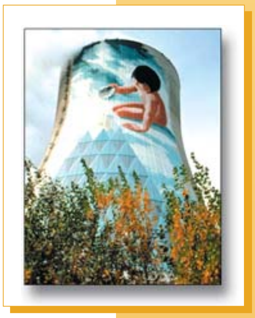
Nuclear Energy and Sustainable Development

World energy demand is likely to grow rapidly against a background of increasing public concern about the environmental implications of competing sources of energy supply.

The question of the sustainability of different energy sources is likely to assume greater significance, and in this context, nuclear energy has certain advantages in its carbon-free generation of electricity and heat, as well as in security of supply.



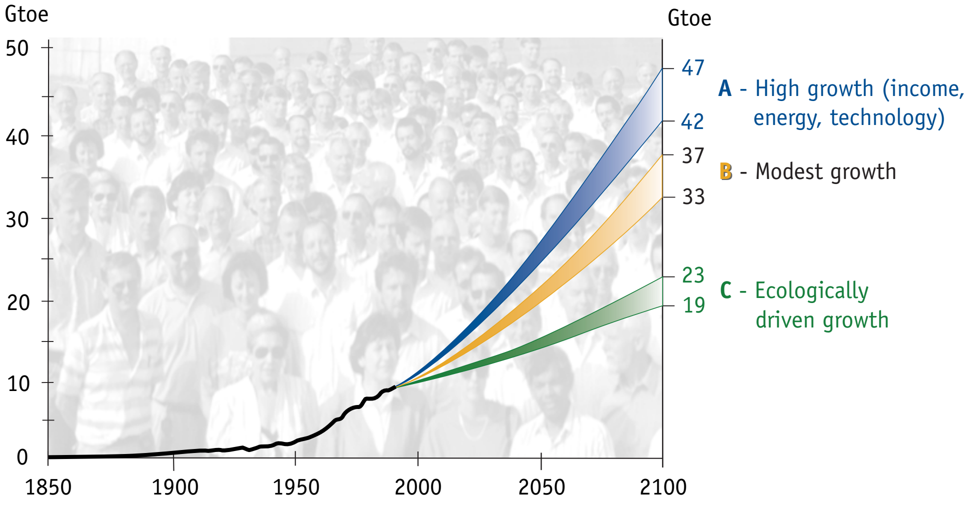
This chapter considers the future of nuclear energy in the broader context of the world's supply of and demand for energy.

Energy demand

The world's demand for energy will continue to increase as a result of economic development and population growth (see Figure 9.1). The overwhelming share of this growth is likely to take place in the developing countries, as they strive to raise the living standards of their growing populations. In 1998, the International Institute for Applied Systems Analysis (IIASA) and the World Energy Council concluded that by 2050, global energy demand would probably grow by a factor between 1.5 and 3.0 with demand for electricity at least doubling. The British Royal Society and Royal Academy of Engineering concluded in 1999 that the consumption of energy would:

> *...at least double in the next 50 years and... grow by a factor of up to five in the next 100 years as the world population increases and as people seek to improve their standard of living.*

Figure 9.1: Projected energy demand to 2100



Source: IIASA. *Global Energy Perspectives* (Cambridge: Cambridge University Press, 1998).

Worldwide, 2 billion people are without access to electricity and an equal number continue to use traditional solid fuels for cooking. *World Energy Assessment, United Nations Development Program, 2000.*

Sustainable development – development that meets the needs of the present without compromising the ability of future generations to meet their own needs. *Brundtland Commission, 1987.*

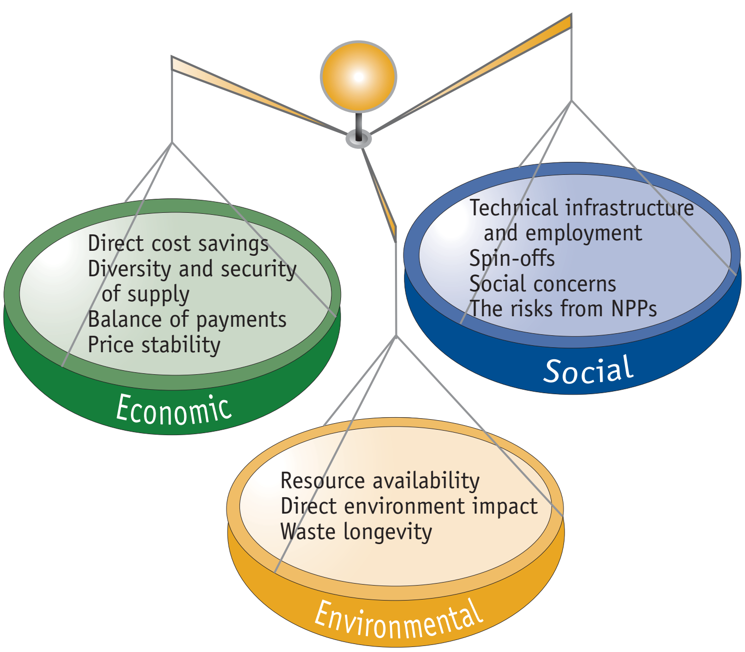
The challenge will be one of responding to these demands in a way that supports society's growing desire to meet current needs without unduly impacting on future generations.

Nuclear energy and sustainable development

Energy is an important component of any policy for sustainable development because it is vital to human activity and economic growth. The fact that current technologies for providing energy are now increasingly viewed as unsustainable provides both opportunity and challenge. The extent to which nuclear energy can be shown to be sustainable will to a significant extent determine its place in the energy supply spectrum.

The sustainability of any development is customarily discussed under three dimensions – *economic*, *environmental* and *social* (see Figure 9.2).

Figure 9.2: Elements of sustainable development applicable to nuclear energy



Economic aspects

The microeconomic aspects of nuclear energy were discussed in Chapter 7. The following paragraphs concentrate on macroeconomic elements.

Direct cost savings

The ability to provide reliable, low-cost electricity is an important aspect of sustainable development. As shown in Chapter 7, nuclear energy can become cost-competitive with other major forms of electricity generation in the long term, possibly supplemented by political action to internalise environmental costs, engender social acceptance and ensure security of fuel supplies. In the shorter run, its competitiveness is different in each country, depending primarily on fossil fuel prices, which tend to fluctuate.

Diversity and security of energy supply

Oil and gas have a fairly limited geographical availability, with Middle Eastern countries and the Russian Federation controlling over 70% of world crude oil reserves and about two-thirds of natural gas reserves. Quite aside from the political instability that has sometimes characterised the supplier regions, the long supply routes to major markets are also vulnerable to disruption by political action.

Conversely, OECD countries produce almost 55% of the world's uranium, and have 40% of the known reserves, as compared with about 7% of oil, 12% of gas and 40% of coal reserves. OECD countries are moreover self-sufficient in the essential services that turn natural uranium into finished nuclear fuels (see Chapter 3).

Unlike fossil fuels, nuclear fuel and fuel feedstock are compact and easy to stockpile; large inventories can be kept at comparatively low cost. About 25 tonnes of fuel assemblies will provide a year's fuel for a 1 GWe current generation pressurised water reactor. A coal-fired plant of similar output would require 3 million tonnes of fuel, i.e. more than one hundred thousand times as much.

As a nation's dependency on foreign sources for its energy increases, so do the costs and economic consequences of any disruption. Any energy source that reduces dependence on external fuel sources can be said to enhance the security of energy supplies and ultimately the security of the nation. Security has always been one of the main aims of energy policy in all OECD countries.

Balance of payments

Nuclear energy can be seen to have two potential positive influences on the balance of trade, assuming its costs are fairly competitive. First, importing relatively small amounts of low-cost uranium would be more attractive than importing relatively large amounts of high-cost coal, oil or gas. Second, the creation or extension of the high-technology infrastructure needed to support nuclear energy can assist technology export.

Price stability

Fuel costs are a major component in the price of fossil fuel electricity. Hence the tendency towards fluctuations in fossil fuel prices (see Figure 9.3) translates itself into variations in the price of electricity, especially in a competitive market. The low share of fuel costs and high share of fixed costs in the case of nuclear electricity generation have, by contrast, a potentially stabilising effect on electricity costs and prices.

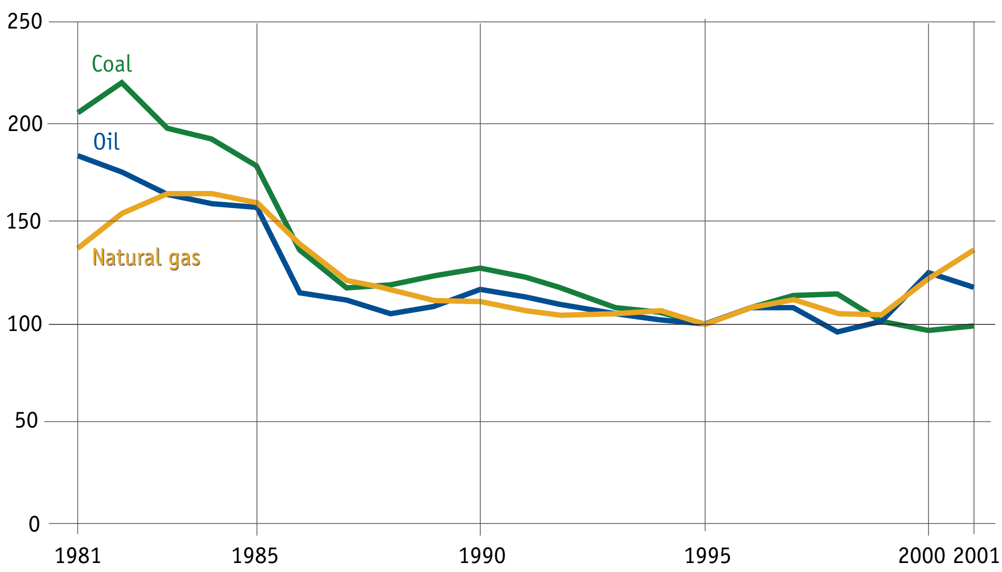
Generally, the availability and use of as wide a range as possible of alternative energy sources tends to reduce demand pressures on any one fuel source and so contributes potentially to macroeconomic stability overall.

Environmental aspects

The environmental sustainability of a particular material is usually discussed in terms of its availability, e.g. the adequacy of reserves, and its direct impacts on the environment.

Uranium resources are classified based on their economic attractiveness and on the confidence in their existence. Resources that are known to exist and are inexpensive to exploit using conventional mining techniques are classed as Known Conventional Resources. These resources are categorised into two sub-groups: Reasonably Assured Resources (RAR) and Estimated Additional Resources – category I (EAR-I). Resources believed to exist and to be exploitable using conventional mining techniques but not yet physically confirmed are classed as Undiscovered Conventional Resources. They include Estimated Additional Resources – category II (EAR-II) and Speculative Resources (SR).

Figure 9.3: Historical price fluctuation in fossil fuels



Note: The "real" price index is computed from prices in national currencies and divided by the country-specific producer price index for the industrial sector and by the consumer price index for the household sector. Here, the base year is 1995.

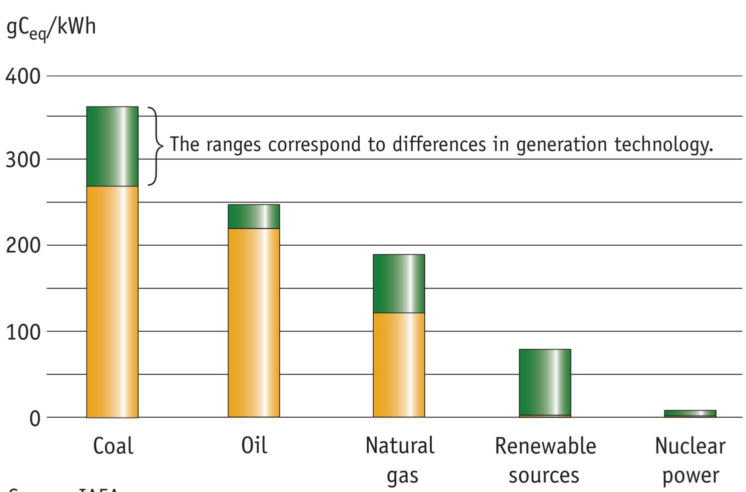
Source: IEA. *Energy Prices and Taxes* (Paris: IEA, Second quarter 2002).

Air pollution causes 2.7-3.0 million premature deaths a year, or 5-6% of global mortality. World Health Organisation, 1997.

Resource availability

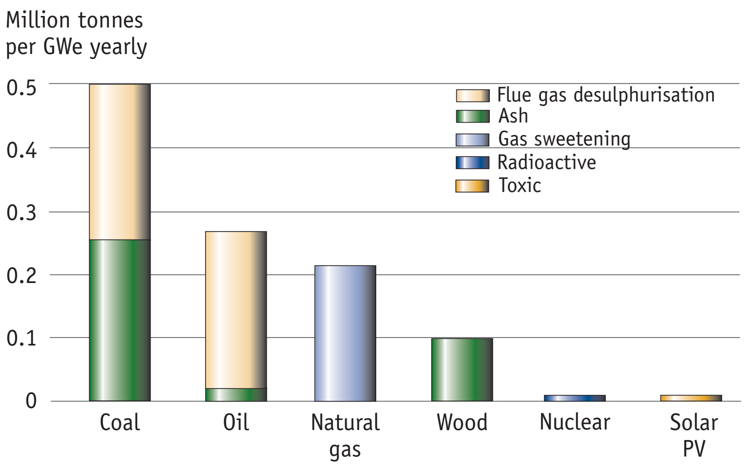
Uranium is widely dispersed in the earth's crust and in the oceans, being more abundant than silver. At the beginning of 2001, estimated conventional uranium resources (known and undiscovered) totalled above 16 million tonnes or nearly 250 years of supply at the prevailing rate of usage. There are, in addition, unconventional resources in which uranium exists at very low grades, or is recovered as a by-product. These amount to about a further 22 million tonnes that exist in phosphate deposits and up to 4 000 million tonnes of uranium contained in seawater. Research has hinted that it is possible to tap the vast seawater resources though, at present, only on a laboratory-scale. The cost of doing so is also estimated to be very high, approximately 5-10 times the current cost of conventionally mined uranium.

Figure 9.4: Greenhouse gas emissions from electricity generation by different sources



Source: IAEA.

Figure 9.5: Overall waste generation by fuel source



Source: IAEA.

In the long term however, the adequacy of natural uranium resources depends on the reactor technologies and fuel cycle strategies adopted. Reprocessing of spent fuel using current light water reactor technology could, in principle, reduce the demand for uranium by 10-15%. The introduction of fast reactors would further increase fuel efficiency; replacing all current thermal reactors with fast reactors and reprocessing fuel cycles would increase uranium resources by a factor of 50 (see Table 10.1). Other advanced techniques currently envisaged could employ thorium as a fuel feedstock rather than uranium, thereby further expanding nuclear fuel resources. India, in particular, with large thorium reserves, is working to implement a thorium fuel cycle. In essence, nuclear energy cannot be considered to be resource-limited.

Direct environmental impact

Nuclear power is one of the few energy sources that emit virtually no air-polluting or greenhouse gases. The entire nuclear fuel cycle including mining of ore and the construction of power plants has been estimated to emit between 2.5 and 6 grams of carbon equivalent per kWh of energy produced. This is roughly equal to the estimated releases from the use of renewable sources (wind, hydro and solar power) and about 20-75 times less than the emissions from natural gas power sources, the cleanest fossil fuel available (see Figure 9.4).

Nuclear power is thus one of the prime means available for limiting the emission of carbon into the environment. In OECD countries alone nuclear power plants avoid some 1 200 million tonnes of carbon dioxide (CO_2) emissions annually. Assuming that all nuclear power plants in the world were replaced by modern fossil-fuelled power plants, CO_2 emissions from the world energy sector would rise by some 8%.

Nuclear power avoids the emission of local air-polluting gases and particulates such as the sulphur and nitrogen oxides that have been linked to acid rain and respiratory diseases. The quantity of solid waste generated per unit of electricity is much lower for nuclear than for any fossil fuel source. It is essentially equivalent to that of renewable energy sources such as solar energy (see Figure 9.5).

However, for nuclear power to make a very large contribution to precluding undue global warming, a large expansion in nuclear generating capacity would be necessary. At present, nuclear power is applied only in the production of electricity, one sector of energy use. Under current estimates, even if installed nuclear power capacity were to increase by a factor of 10 by 2100, its proportion of primary energy use would rise from the current 7% to no more than 25%, thereby avoiding some 15% of the expected cumulative carbon emission during the period. However, if this expansion in nuclear capacity were to take place on the basis of current technology, there would be a considerable addition to the accumulated volume (and also the activity) of radioactive waste.

Nuclear energy is one of the options that could contribute to meeting the projected increases in the world's energy demand, essentially without adding to carbon emissions. But, to be effective and acceptable at this level, advanced reactor technologies and recycling fuel strategies would be required. In essence, as the century unfolds, the current fleet of thermal, light water reactors would need to be replaced by advanced technologies, such as fast-breeder reactors with fuel recycling. Such a change would require considerable investment, though not one likely to exceed the investment demands of other strategies for meeting increased energy demand while limiting global warming.

Waste longevity

High-level waste, though small in volume, remains radioactive for very long periods. Deep geological repositories have been investigated for several decades and the expert judgement is that there are no technical barriers to their construction to very high standards of integrity. Although there has been recent progress in Finland and the United States, no repository is yet operational. So the disposal of high-level waste remains, at present, a challenge to the sustainable development of nuclear energy.

Research and development on advanced fuel cycles and for the treatment of waste promise to reduce the volume of waste requiring isolation and the time this waste must remain isolated. Yet, the results of these investigations will not likely be available for several decades.

Social aspects

Technical infrastructure and employment

It is people who create and maintain any technology. In this respect nuclear energy has certain special characteristics, based as it is on major 20th century scientific and technological developments. Much of the high cost of nuclear facilities is embodied in science and technology, essential for their continued safety and future development. The nuclear industry also employs a high proportion of skilled, graduate staff relative to most other major energy and manufacturing industries. They are important, though vulnerable, social capital as well as a base for continuous improvement in performance within the industry (and in certain respects beyond it).

The sustainability of nuclear power depends upon the complex and expensive infrastructure that underlies this social capital, which, if it were lost, might be hard to replace either cheaply or quickly.

Spin-offs

Maintaining and improving the technical and intellectual infrastructure to support nuclear energy provides numerous spin-off benefits for a society. As with other very advanced technologies, nuclear energy has historically played a very important part in the development of new materials, techniques and skills, which have spun off into other sectors, e.g. medicine, manufacturing, public health and agriculture, with consequent economic benefit.

Social concerns

All energy technologies have a tendency to create social concern, even conflict. In the case of nuclear energy, concern has focused on questions of safety, proliferation and waste disposal. Coal has its own profound history of conflict and social division, as, on an international scale, has oil. The exploitation even of renewable energies has come under recent scrutiny and opposition arising from their visual intrusiveness and large-scale demands on land area. Large hydro projects have raised opposition on a global scale because of the social and environmental impacts of the massive inundations involved.

The risks from nuclear power plants

As with any other major industrial installation, and despite all precautions, nuclear power plants present risks to workers, to people living in the immediate vicinity, and, in the case of a very severe accident such as that at Chernobyl, to people living very far away. Usually, these risks are analysed in terms of radiological consequences as a result of (1) normal operation and (2) from accidents. Given the highly qualified personnel, sound operational practices, and strict regulatory oversight, nuclear energy from an industrial safety viewpoint, is relatively safe. For example, data from the United States for 2000 reveals an accident rate at nuclear power plants of 0.26 accidents per 200 000 worker-hours compared with a country-wide workplace average of 3.0.

Risks from normal operation

Radiological risks from normal operation arise from the day-to-day discharges both to air and to water of radioactive material. Such discharges are strictly governed in all OECD countries by authorisations from the relevant regulatory authorities. They are also the subject of international understandings, such as the OSPAR *Convention for the Protection of the Marine Environment of the North-East Atlantic*, of which the most recent Ministerial agreement, reached at Sintra, Portugal in 1998, called for the reduction of additional radioactive burdens from marine discharges, emissions and losses to be "close to zero" by 2020.

In principle, discharges of this kind can affect the human food chain (via shellfish for example) and so represent a hazard to the public. Estimates can be made of the chances of people being adversely impacted by low-level discharges stemming from living near nuclear plants or eating very large quantities of seafood. Where such estimates have been made they indicate a risk that is considerably less than one in 1 000 000 per annum to any of the people theoretically at risk.

Risks from accidents

The risks from accidents are much harder to estimate, partly because nuclear accidents of all kinds have been very rare, and partly because the consequences could vary over so wide a range.

Studies have been conducted to estimate the chances of the protective barriers built into modern power plants failing in the course of an accident, causing radioactive releases of various hypothetical sizes. The calculations typically show that the chances of any such accident at a modern reactor, one that has been upgraded in keeping with the lessons of Three Mile Island and Chernobyl, are less than 1 in 100 000 per annum. Designs for reactors planned for future deployment have more explicitly considered severe accidents in their design and calculations indicate the likelihood of a severe accident being even lower, on the order of 1 in 1 000 000 per annum. In considering these figures, however, it needs to be borne in mind that the effects of a major nuclear accident may have considerable impacts including the deaths of individuals (which may occur decades after the accident), the loss of use of land for living or farming, and the loss of large amounts of electricity generating capacity, all of which would have serious consequences for society.

In considering the potential risks of nuclear energy it is necessary to regard it in the context of meeting increasing societal energy demands. Looking at the potential risks from different energy sources shows that the potential environmental and public health burdens from nuclear energy are smaller than those associated with fossil fuels (see Figure 9.6).

Taking a wider view, one should also consider the more intangible risks such as placing undue reliance on fuels imported from distant countries that could cause significant economic disruption should those supplies be interrupted. Additionally, fossil energy sources, which are increasingly believed to contribute to global warming, could, in several centuries, have serious consequences such as parts of seaboard cities becoming uninhabitable.

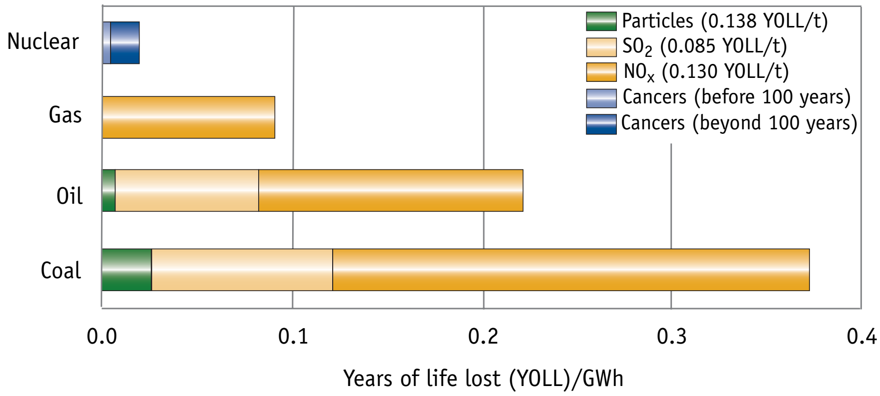
Nuclear installations of all kinds are among the numerous potential targets for terrorist activity. However, unlike many other industrial activities, nuclear power plants take active measures in response to this potential threat, though absolute security can never be guaranteed. It is very difficult to quantify or even describe risks of this kind, but nuclear power stations, because of their inherent robustness, built-in protection, security forces and generally remote locations, are comparatively unattractive and unrewarding targets for a terrorist attack.

Ultimately, only individuals can judge the extent to which particular risks concern them. Comparative risk figures can therefore have only a limited significance, but they are nonetheless a way of putting matters into proportion, and of reminding ourselves that the world is a risky place, and that all the available means for electricity production carry risks.

The social element in sustainable development can only be met by addressing public concerns and gaining public confidence. It will be important to enable the public to put the social, ethical and political issues raised by nuclear power into a perspective with the different, but not altogether dissimilar, issues raised by the alternative sources of electricity generation.

Generally, when viewed by applying the three dimensions of sustainable development, nuclear energy can be seen to have potential to meet a significant part of the world's future energy needs while meeting many of the objectives of sustainable development. The overall political trade-offs between the three dimensions of sustainability will differ from country to country, and will affect both the decisions taken and the means of addressing public concerns and securing public confidence.

Figure 9.6: Comparison of health risks for energy systems



Source: "Comparative Assessment of Emissions from Energy Systems", *IAEA Bulletin*, 41/1/1999.

For further information

See the references listed below provided in the "For Further Information" section for more in-depth information on:

- Projections of future world energy demand, see 1.4, 9.1 and 9.2.
- Projections of uranium resources and demand, see 9.3.
- Nuclear energy in a sustainable development context, see 9.4 and 9.5.
- The role of nuclear energy with respect to climate change, see 9.6 and 9.7.
- The broad impacts of nuclear energy, see 9.8.
- Spin-off technologies developed through nuclear activities, see 9.9.
- The education and supply of qualified personnel, see 9.10.