8.1 and 8.2, the use of nuclear power can save up to 2,500 million tonnes of greenhouse gas emissions, if it substitutes gas power stations, or 6,100 million tonnes, if it replaces coal-fired power stations. However, due to the quick increase in energy consumption, and the slow diffusion of nuclear technology, the potential future saving can only be estimated as low. In the next few years, it will be necessary to produce between 70 and 100 GW_{el} more electricity each year. Additionally, some old plants will have to be replaced as they have reached the end of their lifespan. Nuclear energy can only make a small contribution to this growth, if the current construction rate of four to five new plants p.a. continues. As a result of increasing electricity consumption, the role of nuclear power in reducing global greenhouse gas emissions will be considerably reduced.

9 Fuel reserves and disposal

9.1 Uranium mining and available reserves

Industrial uranium mining began after World War II. The primary aim was to collect fissile materials for nuclear weapons, but also for non-military uses of nuclear power and for the generation of electricity. A market for commercially traded uranium grew. At the end of the Cold War, large amounts of uranium from military supplies became available, which were fed into the market for energy use, and which for many years met almost all the demand. This caused uranium prices to fall, and only the mines which yielded large profits could be operated competitively. According to the IAEA and the IEA, 67,450 tonnes of uranium were used worldwide in 2004. 40,263 tonnes (c. 60%) had been mined, while the rest had previously been used in nuclear weapons. Between 2003 and 2004, the percentage of uranium which had been mined rose by 12%. Uranium prices rose as a result of the lower percentage of ‘cheap’ fissile material. Figure 9.1 shows the historical price course of uranium.

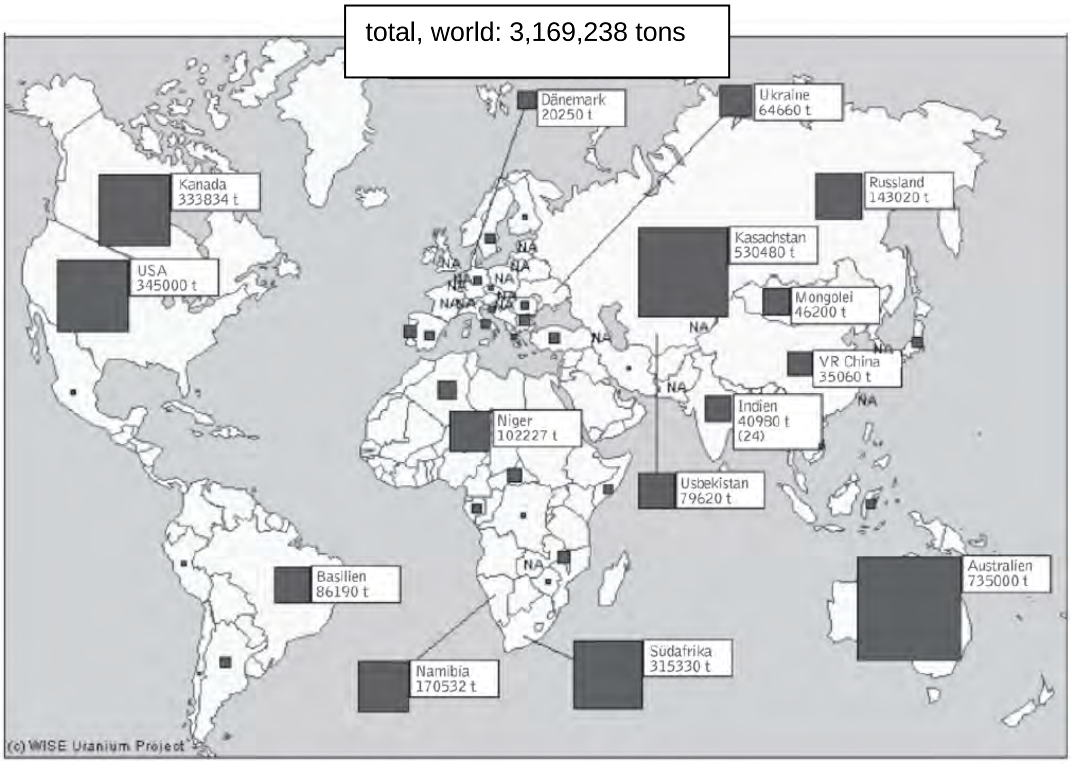
Figure 9.1: Historic development of uranium prices in US$/Pound (1 Pound = 454 Gramm). Source: www.uranium-stocks.net/

Once military surpluses have been used up, the future use of nuclear power will be dependent on fuels which have been mined. The effects this will have on the market price are already clear. As with fossil fuels, there are only limited resources of uranium, and the price of excavating these can vary greatly. Thus, the uranium price will continue to rise in the future, as the given potential cost curve shows.

There are only a few uranium mines left with high uranium concentrations. Currently, the ore with the highest concentration (just under 18% uranium) is being mined underground in the MacArthur River Mine, Saskatchewan, Canada. The lowest grade ore, with 0.029% uranium, in mined underground in the Namibian Rössing Mine. Generally, economically viable mining can only happen if the ore has a uranium concentration of at least 0.1%. The ore in most mines has a concentration varying between 0.1% and 0.5%.

According to market analysis conducted by the IAEA and the IEA, there are 4.74 million tonnes of uranium available worldwide at a price level of US$130/kg fissile material. If consumption remains at the 2004 level, the resources should last 70 years.

In the Heinrich Böll Foundation's comprehensive study (2006), referencing OECD (2004), worldwide resources of 3.17 million tonnes of uranium, also at a price level of US$130/kg fissile material, are mentioned. Illustration 9.2 shows the distribution of these resources.



t = metric ton, NA = no data available

Figure 9.2: Distribution of uranium world wide resources. Source: Heinrich Böll Stiftung (2006)

The total, technically exploitable reserves (disregarding costs, i.e. including all poor quality deposits), have been calculated by the IAEA and IEA at c. 35 million tonnes. Further factors which could lead to increased availability of energetically useable fissile material are the reprocessing of fuel rods and breeder technology.

The retrieval of uranium from burnt out fuel rods currently takes place mainly in reprocessing plants in La Hague (France) and Sellafield (UK). As of yet, however, only a small percentage of the raw material retrieved from reprocessing has been turned into fuel rods, as this is a complex and costly process which is not viable at the current market price of uranium. The majority of recovered material is in long-term storage in the reprocessing plants.

Breeder technology has not yet been able to assert itself. On the one hand, handling plutonium on a large scale poses significantly higher safety and health risks than does handling uranium; on the other, it is not known how economically viable fuel produced in breeder reactors will be. Further problems of a technical nature arise due to the sodium cooling circuit. No evolutionary breeder technology is currently being developed. However, several fast breeder reactors are being considered as Generation IV reactors.

9.2 Radioactive waste and disposing of it

The operation of nuclear power plants produces large amounts of nuclear waste: during the production of fuel rods, by the burnt out fuel rods themselves, during the reprocessing of these fuel rods, and, not least, during the dismantling of the power plant at the end of its lifespan. Figure 9.3 shows the fuel cycle. Nuclear waste is divided into three categories: low active waste (LAW), medium active waste (MAW), and high active waste (HAW).

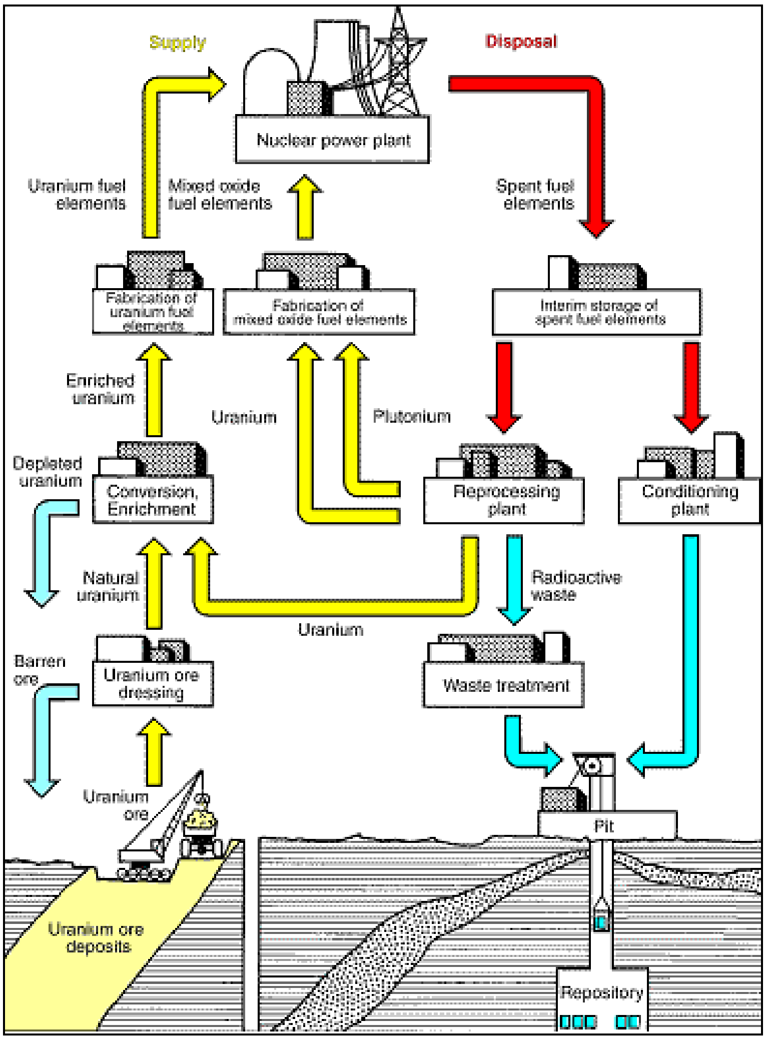


Figure 9.3: The nuclear fuel cycle. Source: www.euronuclear.org

Radioactive waste is dangerous when released into the biosphere. It can be released by the operation of nuclear power plants (e.g. breakdowns and accidents), during the transportation of fuel and waste from the fuel cycle, and during the temporary storage or permanent disposal of radioactive material.

Some radioactive materials are potentially more dangerous than others. Plutonium is particularly dangerous because of its toxicity and radioactivity. Plutonium is so toxic that a few milligrams can be lethal, while the inhalation of a few micrograms can cause cancer. The maximum annual active intake for workers is given as 40 nanograms of Plutonium 239.

Not least because of its direct potential threat, plutonium is the key element in the non-military use of nuclear power. Burnt out fuel rods from light water reactors contain about 1% plutonium. This gives a total of five to six tonnes of plutonium each year from all existing plants. That means that a billion lethal doses and a thousand billion carcinogenic doses of Pu 239 are produced each year by the operation of reactors.

Those who handle nuclear waste are hence faced with a huge responsibility in regard to the world's population. The storage of radioactive waste takes the form of temporary storage and final disposal. The temporary storage of high active substances is necessary to allow heat production to subside; for logistical reasons, medium and low active substances are generally stored on a temporary basis. In aboveground facilities, radioactive material is kept in either wet or dry temporary storage containers. Temporary storage sites are either decentralised and located on the periphery of the nuclear power plant, or they are centralised. Temporary storage sites are considerably less well furnished with safety equipment than the nuclear power plants themselves. For economic reasons, temporary storage sites generally have no safety precautions against the effects of a plane crash.

The potential risk posed by different types of waste determines the demands made on the final disposal of nuclear waste. Major factors in such considerations are the intensity and duration of the radiation. An additional factor which must be considered when disposing of nuclear waste, is heat generation caused by the decay of radionuclides. The half-life of the stored radionuclides is decisive for the time constants of final disposal. There is a very large range in play here, from a few days (e.g. 5.3 days for Cobalt 60), to hundreds of millions of years (e.g. 704 million years for Uranium 235).

'Short-lived', low to medium active waste with a half-life of less than 30 years is generally stored above ground in suitable containers or just under the earth's surface. Some countries, like Germany, are trying to store waste in deep geological formations. In future, long-lasting high active waste should be stored in deep geological formations for very long (geological) periods of time. There is not yet a single final storage site for long-lasting high active waste. Technical reasons on the one hand, and the resistance of the populations of the affected areas on the other, have delayed the construction of permanent storage sites.

Multifarious dangers arise from temporary and permanent storage sites which are not located deep under the earth’s surface. All these risks could lead to the release of nuclear waste into the biosphere. Possible causes could be technical failures (leaking tanks, damaged cooling systems etc.), accidents or natural catastrophes (earthquakes, fires, plane crashes etc.), terror attacks or military conflict.

10. Safety aspects: risks, proliferation, war and terrorism

No other type of technology currently in use on the planet poses a risk to society as high as nuclear power does. This risk stretches from the release of radioactive pollution into the human biosphere during the regular operation of nuclear power plants (uranium mining, reprocessing plants, temporary and final storage of nuclear waste), and the numerous accidents and catastrophes which have occurred in the relatively short history of nuclear power, to the threat to humanity as a whole from nuclear weapons, regardless of whether they are deployed in wars or by terrorists.

Global society pays relatively little attention to the destructive potential of nuclear power. This can be explained, on the one hand, by a lack of understanding, and by the invisibility of many of the physical phenomena, such as radioactivity and its effects, and on the other by the rarity of catastrophic occurrences. Chernobyl is one example of such a catastrophe. After many small and large accidents (see Appendix A), which, if possible, the lobbies played down or kept secret from the public, the Chernobyl catastrophe was so visible that neither the atomic industry not the lobbyists tried to play it down. Although the statistics regarding the dead, injured and those exposed to radiation, cancer rates, genetic damages, or the size of the area which, for geological periods, can no longer be entered without protected clothing, vary in different studies, no author has denied that in this case we are dealing with a nuclear catastrophe with long-term effects on society.

10.1 Risks of using nuclear power

When talking about catastrophic occurrences related to the use of nuclear power (such as the Chernobyl catastrophe), we mean rare occurrences with catastrophic effects. It is symptomatic in this context that nuclear power stations can only be partly insured, as no insurance company in the world would cover a power station against unlimited damages. International agreements have introduced limitation of liability, as otherwise the operation of nuclear power stations would have been impossible. As a result, it is society, and not the operating company, which suffers the damages in the event of a catastrophe.

Before the catastrophe at Chernobyl, nobody had reckoned with a maximum credible accident, although it had always been obvious for risk researchers that such an accident was, in principle, possible. The occurrence of an accident which, in theory, is possible, is only dependent on time and the number of plants in operation (and on the quality of their safety systems). This principle has not changed at all since the Chernobyl catastrophe. It is true that great pains were taken in the improvement of safety systems, and that the number of plants has not increased, but the possibility of a maximum credible accident still exists. Factors which increase this risk include the advancing age of the plants (due to lucrative extension of operational periods), economic restrictions resulting from liberalised energy markets, as well as the tendency to install nuclear power plants in newly industrialised and developing countries, where there are fewer safety precautions.

10.2 The link between military and non-military uses of nuclear power

Proliferation is the spreading or passing on of weapons of mass destruction, support systems, and specific know how from countries which have this technology to those which do not. It is possible to pass on complete weapons, or just individual components or relevant expertise.

The international community tries to curb proliferation with treaties and surveillance (Non-Proliferation Treaty, Chemical Weapons Convention). The possible proliferation of the former USSR's historic nuclear arsenal causes great concern. People worry that WMDs from these stores could be stolen or sold to terrorist organisations.

Proliferation is currently the biggest threat to international safety. The events of 11th September 2001 gave a new dimension to the proliferation discussion. Formerly, only states had been seen as the customers of proliferation; after the attacks on America, however, non-governmental protagonists, e.g. terrorists, must also be seen as potential buyers of proliferated weapons.

The risks of proliferation can be divided into two groups. On the one hand, nuclear materials, nuclear technology and expertise can be transferred from one country which has a legal non-military nuclear programme, to another country which is pursuing a nuclear weapons programme. On the other hand, a country can divert part of its legal non-military programme to an illegal domestic nuclear weapons programme.

According to the IAEA, at least 25kg of high enriched Uranium-235[14] (HEU containing at least 90% Uranium-235) or 8kg of Plutonium-239 are required for the construction of a nuclear bomb. HEU can be produced in various types of enrichment plants, whereby centrifuge enrichment[15] is currently the most common process. In some types of reactor, plutonium is a by-product created when nuclear fuel is exposed to radiation. Depending on the type of reactor, and the duration of radiation, nuclear fuel can produce varying amounts of Pu-239 and Pu-240. The plutonium needs to separated in chemical reprocessing plants before it can be used to build nuclear weapons.

In theory, every non-military nuclear programme produces the basic materials required for the production of nuclear weapons. An additional condition, however, is the availability of an enrichment plant (for the production of

[14] High enriched uranium (HEU)
[15] The physical separation of U-238 and U-235 according to atomic mass is only possible in the gas phase. To this end, the chemical compound uranium hexafluoride (UF_6) is used. As a result, the compound UF6 consists of both a 'heavy' UF6 (from U-238 and F), and a 'light' UF6 (from U-235 and F). By repeatedly passing the gas through many centrifuges, it is enriched and eventually contains the desired concentration of U-235.

weapons-grade HEU), or of a reprocessing plant (for the separation of weapons-grade plutonium). In principle, the production of weapons-grade nuclear material does not require large-scale plants such as nuclear power plants. If enough time is available, the necessary materials can be produced in small reactors (e.g. in an experimental or research reactor).

Nuclear programmes which always had military aims have been realised in the USA, Great Britain, the USSR and China. France, India, Israel, North Korea and South Africa officially launched non-military nuclear programmes, which they have since used to produce nuclear weapons.

Alongside the increased availability of nuclear weapons made possible by proliferation, the creation and deployment of so-called ‘dirty bombs’ is seen as a further potential threat. Dirty bombs are conventional bombs which have been contaminated with radioactive material, so as to pollute the place where they are used. In terms of proliferation, however, the production of such weapons is not necessarily linked to the conventional nuclear fuels and their fission products. The necessary materials can come from other sources, such as medical science.

10.3 The importance of nuclear power plants as targets for terrorism and in the event of war

Nuclear power stations and the associated facilities, such as temporary storage sites, enrichment plants and reprocessing plants can, depending on the attackers’ strategy, be an attractive target for terrorists or in the course of military action.

The radioactive stock and the energy content of a nuclear power station would multiply the effects of a conventional military or terrorist attack; in the worst case, a maximum credible accident could result. The consequences would probably be comparable with those of the Chernobyl catastrophe (see Appendix A). In this case, the affected area would be unusable for the attackers for a very long time, which would be an obstacle for the attackers in a war. A further strategic aspect is the cutting off of the enemy’s power supply; in this case, any large conventional power station would be a target.

Nuclear power stations are structures which are easy to identify, can be seen even from a distance, and are easily attacked with a plane, for example. If a terrorist attack in the style of 9/11 were carried out on a nuclear power station, there would be serious consequences for a large region. According to numerous studies, a normal non-military nuclear power plant would not withstand the impact of a large aeroplane.

11. Political aspects

The level of acceptance which nuclear power receives in different countries varies greatly. Figure 11.1 shows the results of the Eurobarometer survey carried out in 2005 in the 25 EU states. According to the survey, only 37% of Europeans totally or mainly approve of the use of nuclear power.

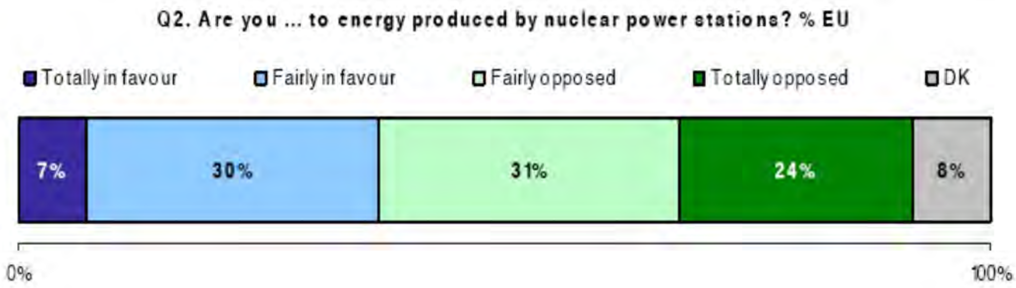


Figure 11.1: Average acceptance of nuclear power in the EU 25 in the year 2005. DK = dont know. Source: Eurobarometer 2005.

This chart shows the individual results for the 25 EU countries. The number given refers to the percentage of the population who are totally or mainly in favour of nuclear power. Hungary has the highest levels of acceptance (65%), Austria the lowest (8%). As Figure 11.1 shows, the EU average is 37%. The relatively low acceptance in France (52%) and the UK (44%) should be noted. It is notable that many nuclear power plants are currently in operation in Germany, despite the fact that only 38% of the population is in favour. Nuclear power is obviously being used in defiance of the wishes of the population.

Member States Results	
Hungary	65%
Sweden	64%
Czech Republic	61%
Lithuania	60%
Finland	58%
Slovakia	56%
France	52%
The Netherlands	52%
Belgium	50%
United Kingdom	44%
Slovenia	44%
Estonia	40%
Latvia	39%
Germany	38%
EU25	37%
Luxembourg	31%
Italy	30%
Denmark	29%
Poland	26%
Portugal	21%
Malta	17%
Spain	16%
Ireland	13%
Cyprus	10%
Greece	9%
Austria	8%

On the basis of these results, it would only be possible to construct new nuclear power plants in a few countries, without acting against the will of the population and thereby exposing oneself to a high political risk. The story of the nuclear power plant at Zwentendorf (see Appendix A) is good example of such a plan and the resulting political consequences. This plant was rejected by a referendum shortly before going into operation, and as a consequence it led to the Law Banning the Use of Nuclear Power.

Changing public opinion *vis-à-vis* nuclear power by means of campaigns and similar methods is lengthy, expensive and risky. The atomic industry is aware of this, and when marketing its products, it avoids the public sphere. Rather, it always turns to the highest political echelons and tries to persuade them to realise nuclear projects. Hereby, the political risk of a damaged reputation, and the high costs of changing public opinion are shifted on to the politicians responsible. (These costs generally become the tax payer’s responsibility.) Even this common course of action is a democratically questionable procedure.

12. Summary and conclusions: the renaissance of nuclear power?

Today, it is not possible to talk of a ‘renaissance of nuclear power’. In the medium term, the construction of new plants will not suffice to replace those which have been taken off stream due to age. In this situation, the atomic industry is trying hard to repel the image of a technology which is becoming obsolete, and, to this end, uses timely arguments such as climate protection. On closer inspection, however, this argument proves to be untenable. On the one hand, nuclear power is by no means carbon-neutral; on the other, the dilatoriness in the diffusion of the technology prevents it from effectively protecting the environment. In free market democracies, new nuclear power plants are seldom built. Due to the large amount of capital necessary, the cost structure of nuclear power plants is not compatible with the ancillary conditions of liberalised energy markets. On the contrary, the continued use of plants which have been written off is very attractive from an economic point of view. This not only secures large profits for the operating company, but also a higher risk to society, due to the use of outdated plants. As a result of international liability limitations, without which it would not even be possible to use nuclear power, society must bear the risk of operating nuclear power plants. The risks are multifaceted, and include the release of radioactive material in the course of everyday operation (uranium mining, reprocessing, temporary and final storage), und in the event of catastrophic accidents (e.g. Three Mile Island, 1979, Chernobyl, 1986). The regions in which nuclear power plants are located could face an increased risk in the event of terrorist attacks or war.

Nuclear power projects are only economically attractive when the majority of the costs are borne by the taxpayer. This is possible due to state-driven propaganda campaigns aiming to ‘shape public opinion’, which are necessary for the realisation of the relevant projects, state subsidised loans and governmental contingent liability, industry dumping, and the shifting of accident liability on to society. Not least, the problems and costs which will arise for thousands of future generations, and which are linked to the final storage of nuclear waste, are ignored.

After consideration of the economic, supply-related and even the ecological aspects of nuclear power, the motives of states which continue to invest in this technology can only lie in strategic military interests, demonstrations of power, or a lack of alternative modes of energy production. France, with its large number of nuclear power stations and an influential industrial lobby, is an exception. There, many effective mechanisms maintain the system, and prevent the abandonment of nuclear power for the time being.

As with fossil fuels, nuclear power depends on limited resources of a raw material (uranium ore). If current consumption levels are maintained, these resources should last between 60 and 100 years. If there is an increase in the use of nuclear power, these resources will last for a proportionately shorter time. Breeder technology, which would allow resources to be exploited more efficiently, has not yet established itself.

Nuclear power is not an option as far as the development of a sustainable energy and social system is concerned. On the contrary. The use of nuclear power ties down large amounts of capital which are desperately needed for the development of renewable energy sources and energy efficiency. Additionally, the mere non-military operation of reactors creates a monstrous legacy in the form of radioactive radiation and cumulating nuclear waste. This legacy will plague thousands of future generations. Hence, nuclear power is not compatible with the demands of sustainable systems and must be refuted as a sustainable solution.

13. Bibliography

Bethge Philip, 2007, “Die nukleare Versuchung“, Spiegel Special, Nr. 1/2007

Bilek Marcela, Clarence Hardy, Manfred Lenzen, 2006, "Life-Cycle Energy Balance and Greenhouse Gas Emissions of Nuclear Energy in Australia" Universität Sydney, November 2006, a study for the Australian Government

Böll Heinrich Stiftung, 2006, “Mythos Atomkraft – ein Wegweiser“, ISBN: 3-927760-51-X, ed. Heinrich Böll Stiftung, 1st Edition, Berlin 2006

Bundesamt für Verfassungsschutz, 2001, “Proliferation“, Vereinigte Verlagsanstalten, Düsseldorf, January 2001

Cohn Steven Mark, 1997, “Too Cheap to Meter: An Economic and Philosophical Analysis of the Nuclear Dream” paperback, Publisher: State University of New York Press (July 1997), ISBN-10: 0791433900, ISBN-13: 978-0791433904

Commission of the European Communities, 2006, “Green Paper - A European Strategy for Sustainable, Competitive and Secure Energy”, Brussels, 8.3.2006, COM(2006) 105 final

Commission of the European Communities, 2007, “Nuclear Illustrative Programme”, Communication from the Commission to the Council and the European Parliament, Brussels, 10.01.2007, COM(2006) 844 final

De Esteban Fernando, 2002, “The future of nuclear energy in the European Union”, Background paper for a speech made to a group of senior representatives from nuclear utilities in the context of a European Strategic Exchange, Brussels, 23rd May 2002

EIA Energy Information Administration, 2007, “International Energy Outlook 2007”, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC 20585

EON, 2008, “Stilllegung und Rückbau des Kernkraftwerks Stade - vom Kernkraftwerk zur grünen Wiese“, Publication der EON

Fairlie Ian, David Sumner, 2006, “The other report on Chernobyl (TORCH)”, an independent scientific evaluation of health and environmental effects 20 years after the nuclear disaster; Afterword Prof. Angelina Nyagu, Ukraine; Berlin, Brussels, Kiev, April 2006

Fritsche Uwe R., 2007, “Treibhausgasemissionen und Vermeidungskosten der nuklearen, fossilen und erneuerbaren Strombereitstellung”, Öko-Institut e.V., Büro Darmstadt, Arbeitspapier März 2007

Gielecki Mark, James Hewlett, 1994, “Commercial Nuclear Power in the United States: Problems and Prospects”, US Energy Information Administration, August 1994

GWEC, 2006, “Global Wind 2006 Report”, annual report of the Global Wind Energy Council 2006

Haas Reinhard, 2007, “The Economics of Nuclear Power in a Historical Context”, lecture in Salzburg, 28th September 2007

Harding Jim, 2007, “Seven Myths of the Nuclear Renaissance”, Euratom 50th Anniversary Conference European Parliament – Brussels, Belgium, 7 March 2007

Hultman Nathan et al., 2007, “What History Can Teach Us about the Future Costs of U.S. Nuclear Power”, Environmental Science and Technology, April 1, 2007

IEA, 2007, “World Energy Outlook 2007”, International Energy Agency, OECD/IEA, 2007

Kernenergie.de, 2007, Internetpräsentation INFORUM Verlags- und Verwaltungsgesellschaft mbH, Informationskreis Kernenergie, Robert-Koch-Platz 4, 10115 Berlin, www.kernenergie.de

Matthes Felix Chr., 2006, “Mythos Atomkraft – über die Laufzeitverlängerung von Atomkraftwerken’’ Copyright Heinrich Böll Stiftung, 1st edition, Berlin, March 2006

Meissner Markus, Antonia Wenisch, 2004, “Bau und Planung neuer Atomkraftwerke – Internationale Recherche des aktuellen Planungsstandes“, commissioned by the Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, January 2004

Rogner Holger, 2007, “Nuclear Energy”, lecture during the expert workshop “Atomkraft und Grünbuch 2“ on 23.01.2007 at the Technical University in Vienna

Rosenkranz Gerd et al., 2006, “Mythos Atomkraft – ein Wegweiser“, Heinrich Böll Stiftung, 1st edition, Berlin 2006, ISBN 3-927760-51-X

Schneider Mycle, 2006, “Renaissance der Atomenergie - Mythos oder Wirklichkeit ?’’, lecture at the Technical University in Vienna, 10th-11th October 2006

Schneider Mycle, 2006b, speech on 29.04.2006 in Munich commemorating the 20th anniversary of Chernobyl

Thomas Steve, 2005, “The Economics of Nuclear Power“, Nuclear Issues Paper No. 5, Heinrich Böll Stiftung, Dec. 2005

Wenisch Antonia, 2006, “50 Jahre Atomenergie sind genug - Zum Status der Atomkraft im 21. Jahrhundert“, a study by the Austrian Institute of Ecology, Vienna 2006

World Energy Council, 2007, “The Role of Nuclear Power in Europe“, London, January 2007, ISBN: 0 946121 23 0

Links

Organisation / Content	Website
International Atomic Energy Agency (IAEA) Official homepage of the IAEA	http://www.iaea.org/
Nuclear Events Web-based System	http://www-news.iaea.org/news/default.asp
Publications about recent nuclear accidents	http://www.x1000malquer.de/unfaelle.html
Nuclear Files.org – Project of the Nuclear Age Peace Foundation	http://www.nuclearfiles.org/menu/key-issues/nuclear-weapons/issues/accidents/index.htm
Wikipedia, the electronic Encyclopaedia	http://en.wikipedia.org/wiki/
Official homepage of AREVA Nuclear energy supply and electrical infrastructure	http://www.areva.com/
Website with information about nuclear weapons	http://www.atomwaffena-z.info/impressum.html
Official homepage of the Democracy Centre; inter alia the nuclear power station at Zwentendorf: construction, protests, referendum	http://www.demokratiezentrum.org/de/index.html?idcatside=9&lang=2
Energy Information Administration; Official Energy Statistics from the U.S. Government	http://www.eia.doe.gov/oiaf/ieo/
Plattform gegen Atomgefahren Salzburg	http://www.plage.cc/cms/themen/Temelin.php
Homepage of CEZ (Czech Power Company)	http://www.cez.cz/en/home.html
Homepage of the German Atomic Forum	http://www.kernenergie.de/r2/en/
Homepage of the World Nuclear Association	www.world-nuclear.org
International Physicians for the Prevention of Nuclear War	http://www.ippnw.org/
Global Wind Energy Council	http://www.gwec.net/
Integrated Nuclear Fuel Cycle Information Systems	http://www-nfcis.iaea.org/
U.S. Department of Energy	http://www.energy.gov/
Uranium Stox.com	www.uranium-stocks.net/

Appendix A: accidents in nuclear power plants

Chernobyl is probably the best known example of an accident in a nuclear power plant. There are many other instances in which accidents have led to significant contamination and/or damage to health. This list gives an overview of the incidents involving radioactivity in nuclear facilities (e.g. nuclear power plants, research laboratories) which were evaluated as being higher than 3 on the International Nuclear Event Scale (INES). This scale was introduced by the International Atomic Energy Agency (IAEA) to provide worldwide standards for the reporting of incidents and accidents. As the INES was only introduced in the 1990s, not all prior events have been classified accordingly. The following section presents the Three Mile Island and Chernobyl incidents in detail, in order to give the reader an idea of the course of events, the links between them, and the consequences.

1950s

Chalk River, Canada

12th December 1952 – The first serious reactor accident occurred in an NRX reactor in Chalk River, near Ottawa, Canada. During a test, the reactor was damaged by a partial meltdown caused by operating errors, misunderstandings between the operator and the operating personnel, false status displays in the control room, the operator's miscalculations and tardiness in taking action. A gas explosion in the reactor core threw the dome of a helium container weighing four tonnes 1.2m into the air; it remained stuck in the structure. The explosion released at least 100TBq of radioactive substances into the atmosphere. Up to four million litres of water, contaminated with c. 400TBq long-living fission products, were pumped from the cellar of the reactor containment into a sandy absorbing well, in order to avoid contaminating the nearby Ottawa River. The damaged reactor core was buried. The later US president Jimmy Carter, at the time a nuclear technician in the navy, assisted in the cleanup operation which lasted many months. The reactor only went back into operation two years later.

Kyshtym, Russia

29th September 1957 – Also known as the Mayak accident. The reprocessing plant stored its waste products in large tanks. The radioactive decay of these substances creates heat, and as a result the tanks must be continually cooled. In 1956, the coolant circuit of one of these 250m^3 tanks began to leak. As a result, the cooling was cut off, and the content of the tank began to dry. A spark in one of the internal gauges caused the nitrate salts to explode, and released large quantities of radioactive material (INES 6). The damage done to the area around Kyshtym was twice as bad as that resulting from the Chernobyl accident. As only the area around the Urals was contaminated, European gauges did not register the accident (cf. the Chernobyl accident), and as a result the accident could be kept secret from the world for 30 years. [1]

Windscale (Sellafield), UK

7th-12th October 1957 – In order to anneal the so-called Wigner energy[16] from the graphite which was serving as a moderator, technicians heated up the reactor in atomic pile No. 1 in Windscale (Sellafield) near Liverpool. The reactor was one of two, which were air-cooled and graphite-moderated. They were fuelled with uranium, and used to produce plutonium for nuclear weapons. These were very simple reactors, cooled by two giant ventilators. On the morning of the 7th October 1957, the reactor was shut down in a controlled fashion, and the ventilation was turned off. The reactor was then turned on again at a low performance level. The technicians noticed that the temperature was falling instead of rising. In order to anneal the Wigner energy more quickly, the performance level was set higher than allowed. However, the technicians were taken in by a false conclusion: temperature levels during everyday operation were totally different to those during annealing. The temperatures were not metrologically controlled and the graphite began to burn. The fire and smoke were only filtered at the beginning. Thereafter, radioactive material was able to escape outside. Blue flames erupted from the rear of the reactor. 750 TBq of radioactive material was released into the atmosphere. The fire burned for four days, and large parts of the graphite moderator were consumed. The technicians were unable to remove the 150 nuclear fuel rods from the reactor. Finally, the reactor was flooded with water. This flooding was very dangerous due to a possible gas explosion. The flood put out the fire. Radioactive gases, mixed mainly with iodine, krypton and xenon, were released into the atmosphere. The production of milk was forbidden within an area of 520km^2. Reactors 1 and 2 were closed in the following years. 1990 marked the commencement of the decommissioning, which was only completed in 1999. The accident, similar in scale to that on Three Mile Island, was categorised by the IAEA as INES 5, and later made responsible for dozens of deaths resulting from cancer. Main article: Windscale Fire.

[16] Wigner Energy is the energy stored a nuclear reactor's graphite moderator. It was discovered by Eugene Paul Wigner. While a reactor is in operation, the graphite is irradiated with fast neutrons. This causes carbon atoms from the crystalline atomic structure to be pushed into the interstices, which means that energy is being stored. This potential energy is called Wigner Energy. It can spontaneously and suddenly discharge itself in the form of heat. Too much Wigner Energy should not be allowed to build up in the moderator, as uncontrolled termperature rises and spontaneous recombination can be a safety risk for a reactor. At temperatures of higher than c. 250^{o}C, the voids begin to recombine, which allows the Wigner Energy to be released in a controlled manner. Therefore, the moderator is annealed. This process involves keeping the reactor at a higher temperature for a period of time. In graphite-moderated high temperature reactors (e.g. pebble-bed reactors), annealing happens automatically during regular operation, as the core temperature is hot enough.

Picture: Nuclear power plant in Sellafield.

Simi Valley, California, USA

26th July 1959 – There was a partial meltdown in the Santa Susana Field Laboratory in California. This was a sodium-cooled reactor. [2]

Knoxville, Tennessee, USA

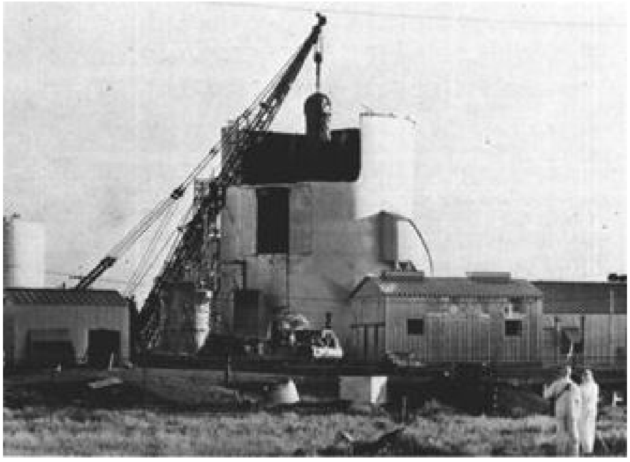
20th November 1959 – In the radiological and chemical factory Oak Ridge National Laboratory in Tennessee, there was a chemical explosion during the decontamination of the plant facilities. In total, 15gr of Plutonium-239 were released. The plutonium caused considerable contamination in the building, in nearby streets, and to the facades of nearby buildings. It is believed that the explosion was caused when nitric acid came into contact with decontamination fluids containing carbolic acid. A technician had forgotten to clean a vaporiser with water, which meant that it was still covered in decontamination fluids. Surfaces which could not be decontaminated were painted with a noticeable warning colour, or set in concrete. The Oak Ridge authorities began to use reactor containment when dealing with radioactive or chemical materials.

1960s

Idaho Falls, Idaho, USA

3rd January 1961 – There was an accident in an experimental SL-1 reactor in the National Reactor Testing Station in Idaho. There was a steam explosion, and a large amount of radioactive material was released. Three workers were killed immediately. Excepting the released Iodine-131, the radiation was restricted to an area of 12,000m^2. Iodine-131 radiation of the vegetation within a radius of 30km from the reactor is around 100 times higher than is naturally the case. Even 80km away from the reactor, the impact on vegetation is twice as large as usual. This affected area includes stretches of countryside along the Snake River near Burley and American Falls.

The transportable reactor had manually adjustable control rods. The movement of just one of these rods could have caused the incident. The actual cause could not be determined. 100m from the reactor, rescue workers found dose outputs above 2 mSv/h. Radiation inside the building measured around 10 mSv/h. According to a report from the United States Atomic Energy Commission, 22 of the rescue workers received an equivalent dose of 30 to 270 mSv. The reactor was disassembled, and a few months later the reactor core (weighing 12 tonnes) and the pressure vessel were removed.



Picture: Removing the SL1-reactor from the national reactor testing station.

Monroe, Michigan, USA

5th October 1966 – A malfunction in the sodium cooling system in the Enrico Fermi demonstration nuclear breeder reactor on the shore of Lake Erie led to a partial core meltdown, which released radiation from the containment. The reactor core consisted of 105 uranium oxide fuel rods which were coated with zirconium. A piece of zirconium, which blocked one of the flow regulators in the sodium cooling system, is blamed for the accident. Sensors automatically isolated the reactor building, and no employees were in the building at this time. Workers were able to shut down the reactor manually. Two of the 105 fuel elements melted, but no radiation was measured outside the catchment tank. The 200MW reactor was operating again at full power in October 1970. This accident was the basis for John G. Fuller's controversial polemic 'We Almost Lost Detroit'.

Lucens, Switzerland

21st January 1969 – In the canton Vaud, there was a partial meltdown in the experimental nuclear reactor (which is built similarly to the NRX reactor) as a result of faulty coolant. The reactor was inspected at the beginning of 1968. In April/May, the reactor went into operation, but was turned off again in January of the following year. During this period of inactivity, the coolant (seal water = part of the seal) ran into the reactor's cooling circuit. The casing pipes, which were made out of magnesium, corroded. The reactor went back into operation in January 1969, and the corrosion product hindered cooling. The fuel became too hot, and several fuel rods melted. A group of fuel rods caught fire, and caused the reactor tank to explode. Carbon dioxide and heavy water (moderator) escaped into the reactor cavern. As the high radioactivity was noticed early on, workers could be evacuated and the cavern was sealed off. Large amounts of radiation were released into the cavern. It was only years later that radioactive parts could be removed from the tunnel system. The cavern still contains lots of radioactive material, but it was sealed so that no radiation would be released into the atmosphere for the time being. The cleanup process lasted until 1973. The reactor components were stored in sealed containers above ground until 2003, when they were transported to the central temporary storage plant (ZWILAG) in Würenlingen.

Rocky Flats, Idaho, USA

11th May 1969 – Plutonium spontaneously caught fire in a container holding 600 tonnes of flammable material. The fire burned two tonnes of this material, and released plutonium oxide. Soil samples taken from the area around the plant showed that the area was contaminated with plutonium. As the plant operators refused to launch an investigation, the samples were taken as part of an unofficial investigation. [3]

1970s

Windscale (Sellafield), UK

1973 – There was an exothermic reaction in a container in the reprocessing plant. Part of the plant was subjected to radioactive contamination. Due to this contamination, the accident was classified as INES 4. [4]

Greifswald, Germany (GDR)

7th December 1975 – An electrician wanted to show his apprentice how to bypass electric circuits. This caused a short circuit on the primary side of the Block 1 transformer. The resulting electric arc caused a cable fire. The fire in the main cable channel destroyed the electricity supply and the control cables for five of the main coolant pumps (six were in operation for each block). A meltdown could have resulted, as reactor 1 was no longer being cooled properly. As counter measures were taken as soon as the fire broke out, and the operational team made all the right decisions, the fire was quickly brought under control by the plant's fire officers, and the electricity supply to the pumps was temporarily reconstructed. After this near catastrophe, fire prevention in the plant was strengthened considerably, and safety-related appliances were 'separated spatially'. Each coolant pump was given its own electricity supply. The accident was only made public after the *Wende* in 1989. A few hours after the accident, Soviet sources informed the IAEA of the accident, and the IAEA categorised it as INES 4. The 10% threshold value for permissible radiation emission was not exceeded. Later evaluations of the events by a governmental commission, and the IAEA's confirmation of this commission's conclusions, show that an experienced operational team can compensate for any plant-specific weak points (in this case faulty containment). Since 1990, this accident has, as a result, been the standard accident scenario for VVER-440 reactors in simulator training at Greifswald.

Three Mile Island, Pennsylvania, USA

28th March 1979 – The reactor cooling in a nuclear power station near Harrisburg broke down due to a combination of faulty machine components and operational failures. This in turn caused a partial meltdown, and the release of 90 TBq of radioactive gases. This is the most serious accident to have happened in a commercial American reactor, and was classified by the IAEA as INES 5.

At 4am on the morning of the 28th March 1979, two of the main feed-water pumps in the secondary cooling circuit containing non-radioactive water went out of action while work was being done to the condenser water purification plant. This break down resulted from mechanical, pneumatic or electrical problems with the pump control, and prevented the cooling of two steam generators. On a website documenting the accident [1], the journalist shows that an employee caused the accident. This employee connected the pneumatic system, which was used to control the pneumatic mechanisms in the power station, to a water pipe with a rubber hose. As a result, water entered the pneumatic system. The report from the president's commission also mentions water in the pressurised air system in question.

Picture: The nuclear power plant Three Mile Island. Source: http://de.wikipedia.org/wiki/Kernkraftwerk_Three_Mile_Island

As a result of the breakdown of the feed-water pumps, the turbogenerator and the reactor were switched off by the so-called SCRAM, the emergency shutdown: the control rods fell into the core and ended the nuclear chain reaction. After a reactor is shut down, a considerable amount of heat is always produced, which is known as post-decay energy. The heat production of the reactor in TMI after shutdown was around 6% of the reactor's nominal thermal output. As a result of this, the pressure in the reactor's primary circuit, which contains radioactive water, rose, and in the pressuriser reached a value of 158 bar. During regular operation, there is a pressure of 151 bar in the primary circuit. One of the pressuriser's safety valves opened, in order to avoid a break in the circuit due to excess pressure. This valve, known as PORV (pilot operated relief valve), should have closed as soon as the pressure reached a value of 155 bar or lower. This should have happened 13 seconds after the accident began, but did not, and this fact remained unnoticed for more than two hours. One tonne of coolant escaped into the pressuriser's blow tank every minute. When the blow tank could not contain any more coolant, the fracture disc broke, and coolant could escape into the reactor containment. A leak in the primary circuit had developed, and an accident due to the loss of coolant was in the making. The indicators in the control room did not warn that the valve was still open. This led to further reduction in pressure in the primary circuit.

At around the same time, another problem had developed in another part of the power station. The emergency feed-water system, which was a back-up for the main feed-water pumps, had been tested 48 hours before the accident. As part of this test, two block valves were closed, and should have been opened again at the end of the test. However, they were not reopened, either as a result of methodological or human error. This meant that the emergency feeder system was not working. The emergency feed-water pumps were functioning, but, due to the closed valves, no water could be transported to the steam generators. Hence the post-decay heat from the primary circuit could not be discharged. After eight minutes, the closed valves were noticed and opened. After they had been opened, the emergency feed-water system began to work normally, and supplied the steam generators with water.

While the pressure in the primary system continued to sink as a result of the open PORV valves, steam bubbles were being created outside the pressuriser. These bubbles meant that the water in the system was distributed differently, and the pressuriser filled with water. The level indicator, which shows the operator how much water is available for cooling, said that the system was full of water. As the level indicator only takes its values from the pressuriser, which under normal circumstances contains $22m^3$ of water as well as $19m^3$ of steam, but at this point contained almost exclusively water, the reactor operator falsely assumed that the system was overflowing. There was no level indicator for the reactor's pressure tank. One of the operators stopped the emergency cooling, which had automatically started. The reactor operators had been told during training that they should, at all costs, prevent the pressuriser from becoming totally filled with water. The steam bubble, which under normal conditions can be found in the pressuriser, and which is the only one permitted in the primary circuit, keeps the pressure in the primary circuit constant, and prevents a surge from bursting the pipes. At this point, however, there was a large steam bubble in the upper area of the reactor's pressure tank.

After 80 minutes, during which the temperature rose slowly, the pumps in the primary circuit began to cavitate, as no more water, but steam, was being taken in. The pumps were switched off, and it was thought that the natural circulation would keep the water flow going. But the steam in the piping blocked the primary circuit. The water, which was no longer circulating, turned increasingly into steam. Around 130 minutes after the initial malfunction, the upper section of the reactor was no longer surrounded by coolant. Due to its low thermal capacity, steam can only transport a small amount of heat away from the fuel rods. This leads to a temperature rise. For this reason it is important to keep the pressure in the primary circuit at a level which prevents water from evaporating at the prevalent temperatures.

A reaction between zirconium and water occurs at high temperatures. This causes the cladding of the fuel rods to oxidise, and hydrogen is released. The zirconium-water reaction destroyed the cladding on the fuel rods from the outside in. At first, the hydrogen which had been created gathered in the closure head, and passed, together with the coolant, over the open connection between the pressuriser and the blow tank, and the broken rupture disc, into the reactor containment. The atmospheric oxygen present in the containment allowed the formation of explosive gases.

The highly radioactive coolant, which had escaped, gathered at the deepest point of the containment, the so-called sump. From there, as a result of a circuit error, it was pumped into the collection tank in an auxiliary building outside the containment. The tank eventually overflowed, the water outgassed, and a small amount of these gases escaped into the surrounding area due to insufficient filters. Another, apparently less important, release path was a small leak in one of the steam generator heat pipes. Apparently, this could also be isolated after a certain time.

At 6am there was a change of shift in the control room. Those who had just arrived noticed that the temperature in the reactor system was too high, and used a reserve valve to end the loss of coolant. Up to this point, 150m^3 of coolant had escaped from the primary circuit. Already 165 minutes had passed since the beginning of the incident, when water contaminated with radioactivity reached the sensors. At this point, the radioactivity in the primary circuit was 100 times higher than expected: the meltdown was under way.

For a long time, the operators in the control room did not realise that there was too little water in the primary circuit, and that more than half of the core was not covered in coolant. Around 3 ½ hours after the incident had begun, the experts who had come running on to the scene began to realise the seriousness of the situation: new water was pumped into the primary circuit. Later, a back-up safety valve was opened, in order to reduce the pressure. After nine hours, the mixture of explosive gases in the containment ignited, and for a short period of time the pressure inside the containment rose to near the delivery pressure. Almost 16 hours had passed before the pumps in the primary circuit were switched on again, and the core temperature began to fall. A large part of the core had melted. During the following weeks, both hydrogen and water vapour were removed from the reactor. This was done with the help of condensers, but some of the gases were simply released into the atmosphere. This was a very controversial decision. It has been estimated that the accident released radioactive gas (in the form of Krypton 85) with an activity of c. $1.655*10^{15}$ Bq. Undoing the damage took more than 12 years and cost around a billion Euro.

Church Rock, New Mexico, USA

16th July 1979 – When a dam, which was a settling and evaporator tank for a uranium mill, broke, c. 460,000 tonnes of water and c. 1,000 tonnes of sullage washed over the surrounding area and into the Rio Puerco. This sullage contained radioactive material such as uranium and radium, and was contaminated with poisonous metals, e.g. cadmium, manganese and lead. The magnitude of the catastrophe can still be observed, years after the accident, within a radius of up to 120km [5][6].

1980s

Saint-Laurent, France

1980 – Due to a partial fissure in the reactor core, the building was contaminated (INES 4) [7].

Tennessee, USA

11th February 1981 – A new employee accidentally opened a valve, and 410,000 litres of radioactive coolant were released into the reactor building of the Tennessee Valley Authority Sequoyah 1 Nuclear Power Station. Eight workers were affected by radioactivity.

Buenos Aires, Argentina

1983 – Safety regulations were disregarded during modifications to the reactor core; an operator died as a result. He was only a few metres away, and was subjected to around 20 Gy of radiation (INES 4) [8].

Gore, Oklahoma, USA

6th January 1986 – In the Kerr McGee reprocessing plant in Gore, Oklahoma, a drum containing radioactive material broke after it had been heated improperly. One worker died, and 100 had to be taken to hospital.

Chernobyl, Ukraine

26th April 1986 – During a so-called maximum credible accident (INES 7) in the Chernobyl nuclear power plant in Ukraine, there was a meltdown and an explosion. Large amounts of radioactivity were released as a result of the exposure of, and a fire in the reactor core. The immediate area was contaminated, and in addition many assistants were subjected to direct radiation. The maximum credible accident was detected thanks to radioactivity readings in Finland and other European countries. A large area was cordoned off and evacuated. Different studies vary greatly in their calculations as to the number of people injured.

The accident happened while the acting head engineer was supervising a test. This test was supposed to show that there would, in the event of the reactor being turned off and concurrent failure of the external electricity supply, be a sufficient electricity supply. The design-specific qualities of the graphite-moderated nuclear reactor (RBMK-1000), and the operation of this reactor at temperatures lower than prescribed, are supposedly the causes of the catastrophe. A strong positive void coefficient – the reduction of neutron absorption by the coolant as a result of the formation of steam bubbles which accompanies an output increase – is characteristic for this reactor type under these conditions. At the same time, the advanced combustion of the nuclear fuel promoted a high void coefficient. Furthermore, the operational reactivity reserve (the minimum necessary reduction in reactivity resulting from the introduction of sufficient control rods) was not integrated in the reactor's automatic safety system; only a minimum value was given in the operational instructions. The reactor should have been switched off hours before the test was begun, as this minimum value had already been undercut. The operational team had also switched off the safety systems so that, if necessary, the test could be repeated. Otherwise, these automatic safety systems would have prevented that from happening. It is disputed whether or not these safety systems, had they been on, could have prevented the first test from being carried out under the unexpected ancillary conditions, or at least prevented a catastrophe from happening during the test.

It is probable that the final explosive output increase was due to a further constructional peculiarity of the control rod system. Most control rods have a graphite following bar on their bottom end. These rods, when they are first inserted into the reactor, cause an increase in output; only when they are deeper do they cause a reduction in output. When the shift supervisor finally activated the emergency shutdown, exactly this effect took place: many rods drew in simultaneously and supplied the reactor with more reactivity. This quickly became hyper-critical, i.e. the nuclear fission chain reaction continued without delayed neutrons, and was thus no longer under control. Within fractions of a second, the output rose, presumably to a hundredfold of the nominal output.

Another weakness of the RBMK was that is lacked containment, even if it is not certain that this containment would have withstood the explosions. The extent to which bad decisions on the part of the plant staff are responsible for the accident is also controversial. It is a fact that the operational regulations were disregarded, but it is unclear whether the staff were aware of these regulations. Here we mention the lack of experience and knowledge, especially regarding the output increase of the reactor (which was contaminated with xenon). As a new tension regulator was to be tried during the test, most of the people present were electricians.

True to the policy of secrecy, which had been adopted regarding the earlier accidents in nuclear power stations at Ignalina and Leningrad, no thorough investigation was initiated, nor were the staff in other nuclear power plants provided with important information.

Delaying the test by c. half a day made a significant contribution to causing the accident. The long exposure time to half load led to the enrichment of the reactor with Xenon-135, which absorbs neutrons. This caused the reactor's neutron-physical behaviour to become more complex and confusing. Additionally, when the test was carried out, a different shift was on to the one which had originally been planned.

Planned test procedure

Even a nuclear power station which has been turned off is dependent on the supply of electricity, e.g. for the maintenance of cooling systems, instruments, and observation. Normally, these needs are fulfilled by the public power supply. If this is not possible, emergency power generators are activated.

The reactor was to be turned off for maintenance works, and during this time the operators wanted to show that the rotational energy of the turbines, which had just been switched off, would, in the event of a concurrent failure of the outside energy supply, suffice for the 40 or 60 seconds before the emergency generators would come into action. According to safety regulations, this test should have been carried out before the plant was put into commercial operation in December 1983. A reactor not contaminated (with Xenon-135) without combustion would have offered safer conditions. It is not known why this did not happen. A test which had been carried out in the meantime in Block III had failed, because the tension fell too quickly. The test was now to be repeated in Block IV with an improved tension regulator. Before the test began, the reactor output was to be lowered (to between 700 and 1,000MW$_{th}$) by closing the steam supply to the turbines.

Chronology of events:

25th April 1986, 1.06: As is normal during a standard reactor shutdown, the first step was to reduce the reactor output from the nominal output of 3,200 MW$_{th}$ to 1000 MW$_{th}$. At 13.05, due to increased energy demand and on the instructions of the grid controller in Kiev, the output reduction was halted at 1600 MW$_{th}$, and the reactor was operated at this level. It was only at 23.10 that a further output reduction was allowed. At midnight there was a shift changeover.

26th April 1986, 00.28: At 500 MW$_{th}$ there was a changeover within the reactor output regulation. Due to an operational failure, as a result of which the nominal value for the total output regulation was not properly entered, or due to a technical defect, the output continued to sink and reached c. 30 MW$_{th}$.

As happens after every output reduction, the concentration of the Xenon-135 isotope in the reactor core increased temporarily ("Xe-contamination"). As

Xenon-135 absorbs the neutrons which are necessary for nuclear chain reactions, its increased concentration caused the reactivity of the reactor to decrease continually. At 00.32 on the 26th April 1986, the operational team wanted to remove more control rods, and thereby increase reactor output. Due to the Xe-contamination which had taken place in the meantime, it was only possible to raise output to c. 200 MW_{th}, i.e. 7% of the nominal output. At this point the reactor should have been shut off, as operation at this output level was forbidden (guidelines stipulate that the reactor should not be used if the output is less than 20% of the nominal output), and at this time fewer control rods were present in the core than are prescribed for safe operation.

26th April 1986, 1.03 or 1.07: When the turbine inlet valves are closed, the emergency core cooling system switches on as usual. However, this system had already been switched off. In order to simulate the cooling system's energy consumption during the test, two additional main cooling pumps were switched on, one after the other. The increased flow rate of coolant which resulted caused heat to be conducted away from the core more efficiently and reduced the concentration of steam bubbles in the core. The positive void coefficient caused a reduction in reactivity. The (automatic) reactor regulators reacted to this change by removing more control rods. The reactor condition moved further into the prohibited range.

26th April 1986, 1.23.04: The actual test was begun by closing the turbines' quick action valves. This stopped the conduction of heat away from the reactor, and the temperature of the coolant rose. The positive void coefficient caused output to rise, and consequently the automatic reactor regulators reacted by introducing more control rods. Control rods can only be introduced relatively slowly, which meant that the output could not be stabilised. The neutron flow continued to increase. This caused a more rapid breakdown of the neutron poisons (especially Xenon-135), which had accumulated in the core. This caused a renewed increase in reactivity and reactor output, due to which ever greater amounts of steam bubbles were created. These bubbles also caused productivity to rise. These effects built up. At 1.23.40, the shift supervisor manually activated the emergency reactor shutdown. In order to do this, all the control rods which had previously been taken out of the core, were reintroduced into the reactor. At this point, a further conceptual error of the reactor became evident: the rods had graphite blocks at the tip (graphite was the main moderator for the reactor), which meant that reactivity increased for a short time when the rods, which had been fully removed, were put back into the reactor. This stopped once the rods had reached a deeper section of the reactor. The simultaneous reintroduction of all rods caused a large increase in neutron production, as a result of which the reactivity rose to such a level that, (at 1.23.44) there were enough fast neutrons (i.e. excluding the delayed neutrons) to sustain the chain reaction ('fast criticality'). Within fractions of a second, the output exceeded the nominal value by a hundredfold.

The heat warped the control rod tubes, which meant that these rods could not reach deep enough to achieve their effect. The pressure pipes were damaged, and the zirconium from the fuel rods and the graphite were able to react with the surrounding water. Large quantities of hydrogen and carbon monoxide were produced, which were allowed to escape as a result of the damaged reactor core. Under the roof of the reactor building, these gases combined with the oxygen in the air to create a flammable gas. Presumably, this gas was ignited and caused a second explosion.

It is not quite clear which of the explosions lifted the upper shell of the reactor core, which weighed over 1,000 tonnes. Additionally, the explosions destroyed the roof of the reactor building (which only served as protection against the weather). The reactor core was no longer shut in, and had direct contact to the atmosphere. The glowing graphite in the reactor core caught fire immediately. Over the following ten days, 250 tonnes of graphite, i.e. c. 15% of the total stock, burned.

The explosions and subsequent burning graphite released large amounts of radioactive material into the environment, and the high temperature of the graphite fire meant that these materials reached high altitudes. It was particularly the volatile isotopes Iodine-131 and Caesium-137 which combined to form dangerous particulate materials which, in the form of radioactive clouds, were carried hundreds or even thousands of kilometres away before leaving the atmosphere as rain. Radioactive material with a high boiling point, however, was mainly released in the form of dust particles which were deposited near the reactor.

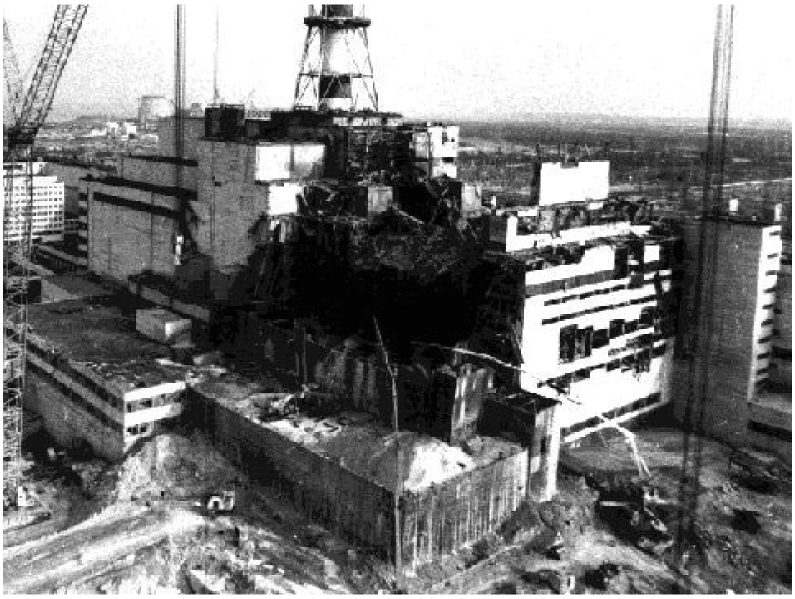
26th April 1986, around 5.00: The fires outside the reactor were put out. Block III was shut down.

27th April 1986: Blocks I and II were switched off at 1.13 and 2.13 respectively. Workers began to fill the reactor in Block IV with lead, boron, dolomite, sand and clay. This reduced the emissions of fissile products and covered the graphite fire in the core.

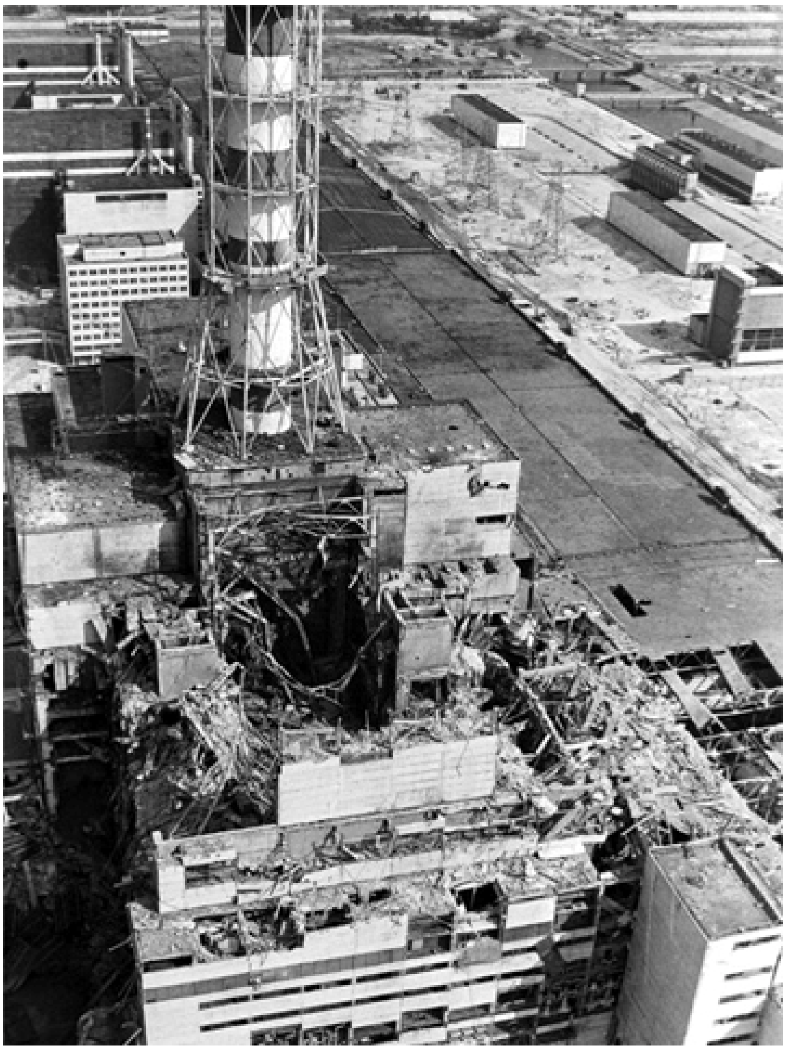
28th April 1986, 9.00: An alarm at the Swedish nuclear power plant in Forsmark was sounded due to elevated radioactivity levels in the surrounding area.[1] Employees' work clothes, when tested, had high radioactivity readings.[2] Once they had been able to exclude their own plants as the cause, the wind direction directed their suspicions towards a nuclear power plant within the USSR. On the same day, the official Soviet news agency TASS made the first reports of an 'accident' in the nuclear power plant at Chernobyl.

29th April 1986: Soviet sources mentioned a 'catastrophe' and two fatalities for the first time.[3]

6th May 1986: A further release of fissile products was largely prevented.



Picture: Nuclear power plant Chernobyl, reactor 4 after the catastrophe from 26th April 1986. Source: http://de.wikipedia.org



Picture: Nuclear power plant Chernobyl, reactor 4 after the catastrophe from 26th April 1986. Source: http://de.wikipedia.org

Consequences of the reactor catastrophe

The consequences of the reactor catastrophe are still a controversial discussion topic. A comprehensive report was produced by the ‘Chernobyl Forum’. The Chernobyl Forum is composed of: four of the UN’s subsidiary agencies (the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)); four autonomous organisations linked to the UN by agreements (the International Atomic Energy Agency (IAEA), the World Bank, the World Health Organisation (WHO), and the Food and Agriculture Organisation (FAO)); and the governments of Belarus, Russia, and Ukraine.[4]

The Chernobyl Forum’s report has been criticised by some scientists and NGOs. On the one hand, the report has been accused of being partisan and deliberately making light of the consequences of the catastrophe. On the other hand, systematic failings have been highlighted. The study has been accused of dealing only with the consequences in Belarus, Russia and Ukraine, even though a substantial amount of radiation exposure occurred in Central and Western Europe. Additionally, it has been claimed that the Chernobyl Forum’s report ignored studies which cited higher number of victims. Criticism was also made due to the fact that investigations were only instigated five years after the accident.[5] ‘The other report on Chernobyl’ (TORCH) was published and offered an opposing opinion. TORCH was written and researched by the British scientists Dr. Ian Fairlie and Dr. David Sumner, and predicts much more severe health risks resulting from the catastrophe than does the report by the Chernobyl Forum. The report was commissioned and privately financed by the Green MEP and anti-nuclear activist Rebecca Harms.

For the most part, the following statistics are taken from the two above-mentioned reports:

Contaminated areas:

The map shows Caesium-137 contamination in Belarus, Russia and Ukraine (Ci/m^2). The largest amounts of radioactive material were released in the ten days following the explosion. The clouds containing radioactive fallout spread firstly over many parts of Europe, before covering the entire northern hemisphere. Changing air streams carried the clouds to Scandinavia, then to Poland, Czechoslovakia, Austria, southern Germany, and northern Italy. A third cloud reached the Balkans, Greece and Turkey. Depending on regional rainfall, the earth in these countries was affected to varying degrees. In total, around $218{,}000 km^2$ were contaminated with more that 37,000 Bq (37kBq) Caesium-137 per m^2. More than 70% of this area is in Russia, Ukraine and Belarus. Although these areas suffered the highest concentrations of volatile nuclides and fuel particles, more than half the total volatile components and hot particles were deposited in other countries. Yugoslavia, Finland, Sweden, Bulgaria, Norway, Romania, Germany, Austria and Poland were each affected with more than a petabecquerel (10^{15} Bq) of Caesium-137. In total, 3,900,000km^2 (40% of the total area) in Europe were contaminated by Caesium-137 (at least 4 kBq/m^2).

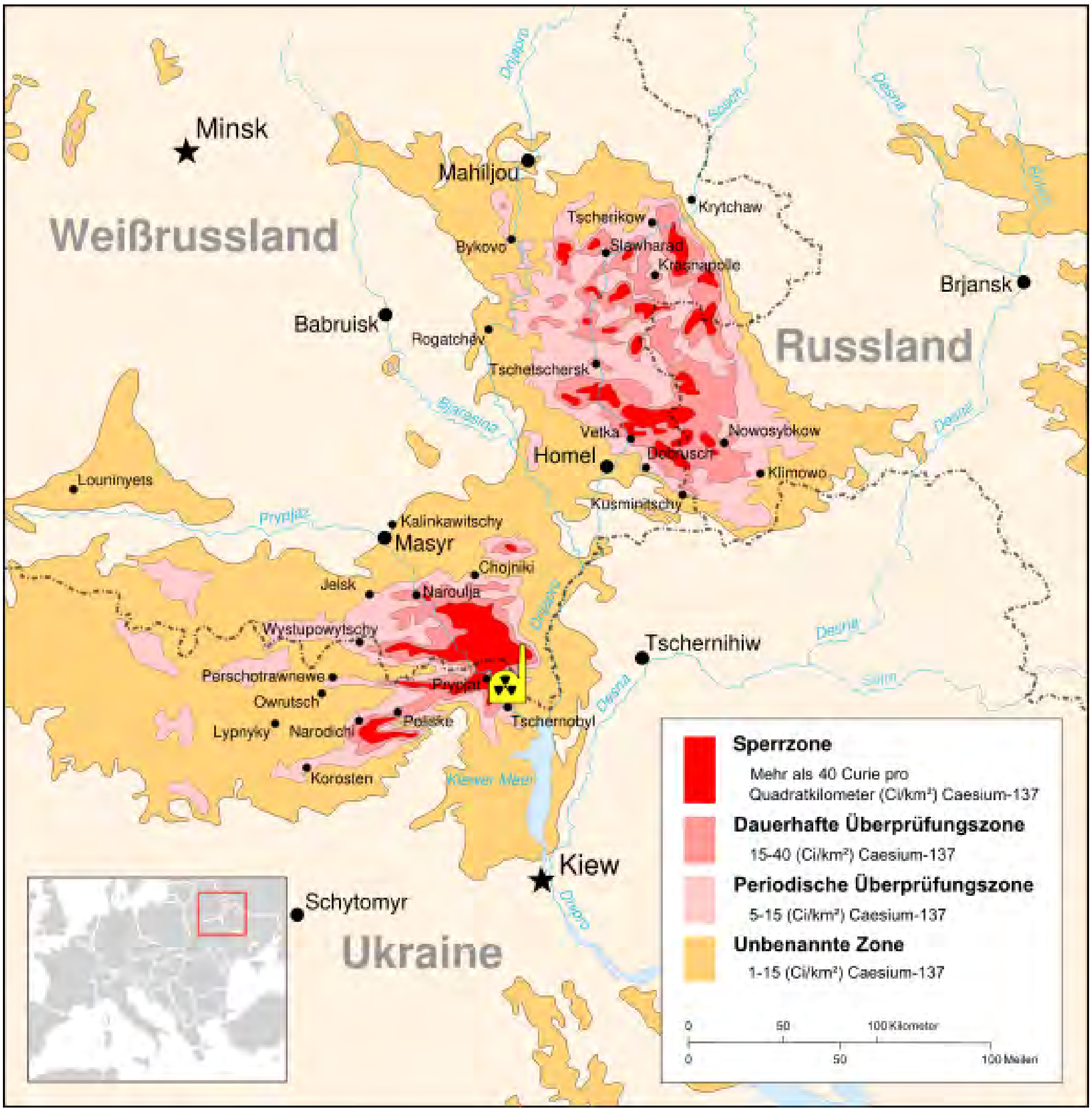


Figure: Contamination with Caesium-137 in the year 1996 — 10 years after the catastrophe of Chernobyl. Source: http://de.wikipedia.org

In the worst affected areas of Germany, in southeast Bavaria, ground contamination was up to 2 Ci/km^2 (74 kBq/m^2) of Caesium-137. In Belarus, Russia and Ukraine, these areas would have been designated contaminated zones. For example, mushrooms, forest fruits and wild animals in some German regions, above all in the south, are still badly contaminated today. According to the Federal Authority for Radiation Protection, contamination in the south is around ten times higher than in northern Germany. In Germany, the flesh of wild boar has registered Caesium-137 values of up to 40,000 Bq/kg. The average was 6,800 Bq/kg, which was more than ten times higher than the EU's maximum stipulated value of 600 Bq/kg. Even some regions in Scandinavia and Great Britain are subject to high levels of caesium contamination. The toxicity in such cases only decreases very slowly over a period of many years. In some countries, there are still restrictions on the production, transport and consumption of foodstuffs which continue to be affected by the radioactive fallout from Chernobyl.

Groups of people exposed to radiation:

Immediately after the accident, and up to the end of 1987, around 200,000 people (known as 'liquidators') were involved in the cleanup efforts. On the first day, around 1,000 of these received very high doses of radiation in the range of two to 20 Gray (external gamma radiation). By comparison, the remaining workers received relatively low doses, to a maximum of c. 500 millisieverts (mSv); the average dose was c. 100 mSv. According to the WHO, the number of liquidators increased to between 600,000 and 800,000 in the subsequent years. The exact number is unknown, as only 400,000 liquidators were registered, and even their data are not complete. Those liquidators who began work later received noticeably lower radiation doses.

Around 116,000 people were evacuated from a 30-km zone around the reactor in spring and summer 1986. Later, a further 240,000 people were resettled. It was calculated that the Ukrainian evacuees had received an average dose of 17 mSv (the doses ranged from 0.1 to 380 mSv). Among evacuees in Belarus, the average dose was 31 mSv. (In two localities, the maximum average dose was 300 mSv.)

In the first days after the accident, the ingestion of radioactive iodine with food led to large variations in thyroid doses (on average between 0.03 and 3.0 Gy, with a maximum value of 50 Gy) among the general public. The few inhabitants of Prypiat, who were quickly given tablets containing stable iodine, were the exception to this, and received significantly lower thyroid doses. In the 20 years since the accident, those inhabitants who were not evacuated have been subjected, both through external radiation and through internal radiation imbibed with food, an average effective total dose of c. 10 to 20 mSv. The highest value was around 100 mSv. Those five million people who were affected and live in the contaminated areas, generally receive an annual Chernobyl dose of less than 1 mSv, although around 100,000 people still receive more than 1 mSv annually.

Health consequences:

237 people were suspected of having acute radiation sickness, and there were 134 confirmed cases (particularly plant employees and fire-fighters). 28 of these people died in 1986, a further 19 died between 1987 and 2004, some possibly from other causes. According to the Ukrainian health authorities, 15,000 liquidators have died in the meantime (a particularly large percentage committed suicide), and 92.7% have become ill.[6]

It is hard to estimate the long-term effects of the accident. Due to the uncertainty of much of the data and the model epidemiological parameters, all predictions regarding future morbidity and mortality rates should be regarded with caution.

A dramatic increase in the number of cases of thyroid cancer in Belarusians, Russians, and Ukrainians, who were children or adolescents at the time of the accident, is one of the most frequently observed health-related consequences. This rise is attributed to contamination with radioactive iodine, and was first seen in the early 1990s in Belarus. In total in the three countries, c. 5,000 cases had been diagnosed by the beginning of 2006. Many more cases are being reckoned with over the next years. It is uncertain whether there is an increased risk of thyroid cancer developing in people who were already adults at the time of exposure to radioactive iodine.[7]

An increase in the number of leukaemia cases resulting from radiation has not yet been conclusively proven, but nor can it be refuted. Some of the studies on this topic were based on unreliable data or produced contradictory results. Among a large cohort of Russian liquidators, the risk of developing leukaemia was almost twice as high (when the ‘registered’ radiation dose was between 150 and 300 mSv).

The release of radioactivity caused by the catastrophe will also cause other types of cancer. These will, however, only emerge after having been latent for many decades. The IARC has not yet been able to prove that there are higher rates of cancers, other than thyroid cancer, which have undoubtedly been caused by radiation, in those areas which were the worst affected. Indications of higher rates of breast cancer, for example, would have to be followed up.

The IARC’s estimates regarding the cancer rates which are to be expected, are based on risk models which have been developed through research on other populations (mainly those affected by the atomic bombs in Japan), and on the controversial linear dose-to-effect relationship. According to these models, Europe will see more than 16,000 cases of thyroid cancer and 25,000 cases of other cancer types by 2065, which have resulted from radiation from Chernobyl. Two thirds of thyroid cancer cases, and at least half of the cases of other types of cancer, will be seen in Belarus, Ukraine, and the most contaminated areas in the Russian Federation. These illnesses will cause around 16,000 deaths. This rise will hardly be visible in the national cancer statistics, as there will be a large number of cancer cases in Europe at the same time. TORCH presented higher estimates as to the number of cases. According to this report, Chernobyl could cause between 30,000 and 60,000 additional cancer-related deaths among the 570 million people alive at the time.

Having evaluated the available epidemiological studies, the Chernobyl Forum sees neither evidence nor indications of direct links between ionising radiation and lower fertility among men or women, the number of stillbirths, negative affects to unborn children or on the general intelligence and health of the children, or complications during childbirth. Decreasing birth rates in the affected regions could be the result of the population’s fear, or of the migration of many young people. The Forum believes that the moderate but constant rise in the number of reported genetic deformities in affected and unaffected areas of Belarus is the result of a more comprehensive census, and not of radiation [8]. However, studies by other organisations and scientists show a temporal connection between the Chernobyl catastrophe and a noticeable increase in genetic or teratogenic damage, e.g. stillbirths, deformities, in the accident area, as well as in Germany and other European countries. These studies suggest that there is a causal link [9].

The researchers or publishers who support one opinion have continually accused the supporters of the other opinion of being biased, or have rejected their findings due to incomplete validation of the data or other methodological shortcomings. These are mostly ecological studies, which should be considered with caution due to the lack of an individual dose attribution. Some authors have found an ecological dose-effect relationship for stillbirths, birth defects, and male-female ratios, for the particularly badly affected areas of Bavaria among others [10][11]. These authors, however, face the argument that such massive effects should not be seen in Germany, where the increase in radiation doses was relatively low, and within the range of natural exposure. This scepticism is supposedly supported by numerous negative epidemiological findings in Germany and other European countries, some of which suffered considerably higher doses of radiation. Additionally, there is no known biological mechanism which could explain such effects to the extent which has been observed.[12]

The objection that non-significance is mistaken for evidence of an effect which does not exist, is raised against negative epidemiological findings. The statement, often formulated in some studies, that such effects either do not actually exist, or due to the study cannot be proven, is correct. Additionally, it has not yet been shown that areas which were relatively unaffected also had increased stillbirth and deformity rates. This would be an indication of other causes, or of a purely coincidental connection.

In the countries most badly affected by the Chernobyl catastrophe, a considerable increase in non-malignant illnesses is also to be observed. The average life expectancy has decreased significantly. Both, however, also apply to the uncontaminated areas. The extent to which these changes are the result of high radiation exposure, or of other factors (e.g. poverty, malnutrition, unhealthy living conditions, economic and social decline since the breakup of the USSR, psychological damage caused by the catastrophe, the evacuation and relocation, self-damaging behaviour, better diagnosis and detection of illnesses) is contested. There is great variation in the reliability of data and in the methodological quality of many studies.

Economic consequences

The Chernobyl catastrophe resulted in huge damages, and badly affected the regional economy. It is hard to assess the actual economic effects of Chernobyl due to the economic upheaval resulting from the disintegration of the USSR. The damages had serious consequences for the budgets of the three affected countries.

Farming and forestry were two particularly badly affected branches of the regional economy. Due to radiation, just under 800,000 hectares of land and 700,000 hectares of forest could no longer be used for economic purposes. Regional agriculture suffered, and continues to suffer from the 'Chernobyl stigma' (a lack of demand for regional produce and of private investment in the region).

Worldwide, in the medium and long term, Chernobyl caused considerable economic losses due to the increased emotionalisation of the discussion of radiological topics. The supporters of nuclear power argue that the loss of rationality and the politicisation of research into nuclear power caused these losses. They argue that, before Chernobyl, political decisions had been taken to abandon nuclear technology; at a later point, many of these decisions were then abrogated.

<u>Foreign responses to the catastrophe</u>

Reactions to the accident outside the former USSR varied greatly:

Germany and Austria

In southern Germany and Austria, heated debates about 'contaminated foodstuffs' and other possible risks to the public raged for months. During this period, the basic attitude towards nuclear power was much more important than relevant arguments. Furthermore, recommendations were made to plow under arable crops and close children's playgrounds, although there is now disagreement as to whether such actions were suitable and necessary. The nuclear accident caused the consensus regarding the use of nuclear power to crumble; this consensus had already been challenged by the opponents of nuclear power. Large sections of society were now in favour of abandoning nuclear power. In the political sphere, this demand was taken on by the Social Democratic Party of Germany (SPD). Due to the Chernobyl accident, those nuclear power plants which were in planning were not realised.

The so-called 'radioactive whey' is an example of the contemporary discussion in Germany. Some dairies in regions which were particularly badly affected were told to separate the whey from the milk. Instead of being sold, the whey was to be stored: the radioactive caesium in the whey had become extremely enriched. The suggestion to use the whey as fertiliser (it is a particularly good fertiliser) had no chance of being accepted, even though the whey was less contaminated than many fertilisers on the market. Using the whey in this manner would even have led to reduced radiation in the fields. Instead, the whey was passed through ion exchangers before being disposed of in expensive, specially constructed plants. After a long odyssey through northern Germany, which was keenly followed by the tabloid media, a group of wagons containing 'radioactive whey' was temporarily stored on a military base pending disposal. Cases like this show that institutions, and society in general, are helpless and overburdened in the face of the underlying event.

In the Federal Republic of Germany, once the nuclear accident had been made known publicly, dairy farmers were requested to delay the changeover from winter to summer feed (and pastures), which had been planned for the beginning of May, until the first rains had fallen. The catastrophe coincided with a dry spell which lasted for several weeks. On the one hand, this encouraged the meadows to flourish, on the other, a constant easterly wind effected the spread of radioactivity to the west. Later, farmers were compensated for the extra feed costs.

A few weeks after Chernobyl, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety was founded in the Federal Republic of Germany. This was, above all, a reaction to politicans' handling of the catastrophe and its consequences, which was seen as being too uncoordinated.

German Democratic Republic:

Out of consideration for the Soviet sister state, information about the accident was only released very slowly, and facts were often downplayed or not mentioned at all. In the weeks after the accident, an abundant array of vegetables was available, while at the same time newspapers were reporting low-level stabilisation of radioactivity. In the GDR, the area around Magdeburg was particularly badly affected. The results of tests carried out by the regional hygiene institute did not reach the public.

<u>The current discussion:</u>

Even today, the boundaries between scientific information, targeted downplaying and fear mongering in the discussion about Chernobyl are blurred. Chernobyl has become a symbol of the dangers related to the use of nuclear power, and is often used by opponents as an argument supporting the speedy abandonment of nuclear technology. The advocates of nuclear power, however, argue that Chernobyl is misused as a knockout argument against nuclear power. Today it is widely recognised that exposure to radiation in Germany and Austria was mostly lower, and only in a few exceptional cases comparable with that caused by atomic bomb tests before the Test Ban Treaty.

<u>Chernobyl and the exclusion zone after the accident:</u>

On the 2nd and 3rd May 1986, c. 45,000 inhabitants were evacuated from areas within a radius of 10km around the reactor. On the 4th May, a further 116,000 people were evacuated from areas within 30km of the reactor. In the subsequent years, 210,000 more inhabitants were evacuated, and the exclusion zone is now 4,300km^2 in size.

As a result of the economic situation, and despite the high radiation, around 1,000 inhabitants returned to the exclusion zone within weeks of the accident. They returned mainly because neither the former Soviet Union, nor the current Ukrainian government, could provide them with a sufficient livelihood in the areas to which they were evacuated. Additionally, many did not think that there was a high risk to their health. As most of those who returned were elderly people, it is difficult to determine how many of them died as a result of radiation. Some who are still alive today believe that ‘many died’. Some report that, after 20 years of living in the area, they have not suffered from any radiation-related complaints. Around 100 returnees live in Chernobyl itself, which is a few kilometres away from the reactor. All returnees and all inhabitants of ‘Zone 3’ (the area around the exclusion zone) who are older than 47 receive a small monthly special pension, equivalent to around $60, from the Ukrainian state. Despite this, almost all inhabitants of the exclusion zone and ‘Zone 3’ (which was affected, but not evacuated), subsist on local produce – wild mushrooms, fruit and vegetables – due to poverty and unemployment. The effects of this on adults are hard to assess, not least due to numerous other adverse factors such as: bad nutrition, the bad economic situation, alcoholism, and rising AIDS rates. According to estimates from the Radiological Institute in Ivankiv, around 50km south of Chernobyl, only c. 3% of the vegetables, fruit and game, which inhabitants have had tested for free, are above the threshold value. However, the values recorded vary greatly depending on the microregion, and some samples contained very large amounts of radiation.

Today, Chernobyl is mainly home to workers and scientists employed in the exclusion zone in connection with the catastrophe. The town was chosen as, in comparison with others in the exclusion zone, it was relatively unaffected. Nevertheless, it is only possible to enter the exclusion zone with special permission. Signs warn of the dangers of dust storms, which occasionally occur in summer and which spread radioactivity. Inhabitants are provided with shelters for such occasions, and warning signs tell them to seek out these shelters immediately, and not to leave them until the storm has abated or they have been rescued. There is a little hotel for foreign scientists, and the exclusion zone’s administration, as well as several Ukrainian scientific organisations, have offices or foreign branches there. In order to protect against the dangers of radiation, workers involved in the repair works on the ‘sarcophagus’ or who live in Chernobyl are rotated every 14 days. The working week for those in the administration was shortened to four days (Monday to Thursday), and at the weekend they return to their hometowns outside the exclusion zone (mostly to Kiev). Before leaving the area, they are tested for radioactivity. Visitors are left to decide how to deal with the radiation risk. While local scientists walk around the exclusion zone without any protection, one also comes across foreign experts in the most highly contaminated areas within a few kilometres of the reactor, who are wearing protective suits and using breathing apparatus.

Most of the thousands of vehicles and helicopters which were deployed in 1986 have been deposited in a central ‘cemetery’, due to high levels of radiation. Despite official monitoring and fencing in, these machines have been taken apart and plundered. Motors and windscreens are missing, and whole helicopters have been dismantled and removed.

Until the breakup of the USSR, locals were not informed of the consequences of the accident. Today, authorities and experts in Ukraine – partly the same doctors and radiologists who were employed at the time of the accident – deal with it in an open and helpful manner. Subsidies for the consequences of the Chernobyl catastrophe are now an important economic factor for Ukraine.

The Chernobyl nuclear reactor today:

After the cleanup efforts, all three blocks, which were still functioning, were powered up again. After a fire in the turbine hall, the second reactor block was taken out of operation in October 1991. Block I followed in November 1996, and Block III on the 15th December 2000. The shutdown was the result of pressure from the EU, and Ukraine received compensation.

The damaged reactor is now protected by a provisional permeable 'sarcophagus'. The inside has been preserved as it was at the time of the catastrophe. Between 150 and 180 tonnes of the reactor core, which weighed 190 tonnes, are still in the building, partly in the form of molten and solidified fuel rods made from uranium, plutonium, graphite and sand, partly in the form of dust and ashes found in liquid form in the reactor sump and foundations.

Picture: Sarcophagus Chernobyl. Source: http://de.wikipedia.org

The goal of the international 'Shelter Implementation Plan' is to erect a new and stable sarcophagus. The first step was to strengthen the roof of the original sarcophagus and improve the ventilation system. The new sarcophagus is to be erected over the old one. This should enable the removal of the old one without the release of further radioactive material. The new sarcophagus will be 257m long, 150m wide and 108m high. The commission was placed on the 17th September 2007 [13] with Novarka Consortium. Some people do not think that an additional casing is necessary.

Picture: Sarcophagus Chernobyl. Source: www.nachlese.at/tschernobyl-sarkophag.htm

Continuation of the chronological documentation of accidents:

<u>Decatur, Georgia, USA</u>
6th June 1988 – The Radiation Sterilizers company in Decatur, Georgia, reported the loss of Caesium-137. 70,000 containers of medical supplies and milk packaging were recalled. Ten workers were contaminated, three of them so badly that they in turn contaminated their cars and houses.

<u>Vandellòs, Spain</u>

1989 – A fire in the Vandellòs nuclear power plant badly damaged the safety systems. This accident was not serious, and the event was classified as INES 3 (serious incident) [10].

1990s

<u>Seversk, Russia</u>

6th April 1993 – An accident in a Siberian nuclear power plant (partly used for the production of weapons-grade plutonium) released large amounts of radioactive material. As a result, many hundred square kilometres were polluted, and the inhabitants of Seversk (formerly Tomsk-7) were exposed to radiation. There was an increase in the number of cancer-related deaths, as well as reports of mutated animals and plants.

Tokaimura, Japan

30th September 1999 – The workers in a fuel rod factory in Tokaimura, Japan, filled a preparation tank with 16.6kg of uranium mixture (instead of the prescribed 2.3kg). An uncontrolled chain reaction was triggered and radiation released. Two of the three workers died of radiation sickness. At least 150 people were exposed to high levels of radioactivity, among them were 81 workers who tried to stop the chain reaction. Several hundred residents were contaminated. The accident was classified as INES 4.

2000s

Paks, Hungary

10th April 2003 – While fuel rods were being cleaned in Block 2, their casing was damaged. Radioactive gas escaped and caused a 'serious incident' (INES 3). No-one was injured.

Windscale (Sellafield), UK

19th April 2005 – After the serious accident in 1957, 2005 saw a second incident (INES 3) in Sellafield. After about 7 months, a leak was discovered in the reprocessing plant. 83,000 litres of radioactive fluid consisting of sulphuric acid, uranium and plutonium had been released. The hall in question was so badly affected by radiation that remote-controlled machines had to undertake the removal of the fluid.

Fleurus, Belgium

11th March 2006 – A worker in a plant belonging to the company Sterigenics, which uses Cobalt-60 to sterilise medical apparatus, was contaminated with 4.6 Gy of radiation and had to be treated by doctors. The worker entered the radiation area without a measuring device to carry out a quick inspection while the plant was not active. The cobalt should have been in a water tank at this time, but apparently was uncovered due to a hydraulic error. (INES 4) [12]

Appendix A: Sources

[1] Peter Jedicke: The NRX Incident, 1st May 2006
[2] California Energy Commission: Nuclear Plants in California, 1st May 2006
[3] nuclearfiles.org: Accidents 1960's, 18th May 2006
[4] The International Nuclear Event Scale, 21st May 2006

[5] ask1.org: Harrisburg / Churchrock - Das China-Syndrom, 18th May 2006
[6] nuclearfiles.org: Accidents 1970's, 19th May 2006
[7] IAEA: The International Nuclear Event Scale, 21st May 2006
[8] IAEA: The International Nuclear Event Scale, 21st May 2006
[9] nuclearfiles.org: Accidents 1980's, 18th May 2006
[10] IAEA: The International Nuclear Event Scale, 21st May 2006
[11] ask1.org: Windscale / Sellafield – Strahlendes Beispiel Großbritannien, 18th May 2006
[12] IAEA: Overexposure of employee in irradiation facility, 18th May 2006

Appendix B: Hiroshima and Nagasaki – the first victims of nuclear bombs

63 years have passed since 6th and 9th August 1945, when nuclear bombs were used for the first time ever on Hiroshima and Nagasaki. The number of living people who can remember these events is constantly diminishing, and the events themselves are being forgotten or becoming ‘sterile knowledge’. Appendix B presents these historical events, starting with the motivation behind the deployment of the nuclear bombs, through to the consequences of their detonation.

Although the 63 years which have passed since the events in Japan are a considerable period, and the topic of nuclear weapons lost some of its explosiveness with the end of the Cold War, it is now becoming more important. The discussion around nuclear weapons now has a new facet. It is no longer the super powers which stand threateningly opposite one another. The main dangers are now considered to be the possible use of nuclear weapons by terrorists, or the emergence of new countries boasting nuclear arsenals. The most current example is the discussion around Iran’s nuclear programme. Even the (assumed) development of nuclear weapons could unleash dramatic global developments in a region as full of tension as the Middle East: one need only think of an (unlikely) pre-emptive Israeli strike, or the use of nuclear weapons following the example of 9/11.

Hiroshima and Nagasaki: Chronology

Prologue

In April 1945, the Soviet dictator Joseph Stalin revoked the Soviet-Japanese Neutrality Pact, which had been signed in 1941. He had promised Harry S. Truman’s predecessor, Franklin D. Roosevelt, to enter the war in the Pacific at the latest three months after the end of the war in Europe. Stalin wanted to guarantee part of the Far Eastern war spoils for himself, and to shape the future of the region.

The Manhattan Project, initiated in 1942, was supposed to produce three deployable nuclear bombs. The American Interim Committee, which had been created in May 1945, was to develop suggestions for their use. On 2nd June 1945, the Committee recommended using the bombs immediately after they had been finished, and without warning, against targets in Japan’s war industry. They were not to worry about the numbers of potential civilian victims. Only the Undersecretary of War, Ralph Bard, voiced concerns over the plan.

Around 12,500 American soldiers died during the capture of the Japanese island Okinawa in July 1945. At this point, a total of 70,000 US soldiers had fallen in the Pacific arena. The American public was worried. It had been estimated that, in the event of a mass US landing on the Japanese mainland, continued Japanese resistance could lead to 300,000 further deaths.

The US air force had completely controlled Japanese air space for nine months. Since February 1945, there had been intensified airstrikes, following the British example of using incendiary bombs, which had destroyed 40% of around two thirds of Japanese cities. Additionally, Japan had lost almost its entire navy, the majority of its air force, and most of its conquered territories. The loss of raw materials had badly damaged the economic basis of the Japanese war effort, but the costly battles at Okinawa and Iwo Jima had clearly displayed Japan's unchanged and unbroken will to fight. Only a small percentage of troops was willing to surrender, the rest fought to the death. No-one was certain if the civilian population would be equally ready to sacrifice themselves. The American assessment of the situation was correspondingly diverse. The US Air Force was convinced of the gruelling effect of its strikes, and believed that the regime could only hope for favourable peace conditions and the retention of its national sovereignty. The status report of the strategic bomber fleet indicated that, if their conventional air strikes continued as they were, the Japanese would capitulate by December 1945. [2] By contrast, the US Army, which had been on the receiving end of bitter losses during previous landings, was reckoning with the worst if it came to an invasion. This would have particularly been the case if the preparations for invasion were delayed, and the Japanese troops had more time to recover.[3]

Until this point, the US Army had only planned for further invasions of the Japanese mainland to take place after November 1945. On July 4th, the British and American military leaders discussed the future course of the war in the Pacific. The British government had been informed of the developments in the construction of nuclear bombs, and agreed to their deployment. The idea of launching the finished bombs over unpopulated areas in Japan as a warning, which had been brought up in passing, was disregarded.

On the 9th July, the Japanese ambassador in Moscow had asked for peace negotiations. The Russian Foreign Minister, Molotov, was to deliver this request to the participants of the forthcoming Potsdam Conference (17th July-2nd August). The USA had been informed by the 13th July 1945.[4]

On the 16th July 1945, in the run-up to the Potsdam Conference, Truman was in Berlin when he heard about the first successful detonation of a nuclear bomb, near Alamogordo in the desert of the US state New Mexico (Trinity Test). The second bomb, 'Little Boy', was immediately shipped to the Pacific island Tinian, where it was to be made ready for use. On the same day, Winston Churchill learned of the successful test, and noted in his memoirs how freeing the news was in the face of costly land battles: 'The nightmare was suddenly over, and in its place emerged the bright and comforting prospect that one or two battles could end the war'.

Later, General Dwight D. Eisenhower reported that the decision to use both nuclear bombs had already been made before 16th July. He had advised Truman against the decision, as the Japanese had already shown themselves to be ready to compromise, and because the USA should not be the first to use such weapons. Nevertheless, Truman wrote in his diary, ‘Believe Japs will fold up before Russia comes in.’

It was only on the evening of 24th July that Truman revealed casually to Stalin that the USA had developed a new type of bomb which would break the Japanese fighting spirit. Truman notes in his diary that Stalin took the news with outward composure and advised him to use the weapons for good. It is assumed, however, that Stalin had been informed of the completion of the US nuclear bombs by Klaus Fuchs, one of the workers at the Manhattan Project, as on the same evening he authorised Lawrenti Beria, his intelligence chief, to accelerate the construction of the USSR’s nuclear bomb, which had been started in 1943.[5]

On the 26th July 1945, Truman delivered the Potsdam Declaration in the name of the USA, the Chinese Republic under Chiang Kai-Shek, and the United Kingdom. The Declaration demanded the immediate and unconditional capitulation of the Japanese government. This had not been discussed with the USSR. Molotov had in vain asked the USA to delay the ultimatum for a few days, until his government had been able to abrogate the Neutrality Pact with Japan. But the USSR’s entrance into the war in the Pacific was not desired. The Declaration went: ‘The full application of our military power, backed by our resolve, will mean the inevitable and complete destruction of the Japanese armed forces and just as inevitably the utter devastation of the Japanese homeland.’ Japan would be fully occupied, its leaders deposed and eradicated, democracy would be introduced, war criminals punished, Japanese territory restricted to the four main islands, and reparations demanded. Thereby, Japan would maintain its industries, and later be allowed to participate in international trade. The alternative was immediate and total destruction.

There was no indication of the planned deployment of an innovative weapon, nor of its target. As the US invasion of Japan was only planned to start three months later, the Japanese government had to assume that this was just the normal ritual of threats, meant to demoralise the Japanese, and not a concrete warning. At the same time, they were still hoping that Stalin would bring the Western Allies to accept the peace initiative which had been set in motion. It was particularly the territorial losses which seemed unacceptable. General Kantaro Suzuki’s response was as follows: ‘The Government finds nothing of any value in the collective declaration, and hence sees no alternative but to fully ignore it, and to commit to ending the war successfully.’ In any case, the US government had not been expecting a positive response. Already on the 24th July, Truman had ordered General Carl Spatz, the commander responsible, to have the bombs ready for deployment by the 3rd August. Truman left the choice of targets to Spatz.

Hiroshima: launching the first nuclear bomb

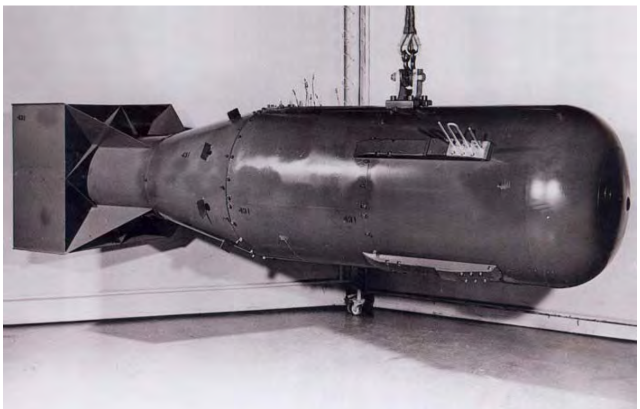
Selecting the target

Hiroshima was one of the few Japanese cities to have been spared bombings. Apart from Hiroshima, the Target Committee in Los Alamos had chosen Kyoto, Yokohama, Kokura, Niigata and Tokyo as possible targets. However, Hiroshima was the seat of the headquarters of the Second Army under Field Marshal Hata Shunroku. The Second Army was responsible for the defence of southern Japan. As a result, it was a troop staging area, and a place where important war supplies were stored. Most of the 225,000 inhabitants, however, were civilians, and 10% of these were Korean or Chinese forced labourers.

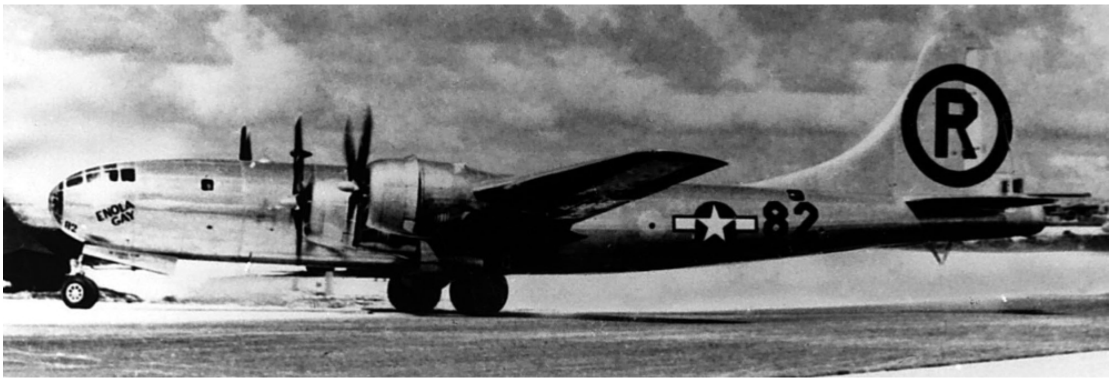
Spatz thought Hiroshima the best suited target, as it was the only one of the possible targets which had no POW camp. There were only a few American POWs and about a dozen Germans there. The assumption that the Japanese would deploy POWs in the city as shields was also the reason why no concrete warning was given.[6] Apart from a few concrete constructions, the centre of Hiroshima consisted of wooden buildings. Hence the US military leaders reckoned with a fire storm. In this way, industrial plants on the outskirts of the city would also be destroyed.

Preparations for take-off

On the 31st July, the uranium bomb ‘Little Boy’ (length: 3m; weight: 4t; explosive force: 12,500t TNT) was ready for use. The components for the second bomb, ‘Fat Man’, arrived on Tinian. The take-off, which had been planned for the 1st August, had to be delayed due to a typhoon over the island. On the 4th August, the pilot, Paul Tibbets, discovered his mission and was sworn to secrecy. He christened the B-29 Superfortress N. 82 ‘Enola Gay’, after his mother. All board weapons, with the exception of the tail gun, had been removed. The steep descent after the release of the bomb – necessary to avoid the detonation waves – had been practised constantly.



Picture: A model of the uranium bomb ‘Little Boy’. Source: US government DOD and/or DOE photograph. Public domain as work of U.S. federal government.



Picture: The combat aircraft B-29 Superfortress N for the transportation of 'Little Boy'. Source: public domain –U.S. federal government.

Clear, cloudless skies had been forecast for the Japanese islands on the 6th August. At 2.45am, the bomber took off with 13 men on board. The Enola Gay was accompanied by the Bockscar and the Great Ariste. The military leadership were very worried that the bomb could explode prematurely. W.L. Lawrence describes the events from the beginning:[7] 'When the General was informed that an unsuccessful take-off could send the whole island up into the air, he answered that "we must pray that it does not happen". The same general then describes the plane's risky take-off: "We almost tried to lift it into the air with our prayers and hopes."' Before take-off, a Lutheran field chaplain said a 'poignant prayer'. This is why the Japanese later called 'Little Boy' the 'Christian bomb'. Only on the journey to Hiroshima did Tibbets reveal to his team that they were going to release a nuclear bomb similar to the one which had recently been tested. The men learnt nothing of radioactivity.

The launch

Around 7am local time, an hour before arrival in Japan, the Japanese early warning system detected the three planes. The alarm was sounded, radio broadcasts were interrupted. Towards 8am, radar monitors in Hiroshima gave the all-clear. They believed the Enola Gay, which was flying at a high altitude, was a reconnaissance plane. Consequently, people were told to enter air-raid shelters only if bombers were actually sighted. The Americans had counted on this deceptive manoeuvre, and earlier they had sent several individual planes into the target area on a daily basis.

At 8.15.17 local time, the Enola Gay released the bomb at a height of 9,450m. At 8.16.02, the bomb detonated at a height of 580m above the town centre at 34^o 23' N, 132^o 27' E. 43 seconds later, the shock waves had razed 80% of the centre to the ground. There was a fire ball with an internal temperature of over a million ^oC. Temperatures of at least $6{,}000^oC$ set trees within a radius of 10km on fire. Of the 76,000 houses in the city, 70,000 were destroyed or damaged.

In the meantime, the mushroom cloud – characteristic of nuclear explosions – consisting of dispersed and contaminated rubble rose 13km high. This cloud was visible from the Enola Gay, which was now 560km away. The cloud spread highly contaminated material, which settled about 20 minutes later as radioactive fallout over the metropolitan area of Hiroshima.

Pictures: Hiroshima after the 6th August 1945.

<u>The victims</u>

Between 90,000 and 200,000 (the statistics vary greatly) people died instantly. The outer layers of skin of those people who were in the city centre literally evaporated. The bright flash of the explosion burned people's silhouettes into the walls of buildings which remained standing, before the shock waves ripped the people away. In the subsequent weeks, the radiation, most of which was released when the bomb exploded, killed 60,000 further inhabitants who had evaded the initial shock and heat waves, but who had nevertheless received deadly radiation doses. Many of those who fled from the unbearable heat to the river and drank the contaminated water, later suffered from hair loss, developed purple bruises on their bodies and bleed to death as a result of internal injuries. By the end of 1945, 140,000 (±10,000) inhabitants of Hiroshima had died in this way.

Pictures: Victims of the first use of a nuclear weapon in Hiroshima on 6th August 1945. Source: http://de.wikipedia.org/

The bomb killed 90% of people within 0.5km of ground zero, and 59% within between 0.5 and 1km. Even today, people who were living in Hiroshima at the time are dying from cancer, a long-term effect of radiation. If one includes these long-term consequences, over 240,000 inhabitants have died (up to 98%).

Between the launches

No survivor from Hiroshima itself could report the events to Tokyo. All connections were broken. Hours later, military bases near Hiroshima first reported a violent explosion with an unknown cause. Initially it was believed that one of the garrison’s large ammunition storage sites had exploded. Officers who were supposed to inspect the area in person were prevented by air strikes on Tokyo. On Tuesday, 7th August at 0.15am, while on his way back to the USA aboard the USS Augusta, Truman told the world about the deployment of the nuclear bomb for the first time: ‘The force from which the sun draws its power has been loosed against those who brought war to the Far East.’ He again urged the Japanese to capitulate, and warned: ‘If they do not now accept our terms they may expect a rain of ruin from the air, the like of which has never been seen on this earth.’

In Tokyo, however, it was days before the war cabinet was aware of the full extent of the devastation in Hiroshima. Even then the ministers could not unite in support of an immediate and unconditional capitulation, as they were still expecting Stalin’s peace initiative to guarantee Japan better conditions. However, the USSR declared war on Japan on the 8th August. The Red Army occupied Manchuria and began to attack the Kuril Islands. The declaration of war, which the Japanese ambassador in Moscow should have sent to Tokyo, never arrived.

The American government had reckoned with a speedy Japanese capitulation, and on the 8th August planes dropped millions of copies of a newly printed flyer over 47 Japanese cities. The flyer compared the effect of the nuclear bomb with that of the bomb load of 2,000 B-29s: anyone who doubted this should ask his government about the fate of Hiroshima. The Japanese people were called upon to demand the end of the war. If this did not happen, the USA would be forced to deploy more nuclear bombs and other types of superior weapons. There was no definite warning regarding the launch of a second bomb.

At 11am on the 9th August, two minutes before the detonation of the bomb over Nagasaki, the war cabinet met in Tokyo. Foreign Minister Shigenori Toro demanded an immediate conclusion of peace. Military leaders, however, made four demands which the USA could not accept:

- the Tenno regime would retain control
- there would be no foreign occupation
- disarmament of the Japanese forces would be voluntary
- only Japanese courts would preside over trials of war criminals

The tempestuous internal discussion ended without any result.

Nagasaki: launching the second nuclear bomb

Choice of target

At the time, Nagasaki was an important military port, and the headquarters of the Mitsubishi armament company. Around 20,000 Korean forced labourers produced and repaired cruisers, torpedo boats etc, for the imperial navy.[8] They had also built the torpedoes with which Japan had attacked the US military in Pearl Harbour. Nagasaki was one of the possible targets for US Air Force attacks. Nagasaki had between 240,000 and 260,000 inhabitants.

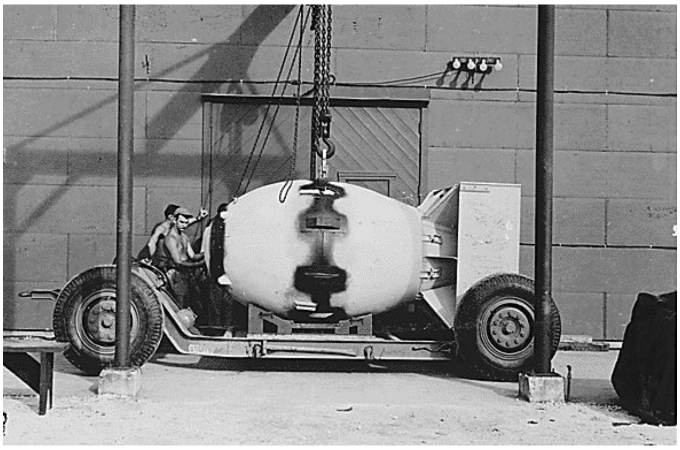
Preparations for take-off

The plutonium bomb 'Fat Man' (explosive force: 22,000t TNT) had been constructed on Tinian in a rush and without important control experiments. Those involved had been affected by the sinking of the USS Indianapolis on 30th July 1945. This heavy cruiser, having delivered parts for the Hiroshima bomb, was hit by two torpedoes from Japanese submarines while on the way back to Guam. It sunk within a few minutes. Only 318 of the nearly 1,200 crew members could be saved. It was the last US warship to be lost in the Pacific arena. If this had happened on the way to Tinian, Japan would have been spared at least one nuclear attack. The production alone of sufficient radioactive material for three bombs had taken over a year.

On the 8th August, the generals on Tinian decided to launch the second bomb. The basis for this command was the President's order of the 24th July, that the 'special bombs' be ready after the 3rd of August and deployed one after the other. There was no further order. They decided to detonate the second bomb two days earlier than originally planned (on the 9th, not the 11th), as bad weather was forecast. At 2am on the 9th August, the 25-year-old pilot Charles W. Sweeney took off in the bomber Bockscar. Part of the crew was new, and the Bockscar had two accompanying planes. Its target was Kokura, a city with significantly more armament factories than Nagasaki. On arrival, Kokura lay under a thick blanket of cloud. Sweeney approached three times, but each time there was such low visibility that he broke off the attack. He was only supposed to release the bomb on sight, as he needed to hit the armament factories. As this was not possible and the fuel was running low, he headed for Nagasaki, the alternative target.

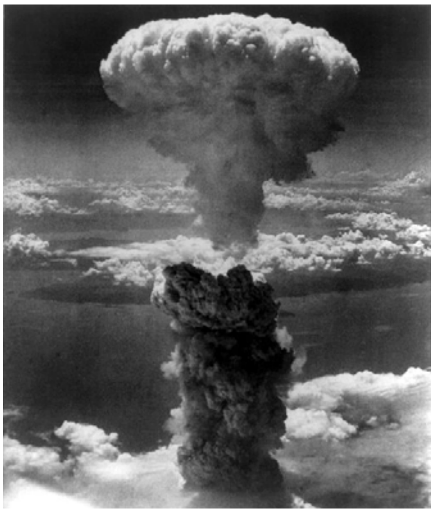
The launch

Initially, a direct attack on the shipyards had been planned. As visibility in Nagasaki was also low, he could not aim exactly for his target. Under these conditions, Sweeney should have cancelled the mission. However, he decided for a radar approach. Only without the bomb on board would they manage to reach Okinawa for an emergency landing [9].



Picture: The nuclear bomb of Nagasaki. Source: U.S. federal government, public domain.

The bomb was launched at 11.02am local time, 3km northwest of the planned target, at 32^{o} 46’ N, 129^{o} 51’ E. The area was heavily populated. The bomb was meant to hit the Mitsubishi factory, but missed this target by more than 2km. Nevertheless, almost half of the city was razed. The bomb detonated at 470m, and destroyed 80% of buildings – mainly wooden houses – within 1km. Only a few people survived. The bomb detonated in a valley, and as such the surrounding mountains lessened the bomb’s impact on the areas around the city. Objects up to 4km away were set on fire by the bomb. There was no fire storm. The mushroom cloud rose 18km into the atmosphere.



Picture: The detonation of the nuclear bomb of Nagasaki. Source: U.S. federal government, public domain.

The victims

Around 30% of the population lived 2km or less from ground zero. As with Hiroshima, there is great variation in the numbers of victims quoted. In the inner city, around 22,000 people died immediately. A further 39,000 died in the next four months.[10] Other sources estimate that between 70,000 [1] and 80,000 [12] died. Around 75,000 people in Nagasaki were injured.[13] The

University of Nagasaki estimates that 74,000 have died to date. According to the University, 119,000 died in Hiroshima. There were seven times as many cases of leukaemia in Nagasaki than in a comparable Japanese city.

The end of the war

The news of the destruction of Nagasaki caused consternation in the Japanese Government. There were fears of a third bomb being dropped on Tokyo. A B-29 pilot who had been shot down fed these rumours. On the 12th August components for further nuclear bombs reached Tinian, which were to be made deployable by the 17th.

On the 10th August 1945, after discussions which had lasted 12 hours and ended without any result, and during which the foreign minister and the military leaders had held irreconcilable opinions, Admiral Suzuki, who up to this point had not involved himself in the discussions, asked the Tenno for his decision. For the first time, Hirohito gave a command, and at 2am declared that the Potsdam Declaration was to be accepted. This decision was delivered to the allies with the additional caveat that the Tenno was to be allowed to retain his sovereign rights.

The USA explained that the Tenno's authority would be subjugated to that of the allied occupational powers as soon as the capitulation had been announced. Thus the Japanese declaration was not highly valued. The capitulation was made known in Japan on the 12th August. Japanese generals called on their soldiers to be prepared for millionfold suicide in order to 'drive the invaders into the sea'.

On the 14th August, Hirohito again decided to capitulate, in order to save the nation and spare the Japanese further suffering. He himself would ask his subjects for understanding. Before his speech could be broadcasted, younger officers attempted a *coup d'état*. After General Tanaka, the commander of Tokyo, had calmed them with a long speech, he and the leaders of the revolt committed suicide. On the 15th August, the last US air strike took place; its targets were Kumagaya (Saitama Prefecture) and Isesaki (Gunma Prefecture). Hirohito's speech was broadcasted at 4pm. The Japanese people, gathered on squares, who had never heard his voice before, learned how the land lied: '[T]he enemy has begun to employ a new and most cruel bomb, which has the power to do incalculable damage, taking the toll of many innocent lives. Should we continue to fight, it would not only result in the ultimate collapse and obliteration of the Japanese nation, but it would also lead to the total extinction of human civilization … This is the reason why we have ordered the acceptance of the provisions of the joint declaration of the powers.'

The speech was accompanied and followed by many cases of suicide. Only on the next day did the Emperor order all Japanese troops to end hostilities. This order had reached all troops in Japan by the 18th August. All Japanese troops abroad had heard the order by the 22nd. On the 30th August the allied pacific fleet entered the Bay of Tokyo.

On the 2nd September, the declaration of surrender was signed by the new foreign minister, Mamoru Shigemitsu, and the chief of staff, Umezu Yoshijiro for Japan, and General MacArthur for the Allies, on board the battleship USS Missouri. MacArthur held an impromptu speech, in which he urged both victors and the vanquished to build a world bound to human dignity. And so World War II ended.

Emergency aid for victims and analysis of the damages

The end of the war meant that foreign aid, i.e. from the Red Cross, could reach Hiroshima and Nagasaki. In the following months, the US Army, under the leadership of General Leslie Groves, the military representative for the Manhattan Project, carried out extensive documentation of the damages caused by the nuclear bombs. Scientists and doctors were involved in the documentation. The published results were affected by propagandistic aims. In particular, the radiological effect of the weapons, which months after the explosion was still claiming tens of thousands of victims, was negated. It is estimated that, by the end of 1945, a further 60,000 people, who had survived the early effects, had died as a result of radiation exposure, as well as burns and other serious injuries. By 1950, 230,000 people in both cities had died, mainly due to the delayed results of primary radiation.

The debate surrounding the deployment of nuclear bombs

Supporters

Those who support the use of nuclear bombs on Hiroshima and Nagasaki argue that the deployment of these weapons

- was necessary to ensure Japan’s surrender.
- shortened the war.
- made a US invasion of Japan unnecessary, and thereby saved the lives of millions of American soldiers who would have been deployed in this invasion.

The origins of this argument can be found in an interview with the former Minister for War, Henry L. Stimson, conducted by Harper. In this interview, Stimson argues that ‘the Japanese surrender was not possible unless the USA proved its ability to destroy the Japanese Empire’. He added that ‘the only alternative was the invasion of Japan’, which possibly ‘would have claimed the lives of more than a million American troops’.[14] The thesis that ‘the nuclear bombs were used in order to save a million American lives’ is now only supported by a few historians.[15]

Opponents

Those who oppose the deployment of the nuclear bombs argue that

- the use of these weapons, especially in the case of Nagasaki, was not necessary, as Japan was already close to surrendering.
- the war would have ended shortly, even without the use of nuclear weapons.

- there were other alternatives, apart from nuclear weapons or an invasion, which could have ended the war but were not exploited.
- at the time, it was estimated that the invasion would costs tens of thousands of lives, but not hundreds of thousands.
- the use of nuclear weapons, especially against civilians, cannot be justified ethically or morally.

Gar Alperovitz was the first well-known scientist to question Truman and Stimson's argumentation. He assumed that the argument about saving Americans was just a pretence hiding the US government's real aims. The atom bombs were deployed, not to avoid an invasion of Japan, but much more within a framework of an 'atomic diplomacy', designed to discourage the USSR from further advances in the Far East, and to display American power.[16]

When justifying the use of nuclear weapons to the US public, the government's main argument was that in using them, American lives were saved by making an invasion unnecessary. Various sources challenge the US government's estimates of the number of potential losses. Bruce Cummings and Samuel Walker, for example, show that in current historical research there is the consensus that US losses were later portrayed as being much higher than was initially thought: before the deployment, the military had estimated that between 25,000 and 46,000 American soldiers would die during an invasion. As the Japanese surrender would have been possible even without an invasion, and as there were in any case many more alternatives for ending the war, the official thesis, that the nuclear bombs saved many American lives, is false.[15][17]

The opinions of some former military leaders show that the deployment of nuclear weapons was not sensible from a military point of view. Important military leaders, e.g. Dwight D. Eisenhower, General Douglas MacArthur, Fleet Admiral William D. Leahy, General Carl Spaatz and Fleet Admiral Chester W. Nimitz, are among those who have challenged the necessity of deploying nuclear weapons.[18] Other scholars believe that the US government may have had other reasons for deploying the nuclear bombs, e.g. as a justification of the high development costs ($2 billion), or as a way of testing the effectiveness of nuclear weapons on real targets. It has been suggested that the deployment could have been racially motivated, and the use of these nuclear bombs has been described as genocide.[19] Martin Sherwin (summarised by Cummings) opines that the use of atomic weapons on Nagasaki in particular was, 'at best, senseless, at worst, genocide'.[20]

<u>Evaluation in America</u>

In the USA, the government still uses the same justifications for the deployment of atomic bombs as were used at the time. As a result, millions of Americans would agree with the statement that George H. Bush made in 1991: 'dropping the bomb spared millions of lives'. Samuel J. Walker traces this public opinion back to the influence of school textbooks which provide basic knowledge for one's entire life. These books often reduce the possibilities for ending the war to the use of nuclear weapons, or an invasion of Japan. They also exaggerate the likelihood and extent of US casualties in the event of an invasion.[25]

Evaluation in Japan

Immediately after the war, the American occupiers imposed strict censorship on all reports, photographs and video recordings dealing with the effects of the nuclear bombs. Only in 1948 did details of the catastrophe begin to reach the public. In the immediate post-war period, with the experiences of war in mind, and in the face of new threats posed by the incipient Cold War, a peace movement arose. This included a campaign, initiated by housewives, for the proscription of nuclear weapons. 30 million signatures were collected.

To this day, numerous Japanese artists, in particular Kenzaburo Oe, have contributed to the process of coming to terms with the horrors of the war.[27] A Peace Memorial Park was constructed in Hiroshima in 1955 to commemorate the event. The resignation of the Japanese Defence Minister in 2007 shows just how sensitive an issue the deployment of the nuclear bombs is. Fumio Kyuma resigned because of a speech made in front of a group of students, in which he said that the use of nuclear weapons on Hiroshima and Nagasaki ‘could not have been avoided’ as ‘they spared Japan a fate similar to Germany’s’ (the partition is what he meant) and expedited the surrender. Large parts of Japanese society, media, and the opposition expressed their outrage and placed huge pressure on the politician.

Further consequences

Since the end of the war, the world’s political and historical consciousness has been determined by the experience of democratically elected governments which, having entered a war with defensive purposes, lose all moral and civilising inhibitions, and commit unprecedented mass murder of civilians and soldiers.

The launch dates are the origin of many initiatives of the international peace movement, as well as of later groups, such as the International Physicians for the Prevention of Nuclear War. 12 years later, the first wide extraparliamentary opposition to the use of nuclear weapons in the German Federal Armed Forces was formed. Federal Chancellor Konrad Adenauer had downplayed the so-called ‘tactical’ nuclear bombs, which had similar capabilities to the one used in Hiroshima, as the ‘mere development of the artillery’. 18 scientists, under the aegis of Carl Friedrich von Weizsäcker, opposed him with the Göttingen Manifesto of April 12th 1957.

Appendix B: Bibliography

[1] David Horowitz, Kalter Krieg p. 46
[2] David Horowitz, loc. sit. p. 46
[3] Richard B. Frank, Downfall, p. 211: Willoughby’s Appendix 1 to "G-2 Estimate of the Enemy Situation with Respect to Kyushu".

[4] David Horowitz, loc.sit. p. 45
[5] Theo Sommer, 1945. Die Biographie eines Jahres. p. 179-186
[6] Theo Sommer, loc.sit. p. 189
[7] Quotation from W.L. Lawrence
[8] Rainer Werning: Hiroshima, Nagasaki und die vergessenen Koreaner
[9] Spiegel-Online: Nagasaki ging wegen Treibstoffmangels unter (2) (22nd April 2005)
[10] Takeshi Ohkita: Akute medizinische Auswirkungen in Hiroshima und Nagasaki p. 85
[11] Atomwaffen A-Z
[12] Stern (magazine): Nagasaki gedenkt seiner Opfer
[13] Summary from the Nagasaki University School of Medicine
[14] Laura Hein, Mark Selden: Commemoration and Silence: Fifty years of Remembering the Bomb in America and Japan. Living with the Bomb. M.E. Sharpe, New York 1997
[15] Bruce Cumings: Parallax Visions. Duke 1999, p. 54
[16] Gar Alperovitz: Atomic Diplomacy. 1965
[17] Samuel Walker: Prompt and Utter Destruction: President Truman and the Use of Atomic Bombs Against Japan. University of North Carolina Press, 2005 (revised edition)
[18] http://www.doug-long.com/quotes.htm
[19] Joshua /Hill: "Remembering the Atomic Bomb" http://www.nd.edu/~frswrite/mcpartlin/1998/Hill.shtml
[20] Bruce Cumings: Parallax Visions, Duke 1999, p. 54
[21] Bernstein, Barton, J. "Understanding the Atomic Bomb and Japanese Surrender: Missed Opportunities, Little- Known Near Disasters, and Modern Memory," Hiroshima in History and Memory. New York: University of Cambridge Press, 1996.
[22] Tsuyoshi Hasegawa, Racing the Enemy: Stalin, Truman, and the Surrender of Japan (Cambridge, Harvard University Press, 2005)
[23] Barton J. Bernstein: "Understanding the Atomic bomb and the Japanese Surrender: Missed Opportunities, Little-Known Near Disasters, and Modern Memory", 'Diplomatic History' 1995
[24] Joshua /Hill: "Remembering the Atomic Bomb" http://www.nd.edu/~frswrite/mcpartlin/1998/Hill.shtml
[25] Walker, Samuel J.: History, Collective Memory, and the decision to use the Bomb, Diplomatic History 1995.
[26] http://kriegsende.ard.de/pages_std_lib/0,3275,OID1642550,00.html
[27] John W. Dower: The Bombed - Hiroshima and Nagasaki in Japanese Memory, Diplomatic History 1995.
[28] Kölner Stadt-Anzeiger:Hiroshima: Zehntausende gedenken der Opfer, 6th August 2006

Further reading:

<u>Reports from victims and contemporary witnesses</u>

- Günther Anders: Der Mann auf der Brücke: Tagebuch aus Hiroshima und Nagasaki. Munich 1959, Verlag C. JL Beck, ISBN 3-4060-2403-3;

- Helmut Erlinghagen: Hiroshima und wir. Augenzeugenberichte und Perspektiven. Fischer TB,, Frankfurt am Main 1984, ISBN 3596242363;
- Gerd Greune (ed.): Hiroshima und Nagasaki: Bilder, Texte, Dokumente. Cologne, 1982
- Michihiko Hachiya: Hiroshima Diary. University of North Carolina, 1955, ISBN 0807845477 (diary of a doctor who was in the city at the time of the bombings, and who documented his experiences in the subsequent months);
- John Hersey: Hiroshima: 6. August 1945, 8 Uhr 15. With a foreword by Robert Jungk. Hamburg, 2005 (report by an American journalist shortly after the start of the occupation. Includes interviews with survivors.);
- Ibuse Masuji: Schwarzer Regen. Frankfurt am Main, 1985;
- Keiji Nakazawa: Barfuß durch Hiroshima. Hamburg, 2004 (internationally renowned manga series by an eye-witness);
- Toyofumi Ogura: Letters from the End of the World: A Firsthand Account of the Bombing of Hiroshima. Kodansha, Japan, 1948, ISBN 4770027761;
- Kyoko Selden u. a.: The Atomic Bomb: Voices from Hiroshima and Nagasaki. Japan in the Modern World. ISBN 087332773X;
- Charles Sweeney et al.: War's End: An Eyewitness Account of America's Last Atomic Mission. ISBN 0380973499
- Prologue
- Nagai Takashi: Die Glocken von Nagasaki: Geschichte der Atombombe. Munich, 1955
- Robert Jungk: Heller als tausend Sonnen: das Schicksal der Atomforscher. Munich, 1994
- Richard Rhodes: The Making of the Atomic Bomb. New York, 1986
- William Craig: The Fall of Japan. New York, 1967
- Stephen Walker: Shockwave: Countdown to Hiroshima. New York, 2005, ISBN 0060742844
- Gordon Thomas, Max Morgan Witts: Enola Gay. New York, 1977
- William L. Laurence, Werner von Grünau: Die Geschichte der Atombombe. List Verlag, 1952
- Historical background
- Florian Coulmas: Hiroshima. Geschichte und Nachgeschichte. Beck, 2005, ISBN 3406527973
- Michael J. Hogan: Hiroshima in History and Memory
- Fletcher Knebel, Charles W. Bailey: No High Ground. Harper and Row, New York 1960
- Pacific War Research Society: „Japan's Longest Day“, the internal Japanese account of the surrender and how it was almost thwarted by fanatic soldiers who attempted a coup against the Emperor.
- J. Samuel Walker: Prompt and Utter Destruction: President Truman and the Use of Atomic Bombs Against Japan.
- Stanley Weintraub: The Last, Great Victory: The End of World War II, July/August 1945. Truman Talley Books/Dutton, New York 1995
- Richard B. Frank: Downfall: The End of the Imperial Japanese Empire. Penguin, 2001, ISBN 0141001461

Background

- Gar Alperovitz: The Decision to Use the Atomic Bomb. Vintage Books, New York 1995
- Thomas B. Allen, Norman Polmar: Code-Name Downfall: The Secret Plan to invade Japan - and why Truman dropped the Bomb. Simon & Schuster, July 1, New York 1995, ISBN 0684804069
- Barton J. Bernstein (ed.): The Atomic Bomb: The Critical Issues. Little, Brown, Boston 1976
- Richard B. Frank: Why Truman Dropped the Bomb: Sixty years later, we have the secret intercepts that shaped his decision. The Weekly Standard, 8th August 2005, p. 20
- Paul Fussell: Thank God for the Atom Bomb Ballantine, Reprint 1990), ISBN 0345361350
- Robert Jay Lifton, Greg Mitchell: Hiroshima in America: A Half Century of Denial. Quill, 1996, ISBN 0380727641
- Robert James Maddox: Weapons for Victory: The Hiroshima Decision. University of Missouri Press, 2004
- Philip Nobile (ed.): Judgement at the Smithsonian Marlowe and Company, New York 1995, ISBN 1569248419 (controversy surrounding the exhibition which was to be held in the Smithsonian Institution in 1995, but then cancelled)
- Ronald Takaki: Hiroshima: Why America Dropped the Atomic Bomb. Little Brown, ISBN 0-316-83124-7, LoC D769.2.T35 1995
- Shigetoshi Wakaki: Hiroshima: die infame Maximierung eines Massenmordes; der erste Bericht eines Experten und Augenzeugen. Grabert, 1992

Consequences

- Gaynor Sekimori: Hibakusha: Survivors of Hiroshima and Nagasaki. Kosei Publishing Company, Japan 1986, ISBN 433301204X
- Angelika Jaeger (trans.): Leben nach der Atombombe: Hiroshima und Nagasaki 1945-1985. Komitee zur Dokumentation der Schäden der Atombombenabwürfe von Hiroshima und Nagasaki, Frankfurt am Main, 1988
- Paul Takashi Nagai: Wir waren dabei in Nagasaki. Frankfurt am Main, 1951
- Takeshi Ohkita: Akute medizinische Auswirkungen in Hiroshima und Nagasaki. In: Eric und Susanna Chivian et al. (eds.): Last aid. Die medizinischen Auswirkungen eines Atomkrieges. Heidelberg 1985
- Peter Bürger: Hiroshima, der Krieg und die Christen. Asphalt Verlag, 2005, ISBN 3980740072
- Robert P. Newman: Truman and the Hiroshima Cult. Michigan State University Press, 1995 (critical analysis of post-war opposition to the bomb)

Appendix C: The nuclear power plant at Zwentendorf: construction, protests, referendum

The construction of the nuclear power plant at Zwentendorf is one of the largest economic losses in the modern history of the Austrian Republic. The background to this case study is representative of the common approach to the realisation of nuclear power plants. The atomic industry's agents always approach the highest political echelons, as surveys in almost every country have shown that this technology is rejected by the population. It would not be possible for diffusion agents to gain public approval, especially since the technology's history has clearly demonstrated its dangerous potential in practice. The Austrian nuclear power plant at Zwentendorf shows that decisions taken by politicians, which ignore the opinions of the public, can have dramatic repercussions.

Zwentendorf: Chronology

1956 The Austrian Atomic Energy Studies Company is founded. It deals with questions regarding future nuclear power plants in Austria.

1958 The Verbund company employs experts to find a location in Austria for a nuclear power plant.

1960 25th September: Austria's first research reactor, in Seibersdorf, goes into operation.

1963 Foundation of the 'Arbeitsgemeinschaft Kernkraftwerke' (Nuclear Power Station Consortium).

1967 The Austrian energy industry decides to construct a nuclear power station in Austria.

1968 1st March: the Verbund and energy companies found the Kernkraftwerksplanungsges.m.b.H (Company for the Planning of Nuclear Power Stations PLC). November: Zwentendorf is chosen as the site of a 600MW nuclear power station.

1969 May: the Federal Government foresees the construction of a nuclear power plant within the framework of its energy policy.
11th August: Parliament passes the Radiation Protection Law.
28th November: the main parliamentary committee unanimously allows the participation of the Verbund in the company for the construction and operation of nuclear power plants.

1970 10th February: the Gemeinschaftskernkraftwerk-Tullnerfeld-Gesellschaft m.b.H. (GKT) is founded. The Verbund takes a 50% stake, the Tirol subsidiary 13.34%, the Lower Austrian subsidiary 10.83%, the Styrian subsidiary 10%, the Upper Austrian subsidiary 8.33%, the Carinthian subsidiary 3.33%, the Salzburg subsidiary 2.5% and the Vorarlberg subsidiary 1.67%. The subsidiaries of Vienna and Burgenland do not take a share in the company.

1971 22nd March: the Federal Government decides to commence construction of the nuclear power plant at Zwentendorf. It is to go on stream in August 1976.
30th April: construction begins

1972 12th January: Parliament passes a regulation regarding radiation protection.
Between April 1972 and January 1978 the Federal Ministry for Health and Environmental Protection issues 53 partial allowances and over 1,000 conditions and sanctions regarding building regulations and the protection of the population and the environment in connection with the construction of the nuclear power plant.

1975 Foundation of the ‘Initiative Österreichischer Atomkraftwerksgegner’ (IÖAG) (Initiative of Austrians against Nuclear Power Stations) as an umbrella organisation for all groups which oppose nuclear power.

1976 The government’s energy plans foresee the construction of three nuclear power plants by 1990.
14th October: the government begins its information campaign which aims to answer five central questions regarding nuclear power

1977 24th March: opponents of nuclear power protest in Vienna, Graz, Salzburg, Innsbruck, and Klagenfurt.
May/June: four Austrian cities host symposia about nuclear energy.
6th June: governmental summit at Hernstein Castle. After speeches from experts, the government voices its support for the use of nuclear power, and for the activation of Zwentendorf as soon as the problem of the disposal of burnt out fuel rods has been solved.
July: ÖVP (Austrian People’s Party) chairman Taus announces that his party can no longer cooperate with the SPÖ (Socialist Party of Austria) as far as nuclear power is concerned.
December: the governmental report on nuclear power is presented to the cabinet and the parliament.
23rd December: the Ministry for Health agrees to the storage of fuel rods in Zwentendorf.

1978 January: the Socialist Youth suggest holding a referendum about Zwentendorf; Kreisky refuses.
10th January: secret delivery of fuel rods for Zwentendorf from Hanau fails, as the IÖAG has found out the delivery date and there are fears of demonstrations.
18th January: fuel rods are delivered by aeroplane and helicopter.
End of January: the FPÖ rejects nuclear power and the governmental report.
Beginning of February: ÖVP declares itself in favour of nuclear power, but rejects both Zwentendorf (due to a lack of safety provisions) and the governmental report (due to the incompleteness of the report).
Mid-February: an ‘Atomic Subcommittee’ is to rectify the faults in the report. Experts, advocates and opponents are supposed to give evidence and their opinions. The committee cannot reach an agreement on the report. At the end of May, both the FPÖ and the ÖVP refuse to approve the plans.
22nd June: the SPÖ chairman decided that the question of nuclear power must be put to the people in a referendum. He fears that he will not have parliamentary support.
28th June: the governmental report on nuclear energy is accepted in parliament with the SPÖ’s votes, as is the draft law regarding the

peaceful use of nuclear power. Unanimous acceptance of the decision to hold a referendum.
6ht July: the draft law is rejected by the cabinet.
7th July: parliamentary decision overrides cabinet's decision.
25th August: 'Committee for Zwentendorf' is founded. Members include the general director of the Austrian National Bank, and the acting general secretary of the Industrialists' Association.
30th August: the association 'No to Zwentendorf' is established.
13th September: Federal President Kirchschläger orders a referendum regarding the adoption of the law.
From October: supporters and opponents of Zwentendorf run ad campaigns, endorsements from political parties, lobbies, and public figures.
5th November: Referendum regarding the activation of the nuclear power plant at Zwentendorf. 1,576,839 (49.33%) vote Yes, 1,606,308 (50.47%) vote No.
9th November: general meeting of members of the Gemeinschaftskernkraftwerk-Tullnerfeld-Gesellschaft decides to terminate work on the nuclear power plant.
13th December: parliament passes a law banning the construction and activation of extant nuclear power plants in Austria.

1985 8th February: Federal Chancellor Fred Sinowatz announces an SPÖ motion for a referendum regarding the peaceful use of nuclear power. The lifting of the law banning the use of nuclear power is a prerequisite.
20th February: Federal Chancellor Sinowatz informs the whips of the three parliamentary parties of the USSR's offer to accept burned out fuel rods.
21st February: Federal Chancellor Sinowatz presents the safety report of the Commission for Reactor Safety. According to the report, Zwentendorf meets international safety standards for modern nuclear power stations.
6th March: the SPÖ inserts a motion to a constitutional act. The motion stipulates that a referendum is to be held regarding the peaceful use of nuclear power. Should a majority of the population express itself in favour of nuclear power, then the law banning nuclear power will automatically cease to be effective.
15th March: the SPÖ's motion to hold a referendum on the activation of Zwentendorf, and hence on the abrogation of the law banning the use of nuclear power, does not find the required majority in the appropriate parliamentary committee (10 votes against 10).
21st March: the SPÖ's motion for a referendum regarding the activation of Zwentendorf does not have the required majority in parliament (91: yes, 90: no). No whipping took place during the vote.
18th March: Federal Chancellor Sinowatz announces that he will not enter a motion for the lifting of the law banning the use of nuclear power.
27th March: the proprietors of the Gemeinschaftskraftwerkes Tullnerfeld (GKT) decide to 'quietly liquidate' the nuclear power plant.

Conclusion:

14 years passed between the decision to begin construction on the nuclear power plant at Zwentendorf in 1971, and the decision to liquidate the still unfinished power plant in 1985. During this time, Zwentendorf cost 14 billion Schilling (= about 1 billion Euro, mostly from the taxpayer), and alone 600 million of this was used for conservation. We know today that, even without the huge political problems, the planned activation of the power plant in August 1976 (i.e. after 5 years' planned construction) would have been unrealistic.

Appendix C: Sources

- Forum Politische Bildung (ed.): Wendepunkte und Kontinuitäten. Zäsuren der demokratischen Entwicklung in der österreichischen Geschichte (Sonderband der Informationen zur Politischen Bildung). Studien-Verlag, Innsbruck 1998, p. 158-159;
- Pelinka, Anton: Die Kleine Koalition SPÖ-FPÖ 1983-1986. Böhlau Verlag, Vienna/Cologne/Graz 1993;
- Der Österreich-Bericht 1985. Presseübersicht. Zusammengestellt vom Bundespressedienst des Bundeskanzleramtes; http://www.aai.at.)