INTERNATIONAL ENERGY AGENCY

NUCLEAR POWER IN THE OECD

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-five* of the OECD's thirty Member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions;
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations;
- To operate a permanent information system on the international oil market;
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use;
- To assist in the integration of environmental and energy policies.

**IEA Member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States. The European Commission also takes part in the work of the IEA.*

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- To achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- To contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- To contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), the Republic of Korea (12th December 1996) and Slovakia (28th September 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

FOREWORD

Nuclear power is an important feature of today's energy supply. It provides about a quarter of OECD electricity. In Belgium and France it provides over half. The OECD's 300 GWe of nuclear capacity is a major component of our aggregate energy supply and an important element in energy security. Commercial nuclear generation is a mature, established technology, having accumulated over forty years of successful operation.

Yet nuclear power raises passions as do few other energy issues. Within countries and among them, both support and opposition are strong. This review of nuclear power's status is, therefore, sure to evoke diverse reactions. It does not avoid the prickly facts on economics, environment, wastes or safety. We state that nuclear power cannot and should not be omitted from consideration in future energy supplies, but we do not presuppose that it is indispensable. We have sought to identify clearly the challenges facing governments as they consider nuclear power within the context of overall energy supply.

Charged, as it is, with collecting and analysing energy data and formulating overall energy policy guidance for its Member states, the IEA must assess the implications of various nuclear energy strategies for our collective energy security in order to help the world chart energy policies for sustainable growth. The OECD Nuclear Energy Agency has been and will continue to be the IEA's partner in identifying robust energy policy recommendations for the future. We acknowledge NEA's contribution to the preparation of this report. But responsibility for it is that of the IEA Secretariat alone. The analysis and judgements expressed do not necessarily reflect the attitudes or positions of the IEA Member countries.

Robert Priddle
Executive Director

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The views expressed in this report, and any errors or omissions, remain the responsibility of the IEA Secretariat.

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CHAPTER 1

EXECUTIVE SUMMARY

Overview

This report reviews the status and prospects for nuclear power generation in OECD countries. Nuclear power provides about 11% of primary energy supply and nearly one-quarter of total electricity generation in the OECD (Figure 1). It is a major component of the current energy mix.

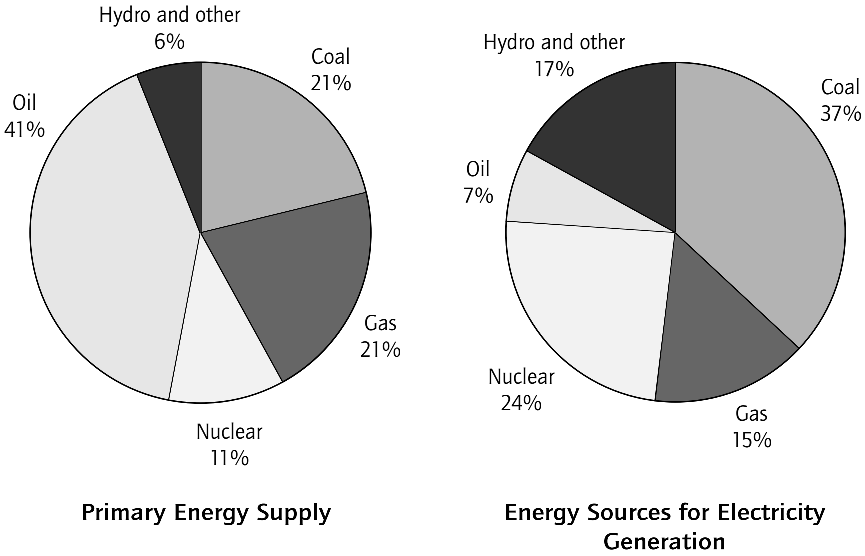
Nuclear power is important, but its future is uncertain. In the immediate future, the only OECD countries where new plant orders are planned are Korea, Japan and possibly Finland. The outlook for nuclear power is affected by many factors. Commercial economics is a key factor. Governments are liberalising their energy markets, increasing the importance of cost-effectiveness for all electricity generation sources. The long-term future for nuclear power, like that for other energy sources, will increasingly be based upon its cost-effectiveness.

Commercial economics is far from being the only key factor. The wider energy policy framework remains a vital consideration for future decisions on nuclear power. Although electricity market reform is encouraging the trend towards commercial decision-making in the interests of economic efficiency, this does not mean that governments have withdrawn from energy policy-making. They remain responsible, as they have always been, for strategic issues such as energy security and the environment. The latter is of increasing importance, and the former remains central to energy policy-making.

From the perspective of commercial economics, existing nuclear plants are generally in a sound economic position. Nuclear power's cost

Figure 1

Breakdown of OECD Primary Energy Supply and Energy Sources for Electricity Generation



Source: IEA, Electricity Information 2000.

structure makes it well-suited for baseload power generation, since it has a high fraction of fixed construction costs and a low fraction of variable operating costs. Well-run nuclear plants have operating costs similar to, or lower than, those of competing plants. The introduction of competitive electricity markets in most OECD countries is encouraging all operators to achieve improved plant performance and is leading to consolidation among nuclear generators and among suppliers of nuclear equipment, services and fuel.

New nuclear power plants face challenging competitive conditions. Fossil-fuelled plants are expected to have a lower total cost of electricity than nuclear plants in most countries under the energy market conditions and fuel prices that have prevailed in recent years. Gas-fired combined cycles are the strongest competitors in countries with access to pipeline natural gas. High capital cost is the single most important economic factor weakening the prospects for new nuclear plants. Nuclear equipment suppliers have successfully reduced capital cost over the years, but the current plant concepts are not yet cheap enough to provide a clear economic advantage. While governments have played a pivotal role in securing the economic viability of nuclear power in the past, today the technology is mature. Private investors and commercial generators must bear most of the financial risks of new nuclear plants. Nuclear power must increasingly face the future on its economic merits and drawbacks as judged by electricity markets.

It should be noted, however, that a number of plausible developments could make a big difference to the commercial economics of nuclear power. A sharp increase in fossil fuel prices, restrictions or taxes on the emissions of carbon dioxide, or more substantial progress in reducing nuclear plant capital cost, could tip the economic balance.

The wider energy policy framework is equally important. The search for greater energy security could once again work in favour of nuclear power, as it did in the past. Energy security is a fundamental consideration for some countries that have chosen to develop nuclear power. France and Japan both rely on nuclear power to underpin their energy security because of their limited domestic energy sources. Energy security has also been a consideration for some of the countries that have developed nuclear fuel reprocessing facilities. Nuclear energy today displaces large amounts of energy that would otherwise have to be purchased outside the OECD.

On the other hand, public concerns about plant safety, accidents, environmental protection and disposal of long-lived plant wastes have had a great impact. Almost half of OECD countries have placed legal or policy restrictions on building nuclear power plants. Some opposition to new and existing nuclear facilities is to be found in all OECD countries, including those with active nuclear programmes. Belgium, Germany, the Netherlands and Sweden have made political decisions to phase out the use of nuclear power. Italy implemented a phase-out in the 1980s.

The two most important environmental questions facing nuclear power today are the fate of long-lived radioactive wastes and climate change. Nuclear waste is often seen as the weak point of nuclear power. The ability of nuclear power to help respond to climate change concerns (because it does not emit carbon dioxide unlike fossil-fuelled plants) is seen as its strong point. Most countries with operating nuclear plants have active programmes to develop disposal facilities for high-level nuclear waste. These programmes have made much technical progress in the past 20 years in identifying suitable sites and procedures for safely isolating radioactive wastes from the environment. There is a wide agreement among scientists that geological isolation is the best method to dispose of high-level and long-lived wastes. Most governments have adopted such an approach. Yet, progress on implementing these concepts remains slow. The first disposal facility in the world for high-level civilian wastes is not expected to be operating before 2010, in the United States. Other countries do not expect to put facilities into operation before 2020.

Efforts to combat climate change could alter the perception of, and the prospects for, nuclear power. Electricity generation accounts for about one-third of emissions of man-made carbon dioxide. Nuclear power is a potential contributor to reducing those emissions. A strong commitment to reduce emissions of carbon dioxide could have a dramatic positive effect on the prospects for nuclear power over the coming decades. A focus on nuclear power's potential benefits in relation to climate change could put concerns about nuclear plant safety and environmental protection in a different perspective.

Governments face the challenge of ensuring that the full costs of environmental protection and the costs and benefits of energy security are incorporated in the cost of generating electricity from all sources, not just nuclear. Opinions vary on how such externalities would affect the competitiveness of nuclear power if included in the generating costs of all types of power plants.

While the trends and issues in nuclear power are common to many countries, they are not the same for all countries. In most countries, for example, public opinion is a factor that electricity generators and governments must take into account, but it is certainly not the case that public views are uniform either in all countries or even within countries.

Summary of Issues for Government Action

National circumstances and objectives with respect to nuclear power vary considerably among OECD countries. Among the countries with nuclear plants, there are those that wish to increase nuclear power's contribution to the electricity supply, others that wish to reduce it, and still others that wish to retain it as an option for the future. Among countries without nuclear power, there are some that have strong policies against its development whereas others consider it an option for the future.

The issues listed below have been organised in light of these differences: issues of general relevance to OECD countries, including some that are relevant to countries without nuclear power; issues of relevance to countries with nuclear power that wish to retain it as an option for the future; an issue specifically for those countries with nuclear power that wish to phase it out.

General

Economics

▸▸▸ *Aim to ensure that the full, unsubsidised costs of all forms of power generation are borne by generators. To the extent possible, make sure that the full costs and benefits of environmental protection are reflected through all stages of fuel production, power generation and waste disposal, ideally through market pricing mechanisms.*

▸▸▸ *Recognise the various effects of the externalities (environmental and others) from power generation and aim to establish common* *methodologies and procedures that would facilitate their appropriate inclusion in decision-making mechanisms. Facilitating access to information, as well as the involvement of stakeholders, should be key components of this process.*

- *Whether supporting or discouraging nuclear power development, do so on the basis of clearly defined and accepted public costs, risks and benefits. Devote particular attention to evaluating the potential energy security and environmental characteristics of nuclear power.*

Energy Security

- *Seek to better define the value of the energy security and diversity benefits of nuclear power, including the costs and benefits relative to other current and potential energy sources.*
- *Consider the extent to which other government actions such as strategic stockpiling already integrate energy security.*

Wastes

- *Give the highest priority to implementing realistic, broadly-accepted programmes for high-level waste disposal, including disposal of spent fuel considered as waste.*
- *Make steady, step-by-step progress in implementing ongoing waste programmes, thus building confidence in their adequacy. Make sure, more than in the past, that there are ample opportunities for consultation and public review of waste disposal plans. Waste programmes should be designed to take into account the ethical, health, economic and political concerns of all interested parties, especially those directly affected.*
- *Continue to work towards resolving all outstanding issues of waste disposal, not just those connected with high-level wastes. Consider the important benefits of cleaning up all radioactively contaminated sites, even if not related to civilian nuclear power. This should be done not only to secure long-term environmental*

benefits, but also to build trust in the methods for dealing with the environmental problems caused by radioactive materials.

- *If spent fuel is disposed of in geological disposal facilities, make sure it is feasible in the future to retrieve the spent fuel in order to recover its unused energy value. For both spent fuel and high-level wastes, consider such retrievability as a matter of public policy and not as a matter of purely technical debate.*
- *Support and strengthen international co-operation on research and development related to radioactive waste disposal.*

Climate Change and Air Pollution

- *Carefully consider the potential contribution of nuclear power to limit carbon dioxide emissions and fossil fuel airborne emissions and its role in future abatement strategies.*

Nuclear Safety Regulation

- *Make sure that regulatory authorities have adequate resources, visibility and authority to meet the need for greater regulatory effectiveness and electricity market competition. Sustain an industrial and regulatory environment that gives the highest priority to safety and adherence to radiation protection standards. Industry and regulators must fully accept, implement and enforce rules as written, or work together to improve them so that high levels of compliance can be attained.*
- *Support efforts to improve nuclear safety regulation while still ensuring high standards of protection. Give priority to simplifying safety regulations and improving their cost-effectiveness.*
- *Assure the maximum degree of independence for nuclear safety regulatory authorities, consistent with national practices for the control of government institutions. Regulators should be institutionally separate from industrial support organisations and should be designed to limit the scope for political interference in regulatory decisions.*

- ▸▸▸ *While allowing for continuous advances in techniques and knowledge related to safety, support administrative procedures that provide stable and predictable regulatory processes.*

Non-OECD Countries

- ▸▸▸ *Promote dialogue and information exchange with non-OECD countries over safety issues and best practice. For example, by encouraging nuclear safety regulators to meet regularly.*

Non-Proliferation

- ▸▸▸ *Continue to monitor closely the adequacy of non-proliferation measures.*

- ▸▸▸ *Continue to support efforts to extend and increase the effectiveness of the non-proliferation regime. Make sure that the relevant national and international organisations, especially the International Atomic Energy Agency (IAEA), have adequate resources and are suitably equipped and structured to carry out their missions.*

- ▸▸▸ *Given that non-proliferation issues contribute to public concern about nuclear power, consistently and regularly emphasise the commitment to preventing the spread of nuclear weapons in connection with civilian nuclear power development.*

Countries Wishing to Retain Nuclear Power as an Option

Evaluation of Nuclear Power

- ▸▸▸ *Consider nuclear power in connection with overall energy strategies, including other non-fossil energy technologies.*

- ▸▸▸ *Consider long-term sustainable development in decisions on nuclear power.*

Policies Affecting the Operation of Current Plants

▸▸▸ *Consider removing any unnecessary obstacles to the continued operation of existing facilities. Support the expeditious handling of regulatory safety reviews for existing power plants or of facilities that support the ongoing operation of plants. Similarly, retroactive application of changes in safety regulation should be encouraged only where past requirements are clearly inadequate.*

Public Trust in Policies

▸▸▸ *Strive to be open in all policy decisions. Eliminate the "culture of secrecy" where it still exists. Any direct government financial support, such as subsidies or provision of no-cost services or facilities, should be indicated in clearly identifiable government accounts.*

▸▸▸ *Ensure that nuclear policy decisions are part of a fully democratic process. This means not relying upon purely administrative decisions, taken without public debate, to support nuclear power development. The need for consultation and public review of policy decisions is especially important in the area of high-level radioactive waste disposal.*

▸▸▸ *Government-sponsored communication programmes can help to inform the public about nuclear power but should not be over-emphasised. When undertaken, their objective should be broader than that of conveying facts. They should be designed to help those affected by nuclear-related decisions to expand their appreciation of all the issues involved, i.e., issues related not only to safety and technical efficiency but also to values and norms in society, including environmental values.*

▸▸▸ *Refrain from suggesting that nuclear power (or any other source of energy) is perfectly safe. The environmental effects of potential nuclear accidents should neither be portrayed as zero nor as known with certainty to be negligible.*

▸▸▸ *Although an absolute separation of military and civilian nuclear facilities may not be possible, in the interest of public acceptance, do not use civilian power plants for the production of military materials.*

Research and Development

▸▸▸ *Consider a re-evaluation of current expenditures for research and development (R&D) on new designs, with due regard to current public and private R&D efforts and funding.*

▸▸▸ *Make sure that policies supporting nuclear R&D are complementary to overall energy strategies and that the level of public R&D spending is appropriate.*

International Co-operation

▸▸▸ *In light of shrinking overall government R&D budgets, make sure that there is adequate international co-ordination of nuclear research in programmes supported by public money. Consider how international R&D collaboration could accelerate development of new concepts and make the most of the available R&D resources. Co-operation on prototype or demonstration plants may be of interest.*

▸▸▸ *Consider actions to maximise sharing of knowledge, experience and research facilities among countries to facilitate availability of nuclear infrastructure while reducing its cost. Consider how international harmonisation of safety standards could be improved.*

▸▸▸ *Ensure that nuclear power programmes and policies take appropriate advantage of the international framework for nuclear law.*

Countries Wishing to Phase Out Nuclear Power

▸▸▸ *Assess the costs and benefits of phasing-out nuclear power, including implications for the environment, the national energy* *balance and radioactive waste disposal. Evaluate the costs to the owners of nuclear facilities and consider how those costs will be borne among electricity consumers, taxpayers and facility owners. The results of those assessments should be published.*

Organisation of the Report

Part I of this report examines the policy issues related to nuclear power and offers policy recommendations to governments. Energy policy-makers and others whose main interest is in policy matters may wish to focus on Chapter 2.

Part II (Chapters 3 to 7) provides a comprehensive overview of nuclear power from a broad energy perspective. Chapter 3 sets out the development and current context of nuclear power in the electricity supply of OECD countries. It provides statistics on nuclear generation and capacity, ordering patterns, uranium supply and fuel production capacities. Chapter 4 considers the economics of nuclear power for both existing and future facilities. Chapter 5 examines the environmental issues related to nuclear power, including environmental and health hazards, environmental benefits and nuclear safety regulation. Chapter 6 considers the state of nuclear power in public opinion. Chapter 7 considers R&D and technology trends and developments.

The annexes provide additional background material. Annex I provides a summary of national developments and current issues. Annex II is a record of statements by the IEA Governing Board on nuclear power issues from 1974 to the present. Annex III explains the nuclear fuel cycle. Annex IV sets out projections for future nuclear power generation.

CHAPTER 2

POLICY ISSUES AND ISSUES FOR GOVERNMENT ACTION

Introduction

This chapter considers the energy policy issues related to the future use of nuclear power. Some countries see nuclear power as a vital component of their energy supply. They recognise and emphasise nuclear power's economic, environmental and energy security benefits. While insisting upon the absolute need for safety, safe disposal of radioactive wastes, and non-proliferation, these countries do not believe these issues present any insurmountable obstacles to nuclear power. Other countries take the opposite view, and maintain that nuclear power's disadvantages outweigh its advantages. These differing perspectives result in a wide range of projections for future nuclear generation (Annex IV).

The chapter begins by summarising past IEA policy statements on nuclear power (statements by the IEA Governing Board and recommendations from in-depth reviews of national energy policies are included in Annex II). Next, policy areas are discussed under the headings of economics, energy security and diversity, environment, and safety. The section "Policy Issues for Governments Wishing to Retain Nuclear Power as an Option" discusses key issues that must be addressed in current and future nuclear power programmes. It is also aimed at those countries that intend to continue with nuclear power development. The section "Policy Issues for Governments Wishing to Phase Out Nuclear Power" identifies key issues for countries wishing to phase out the use of nuclear power. To some extent, the issues discussed in these two sections are similar for all countries with nuclear power plants, whether or not they wish to have nuclear power available in the future. Moreover, national views on developing, maintaining or phasing out nuclear power can change over time. The chapter concludes with brief discussions on nuclear power in non-OECD countries and on non-proliferation.

Policy issues are addressed from the perspective of OECD countries, which account for about 85% of world nuclear generating capacity. Many policy issues are international or global in scope. Energy security, environmental issues and non-proliferation are examples. Policy decisions by individual OECD governments can affect both other OECD countries and non-OECD countries.

Issues for government action regarding wastes, climate change and air pollution, safety regulation, and non-proliferation are directed towards all countries with nuclear power programmes. Issues for government action for countries wishing to retain nuclear power as an option for the future are given separately. The issues for government action are derived in part from the IEA Shared Goals (see Annex II), specifically those relating to:

- Diversity, efficiency and flexibility within the energy sector.
- Environmentally sustainable provision and use of energy, making use of the polluter-pays principle wherever practicable.
- Technology research and development.
- Undistorted energy prices.
- Free and open trade.

IEA Policy Statements on Nuclear Power

Statements issued following Governing Board ministerial-level meetings of the IEA include policy statements on nuclear power. The complete set of ministerial statements on nuclear issues is given verbatim in Annex II. Most such statements include just one paragraph specifically concerning nuclear power. In summary, IEA policy statements on nuclear power have followed a progression similar to that observed in many countries:

- In the 1970s, the IEA supported nuclear power development, while recognising the choice of some countries not to use it. The foundation for this support was nuclear power's potential to increase the diversity of energy supply. Initially there was concern about the availability of uranium and fuel cycle services.

- Following the 1979 oil shock and the Three Mile Island accident, IEA statements concentrated on safety and on policies to support the completion of nuclear plants already under construction. IEA policy statements note the importance of public understanding, waste management and disposal, licensing and regulation, international trade in nuclear fuel and technology, and R&D. This focus lasted throughout the 1980s.

- In 1991 and 1993, the contribution of nuclear power to energy supply was acknowledged. Its historic and potential role in reducing emissions of sulphur dioxide, nitrogen oxides and carbon dioxide was emphasised.

- Since the 1993 statement of IEA "Shared Goals", there have been no policy statements on nuclear power. The role of nuclear in energy supply and its contribution towards reducing carbon dioxide emissions has been noted.

Three constant themes have been nuclear power's contribution to energy security, respect for national decisions on the best fuel mix, and nuclear safety.

Economics

This section starts by considering the commercial economics of nuclear power. It then addresses those costs and benefits that are not taken into account by the market, known as externalities, unless governments take explicit action to ensure that they do so. An effective assessment of the future economics of nuclear power requires that both aspects be taken into account.

Commercial Economics

Nuclear power faces a fundamental question. After half a century of government support, and with the introduction of competition in electricity markets, is it economically ready to sustain its own future? Governments must consider at least three key issues:

- Economic performance of existing plants.
- Prospects for investment in new plants in today's energy market conditions.
- Prospects for investment in new plants under future economic conditions.

In brief, most existing nuclear plants are in a strong economic position for the future, but under energy market conditions prevailing in recent years, new nuclear power plants face significant difficulties. In most OECD markets, other options offer lower total generation costs. Future economic conditions could give nuclear power a stronger competitive position and improve the prospects for new plant investment. On the other hand, improvements in existing technologies or new technologies, such as renewables, could improve their competitive position compared to nuclear power.

The introduction of competition in electricity markets has highlighted the dichotomy between prospects for existing plants and for new plants. Most existing nuclear plants are expected to be strong competitors in liberalised electricity markets. Low-cost plants will thrive, *all* plants will reduce costs, except the fraction of high-cost plants unable to improve that will shut. Well-run nuclear plants are considered valuable assets because their operating costs are competitive with coal- and gas-fired plants. It is widely expected that the lifetime of nuclear plants will be extended and their capacity incrementally increased to take advantage of the existing infrastructure. In the United States, there has been a strong trend to merge and rationalise nuclear power operations in order to decrease operating costs and position nuclear plants for continued, long-term operation.

On the other hand, given the fuel prices and other energy market conditions prevailing in recent years, few markets would choose nuclear generation as the least-cost option for *new* plants. Among OECD countries, new nuclear capacity has been ordered in only France, Japan and Korea in the last two decades. In recent years, the stable or decreasing real price of natural gas, combined with steadily improving combined-cycle generation technology, has made natural gas the cheapest option for baseload power generation in regions with pipelines to access natural gas. Coal-fired power generation, incorporating modern pollution control equipment, remains a strong competitor.

This situation may not necessarily prevail in the future. Developments in energy markets may substantially alter the *future* competitiveness of nuclear power in relation to other power generation technologies. Increasing demand for natural gas could tighten gas supply and lead to increased prices. Depletable reserves of fossil fuels could become more expensive to exploit in coming decades, thus improving the relative position of nuclear power. Stricter regulations on emissions of pollutants from non-nuclear power plants, especially coal plants, could have the same effect by increasing the cost of pollution control.

Furthermore, there will remain *regional* opportunities for new nuclear plant construction. There can be significant regional variations in costs, financial framework and other conditions that affect economic evaluations and decisions to build new plants. For example, recent official French and Japanese economic evaluations have found new nuclear plants to be competitive under certain reasonable assumptions.

The continuous trend towards improvement in nuclear plant technical performance will decrease nuclear generation costs in the future, as it has in the past. Higher capacity factors, higher fuel burnup, decreasing generation of low-level wastes and many other technical improvements have already lowered nuclear generation costs (see examples in Figure 14). Electricity market competition will support and accelerate these trends. New design concepts and pre-certified plant designs can take advantage of these improvements and provide further economic gains. The costs of operating and maintaining a new nuclear plant, and existing plants, are likely to decrease as a result of efficiency improvements from electricity market competition. There is good reason to assume that nuclear technology could achieve additional improvements and corresponding cost savings.

It has been argued that competitive markets will place difficulties in the way of decisions to build power plants and related infrastructure with certain characteristics. Many basic energy projects entail high capital intensity, long development times and large risks. This is true for nuclear plants, coal-fired plants, hydroelectric plants, offshore oil platforms or liquefied natural gas terminals. The argument is that competitive markets favour short-term investments with high returns and low risks. Two observations are often made to support these views.

The first is that introducing competition creates a state of investment uncertainty. But there is a decisive difference between transitional uncertainty as competition is introduced and market behaviour when market conditions have stabilised. It is true that, during a transition to competition, investors tend to focus on those with short times to market and low capital costs, because long-term market conditions may not be clear.

The second observation is that investors in electricity generating plants have shown a strong preference for gas-fired combined cycle power plants in many markets. These plants have short development times and low capital costs. But the start of this trend predates competitive markets. Over the last decade, gas turbine power plants have been the fastest growing power plant type. The most important reason for their attractiveness is that their expected total generation costs are competitive. Low gas prices, in real terms, have been a major factor in these expectations.

An IEA analysis confirms that competitive electricity markets can efficiently attract adequate and appropriate investments in all types of power generation plants (IEA, 1999). However, the study also recommends that the situation be monitored. Governments have introduced competition specifically to allow markets to make the most cost-effective allocation of resources, risks and technologies. Nuclear power's technological characteristics ultimately translate into its costs. If its expected total generation cost is lower than that of other generation technologies, there should be little economic impediment to its selection and use. Risk barriers for nuclear projects are not evidence of market failure. Investors in a given market assess the financial risks of nuclear power projects in relation to the magnitude of risks *likely to be encountered in practice*. Markets and investors can tolerate high risks as long as the expected profitability of an investment is satisfactory, all risks considered.

A related argument is that competitive markets place too high a discount rate on nuclear projects. Discount rates (including risk premia), hurdle rates, rates of return, or other financial criteria in competitive markets do no more than reflect the capital allocation preferences of individual investors, including their assessment of project risk. If investors do not support particular types of projects, this is not evidence of market failure. It merely means that they expect the profitability of those projects to be inadequate to meet their evaluation criteria.

Nuclear power's competitive position among options for new power plants is closely tied to its high capital costs. Nuclear plants typically cost roughly \$2 000/kW, compared to \$1 200/kW for coal-fired plants and \$500/kW for combined-cycle gas turbines. Capital costs represent roughly two-thirds to three-quarters of nuclear generating cost, compared to one-half for coal-fired plants and only one-third for gas-fired plants. The nuclear industry has for some time recognised the importance of reducing capital cost. However, the cost reductions incorporated in the latest generation plant designs do not appear sufficient in today's energy markets. Reducing nuclear plant capital cost therefore remains a key technical priority in new nuclear plants.

Nuclear power's high capital costs are compounded by uncertain liabilities and high political and technological risks (Table 18). In the past these risks have caused large increases in nuclear plant costs in some countries. Technological risk is less an issue now in a mature industry but political risk remains an important factor that can adversely affect evaluations of nuclear plant economics. Stable political and regulatory regimes help to minimise the financial risks of nuclear power projects.

Externalities

The preceding discussion considers the competitiveness of nuclear power from a commercial point of view, in other words the view that an investor would take when making operating or investment decisions. Such commercial economic evaluations do not include externalities. By definition[1], externalities are costs and benefits that are not incorporated in market decisions unless governments take specific policy actions. Examples are the cost of environmental protection and the benefit of energy security. Yet internalising these public costs and benefits into investment decision-making could make a significant difference to the prospects for nuclear power.

Governments have a key role in evaluating costs or benefits that are national or regional in scope and that may not be relevant until some time well into the future. Such strategic issues may not be taken into account by markets in time to respond to future changes. Current investments in energy infrastructure such as power generation can "lock in" a national fuel mix that is constrained for many years. Government policies can help provide "insurance" against certain risks too far in the future to be considered by markets.

1. An externality exists when an economic transaction leads to *uncompensated* gain or loss of welfare to another. Pollution is an example of a negative externality. Energy security is an example of a positive externality.

Governments are increasingly striving to ensure that markets take into account all the external costs and benefits of different forms of electricity generation. They implement policies intended to compensate for public costs and benefits that would not otherwise be taken into account in market decisions. It is critically important that externalities are identified and, as far as possible, absorbed into energy market decisions, in order to ensure that market choices result in the most efficient allocation of resources.

It is not possible to assess whether the net effect of incorporating externalities would be positive or negative for nuclear power's competitiveness. More stringent restrictions on fossil pollutants or strong restrictions on carbon dioxide emissions would improve nuclear power's competitive position. For some governments, nuclear power's security benefits, if taken fully into account, would also improve nuclear power's competitiveness. Other governments are very concerned about the environmental and public health costs of high-level waste disposal or of accidental releases of radioactive elements. They believe nuclear power's competitiveness would be worsened if these externalities were taken into account.

Governments have a role in helping to improve methods of valuing externalities, which can be a very difficult task. Governments can facilitate debate on the issues and seek methods that allow externalities to be included in economic decision-making. Facilitating access to information and involving all the potentially affected parties are important steps to any such process. Studies and methods to evaluate externalities of all forms of energy are not in themselves sufficient to establish values for public costs and benefits. Governments must decide upon the laws and regulations that enable a market value to be placed on externalities such as laws requiring pollution control equipment on fossil-fuelled power plants and the proper disposal of their solid wastes.

Stricter safety regulations on nuclear generation, waste disposal or other parts of the nuclear fuel cycle could increase nuclear generation costs.

It may not always be possible to devise market-compatible policies to make sure that certain externalities are brought into market decision-making. For example, an accurate valuation of some external costs in domestic markets might result in unacceptable consequences for domestic electricity generators if foreign producers were not subject to the same valuation. Some policies to bring externalities into market decision-making may also be politically unfeasible.

Energy security and environmental protection are the two key policy areas that highlight the issue of valuing externalities. They are considered in more detail later in the chapter.

Implications for Effective Government Action

A fundamental point of departure in formulating the energy policies of IEA Member countries is the establishment of free and open markets (IEA, 1993). Competitive markets and undistorted energy prices help to ensure efficient energy use and investment decisions. Over time, OECD governments have sought to create energy market conditions that allow them to minimise their direct role in energy market decisions. Basic principles are that energy markets should be allowed to work efficiently through energy prices that reflect the full costs of energy, including externalities and the avoidance of subsidies to attain social or industrial goals.

OECD governments broadly accept these objectives and are applying them to electricity generation. Governments increasingly must find ways to make sure that all forms of power generation bear their full costs of production. Market decisions on electricity generation should include the cost of associated infrastructure, of fuel production and transportation, of pollution control, and of waste disposal. Nuclear power has received substantial government support and subsidies for its development, such as the provision of fuel supply services at subsidised prices, capital at low cost, subsidised waste disposal, or research and development. As an example, OECD governments have spent on average over $250 per kilowatt of operating capacity on non-breeder fission technologies since 1974, or over 10% of the overnight capital cost of a "model" $2 000/kWe nuclear plant. Research and development expenditures on breeder and fusion technologies represent the equivalent of an additional $125/kWe. The support for nuclear power is not unique among power generation technologies, but it has been especially wide-ranging and substantial. So, the objective of making sure that all forms of power generation bear their full costs of production is of particular relevance for nuclear power generation.

By introducing competition in electricity markets, governments naturally decrease their ability directly to influence the choice of generation technology, since one major objective of competition is to allow the electricity market to choose technologies in order to ensure the best possible resource allocation. Governments could, of course, try to retain control over the choice of nuclear plants in competitive markets by explicitly requiring a specific share of nuclear power, creating a protected market for nuclear generation, or by explicitly limiting the role of nuclear power. By doing so, they will lose a main benefit of competition and partly defeat the objective of liberalisation programmes.

Countries wishing to favour or discourage nuclear power as an option for the future may still legitimately influence commercial decisions to continue operating existing plants or to build new ones. In many cases, markets do not yet fully account for the public benefits of energy security and environmental protection. But any government action should be based on clear evidence that it is justified, by the nature of the problem, by the likely benefits and costs of action, and by the availability of alternative mechanisms for addressing the problem (OECD, 1997). Before promoting specific policies, governments must assess whether the issues are not already taken into account in energy and electricity markets, either by the market itself or by other government policies. This applies equally to policies designed to foster nuclear power development and those to restrict it.

If the policy context indicates a need for government action, governments retain the ability to implement a range of policies, including market-compatible policies and measures. Tonn *et al.* (1995) list 31 "enabling mechanisms" suitable for use in a competitive electricity industry. For example, governments can require the costs of some policies to be borne by users of the transmission or distribution system. Charges on the use of the network can include such a policy-related component. Taxes, investment support, special-purpose markets and government research and development are potential measures. Nuclear power can be affected, if governments so wish, by these and many other mechanisms.

Issues for Government Action

- *Aim to ensure that the full, unsubsidised costs of all forms of power generation are borne by generators. To the extent possible, make sure that the full costs and benefits of environmental protection are reflected through all stages of fuel production, power generation and waste disposal, ideally through market pricing mechanisms.*
- *Recognise the various effects of externalities (environmental and others) from power generation and aim to establish common methodologies and procedures that would facilitate their appropriate inclusion in decision-making mechanisms. Facilitating access to information, as well as the involvement of stakeholders, should be key components of this process.*
- *Whether supporting or discouraging nuclear power development, do so on the basis of clearly defined and accepted public costs, risks and benefits. Devote particular attention to evaluating the potential energy security and environmental characteristics of nuclear power.*

Energy Security

Nuclear power is the only large-scale source of electrical energy that is not dependent on fossil fuels or site-specific renewable energy resources. It offers a source of electricity that many governments consider quasi-domestic once the plant is built. Since the 1970s, energy security has been a fundamental reason for government support of nuclear power. Some countries without domestic fossil energy resources, particularly Belgium, France, Japan and Korea, have strongly supported the development of nuclear power because of its contribution to energy security.

Nuclear power can contribute to energy security in several ways:

- Nuclear fuel is available in ample supply from OECD countries. The risk of interruption in nuclear fuel supply to OECD countries and the risk of a short-term increase in price are lower than for fossil fuels.

- Nuclear fuel can displace the use of fossil fuels and thereby reduce the economic consequences of any disruption in fossil fuel supply. This "diversity" value is especially relevant when alternative fossil fuels for power generation must be imported.

- The financial risks of nuclear power over the course of a plant lifetime are different from those of fossil-fuelled options and not strongly correlated with them.

Nearly half of the world's current uranium production is from Canada, Australia and the United States (Table 6). Seven other OECD countries account for an additional 6% of world production. The OECD's share of current uranium production is higher than its share of fossil energy sources (Table 1). The OECD's share of estimated uranium resources is roughly 40%, which is about the same as its share of coal reserves, but it is much higher than the 7% and 12% shares estimated for oil and gas reserves. OECD countries have considered that the long-term availability of uranium at acceptable prices is assured, regardless of developments in non-OECD countries. OECD countries, taken as a whole, are self-sufficient in enrichment and fuel-fabrication capacities (Table 11).

Breakdowns or failures in fuel transportation systems are less likely to affect nuclear plants than others are. For example, lost fuel

Table 1

OECD and World Energy Production and Reserves

	OECD	Non-OECD	OECD Share (%)
1998 Production			
Oil (Mtoe)	1 046	2 564	29
Gas (Mtoe)	975	1 075	48
Coal (Mtoe)	1 006	1 212	45
Uranium (kilotonne)	19	16	55
1998 Identified Reserves			
Oil (Mtoe)	9 580	127 108	7
Gas (Mtoe)	15 592	113 742	12
Coal (Mtoe)	207 557	282 443	42
Uranium (kilotonne)	1 877	2 539	43

Notes: Oil reserves refer to conventional reserves and do not take into account possible increases due to new information or technology. Uranium reserves are those estimated in 1999 to be available at a cost of $130/kg U or less.
Sources: Oil and Gas Journal; *Cedigaz; IEA* World Energy Outlook 2000; *NEA (2000c).*

transportation capacity from damage to a coal-handling port, a critical rail bridge or a natural gas pipeline could be difficult to replace and take a long time to repair. The quantities of fuel needed for fossil-fuelled plants are so large that the associated transportation infrastructure is vital. Likewise, stockpiling of coal or natural gas is relatively expensive. On the other hand, storage of nuclear fuel sufficient for a year of plant operation is economically feasible and physically convenient because the fuel occupies a relatively small volume. Stockpiling of larger amounts of nuclear fuel is feasible. An industrial facility with the area of a standard football field could hold enough nuclear fuel to run all OECD reactors for one year. Interruption of nuclear fuel supply because of either technical or political problems is thus less of a short-term problem for nuclear generation than for fossil-fuelled plants.

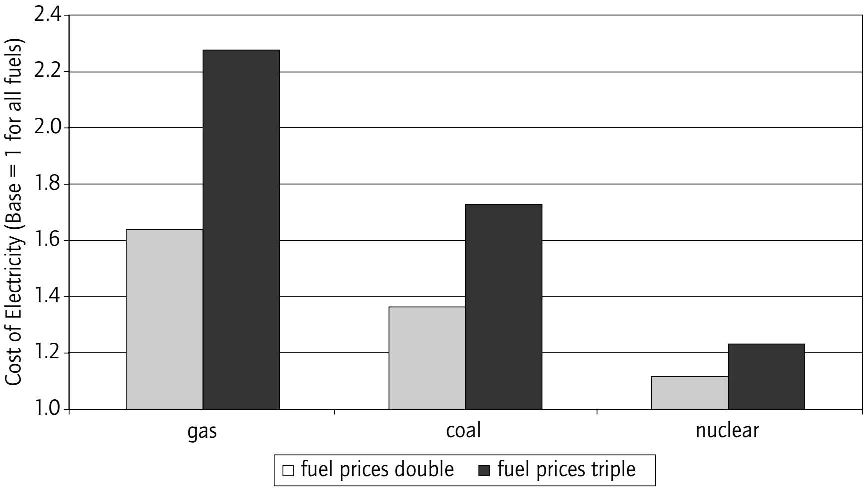
Nuclear power can contribute to energy security as part of a diversified portfolio of input fuels. By displacing the use of fossil fuels, nuclear power can reduce the impact on the economy of price or supply disruptions in those other sources of energy. If a large fraction of energy supply is imported, fuel diversity is particularly relevant. The growth of nuclear power after the oil shocks of the 1970s provides an example. In 1973, oil products provided one-quarter of OECD power generation. In OECD Pacific countries, the share of oil-fired power generation reached 60%. Following the oil shocks, the growth of nuclear power helped to decrease the use of oil-fired power generation to current levels of less than 10%. On average, the sensitivity of electricity markets to oil price increases has thus been reduced by over half because of the growth in nuclear (and coal-fired) power generation. As an element of diverse energy supply for power generation, nuclear power can also provide a hedge against the costs of responding to new requirements for environmental protection such as climate change and airborne pollution.

The risks of cost increases of nuclear power are different from those of fossil fuels. A mix of fossil, nuclear and renewable energy sources for power generation can reduce the risk of increased system generation cost due to the increase in cost of any one fuel. In the short term, the risk of increased nuclear fuel prices due to increased fossil fuel prices is small because there is little short-term correlation between prices of nuclear fuel and fossil fuels. On the other hand, nuclear power is more capital-intensive, so the risks of increased generation cost because of increased cost of capital and inflation are greater.

Compared to fossil-fuelled power generation, two characteristics of nuclear power tend to reduce the risk of rapid or large increases in total generation cost owing to changes in fuel markets. First, various parts of the nuclear fuel supply chain have storage capacity and stockpiles of uranium and intermediate products that can be drawn down in case of an interruption upstream. This significant "internal" storage follows from the relatively high energy density of uranium. This tends to moderate the rate of change of prices in case of a supply disruption. Second, because of the small weight of fuel cost in the overall cost of generation, nuclear generation is much less affected by increases in the price of nuclear fuel. If nuclear or fossil fuel prices were to rise by equal amounts, the effect on the cost of electricity would be much less pronounced for nuclear power generators. A doubling in the price of nuclear fuel would result in only a 10% increase in the cost of generation (Figure 2). If raw uranium prices doubled, generation cost would increase by only 2 to 4%. Nuclear generation costs, including capital, would rise by only about one-third of coal's costs, or one-fifth of gas-fired costs.

Figure 2

Sensitivity of Generation Cost to Fuel Price Increases



Notes: Values are illustrative only. Cost of electricity values assume capital cost fractions equal to averages in the OECD Generating Cost Study (OECD, 1998).
Source: IEA.

Source: IEA, Electricity Information 2000.

The energy security and diversity benefits of nuclear power are recognised by many governments. A challenge for the future is to define better the value of these benefits and implement policies to capture them in a market context, while not disturbing the efficient operation of energy markets or distorting prices. In the past, governments promoted nuclear power by providing infrastructure, encouraging or requiring utilities to build nuclear plants and through other policies. Such approaches were often pursued without fully accounting for the cost of implementing them, either to the government or to the economy, compared to the benefits not otherwise captured by the economy. The strong policy support for completion of nuclear plants under construction after the 1979 oil shock (about one-half of US capacity and two-thirds of capacity elsewhere in the OECD) was based in large part on their expected contribution to energy security and diversity. Under the prevailing energy market conditions, nuclear plants were expected to cost little more than other options. Many governments felt that the cost-benefit balance clearly favoured nuclear power.

A number of changes since the 1970s make it more difficult for governments today to provide policy support in the same way as in the past. While energy security is still an important objective of IEA Member governments, environmental issues and economic efficiency have grown in relative importance. Public scepticism about nuclear power has grown. The quest for economic efficiency has undercut policy support for nuclear energy. Nuclear power is no longer the option with the lowest expected cost of electricity in most evaluations. Few nuclear plants will be built if the market conditions prevailing in recent years continue. Nearly all governments in the OECD have introduced or intend to introduce competition in electricity markets. In such markets, any government support for specific generation options will have to be transparent and subject to greater political scrutiny. Government support may no longer be possible through purely administrative actions. Policies favouring nuclear energy may face more rigorous public debate because proponents of competing options will draw attention to what they consider as discriminatory treatment.

The policy tools available to governments to achieve energy security benefits need careful assessment. To justify support for nuclear power on the basis of energy security, governments must attempt to answer such questions as:

• What is the value of energy security provided by nuclear power?

• Is this greater than for other options, such as gas or coal?

• Are markets already able to incorporate the energy security benefits? Do other government actions such as tariffs, taxation or strategic energy stockpiling already provide adequate security against energy supply disruptions?

• If not, what policies should the government implement to obtain these benefits?

• Given the difficulties and uncertainties surrounding energy security policy, should governments adopt a portfolio approach to nuclear power's role, in other words, a long-term public policy perspective on the fuel mix?

There are no simple answers. Other policy areas show that security benefits need not be quantifiable in order to justify government policy action. For example, governments maintain large national defence budgets even though the "benefits of peace" are not quantifiable. Governments invested considerable money to make sure that Year 2000 computer problems did not affect their economies, even though most of the direct costs of major failures would have been borne by companies using computers and their clients.

The generating cost study published jointly by the International Energy Agency and the OECD/Nuclear Energy Agency also examines the issue of energy security and diversity in electricity generation (OECD, 1998: Annex 9). It concludes, however, that, for many countries, the additional energy security obtained from investing in non-fossil-fuelled generation options is likely to be worth less than the cost of obtaining that security. The analysis highlights the need for governments to consider externalities in a consistent, even-handed way. For example, implementing policies or choosing specific technologies to capture energy security benefits, while not considering any environmental costs, might improve security but harm the environment. Governments must attempt to balance the benefits and the costs of policies to enhance energy security through nuclear power. The net cost can be positive or negative according to national circumstances.

In summary, nuclear power offers benefits of energy security and diversity. These benefits are among the most important reasons why some governments have supported and continue to support a role for nuclear power.

Issues for Government Action

- *Seek to better define the value of the energy security and diversity benefits of nuclear power, including the costs and benefits relative to other current and potential energy sources.*
- *Consider the extent to which other government actions such as strategic stockpiling already integrate energy security.*

Environment, Climate Change and Air Pollution

The two most important environmental topics facing nuclear power today are the disposal of long-lived radioactive wastes and the threat of climate change. The first is negative for nuclear power. There is no consensus on the environmental impact of long-lived radioactive wastes, but many are concerned that the potential impact could be large. There are currently no operating facilities for final disposal of high-level waste. Thus, there is no practical basis for confidence that environmental risks can be minimised to acceptable levels. The second issue is clearly positive for nuclear power, which in operation produces virtually no gaseous pollutants, carbon dioxide or other greenhouse gases. Along with support for other power generation technologies that do not emit greenhouse gases, support for nuclear power could be among the policies adopted to respond to climate change concerns.

The environmental debate on nuclear power revolves around the value assigned to environmental costs from nuclear wastes (and other emissions of radioactive elements) and from greenhouse gases. Costs associated with non-nuclear environmental problems, such as airborne pollutants or mining damages, are also relevant. Depending on the valuation of these costs, nuclear power can be less or more expensive than other generating options. Governments that have placed restrictions on nuclear power development implicitly have assigned large values to nuclear power's environmental and public health costs. Those favouring nuclear power development consider that the costs of protecting the environment are already fully borne by nuclear facilities and that nuclear power provides other environmental benefits. The debate continues on nuclear power's net environmental balance, including nuclear waste disposal and climate change, in comparison to other power generation options.

From a public policy perspective, the two most important challenges are: 1) ensuring steady progress on developing broadly accepted programmes and facilities for waste disposal, especially high-level waste disposal, including spent fuel considered as waste, and, 2) ensuring that radioactive discharges from all nuclear facilities are kept within regulatory limits.

Wastes and Emissions of Radioactivity

High-level waste can be expected to continue figuring prominently in debates on nuclear power. The earliest planned operation of a facility for final disposal of civilian high-level waste (including spent fuel considered as waste) is not expected for at least another decade. Governments have recognised that high-level waste disposal is often a focal point of public concern about nuclear power.

There are active national programmes for the permanent disposal of high-level wastes in most countries with nuclear power plants (Table 25), and these programmes have made steady technical progress. Disposal programmes have identified geological disposal facilities as a technically feasible, environmentally safe, long-term solution for the disposal of spent fuel and high-level waste. Many governments have adopted geological disposal as the primary approach to high-level waste disposal. The consensus of engineers and nuclear scientists is that nuclear waste can be safely isolated from the biosphere over the time periods necessary.

This view is not one fully shared by the general public and by some authorities. Critics point to the continued absence of operational solutions after some 40 years of development and large expenditures. The absence of broadly accepted political processes for designing and implementing waste disposal policy, concerns about the transport of waste to central disposal sites, and ethical concerns about shifting burdens to future generations have slowed progress and fuelled public debate. Among many non-specialists, there is a lack of confidence in the long-term safety of proposed solutions and a lack of trust in the institutions responsible for implementing waste disposal programmes. Attitudes vary country by country.

Controversies over geological waste disposal have led governments to support research on other disposal options. Transmutation of wastes to shorten their half-lives (see Chapter 5) could, theoretically, reduce the total amounts of high-level wastes and shorten the time periods over which high-level wastes remain dangerous. Fast reactors or accelerator-driven reactors could be used for this purpose. But transmutation would be expensive and would not begin to reduce the total radioactive toxicity of wastes until after many decades or, more likely, centuries. These time scales are imposed by limitations in the ability to separate certain waste isotopes and the physics of transmutation itself. Monitored retrievable storage could be used to store wastes indefinitely, but would leave the burden of monitoring to future generations. The consensus view of waste management experts is that, at present and for the foreseeable future, the only real option for safe disposal of long-lived radioactive wastes is geological disposal (NEA, 1999c).

There is a risk that efforts to identify new disposal options repeat an error of the past: that they will focus on purely technical solutions while failing to address the more fundamental social issues of consensus and trust.

Long-term solutions for some categories of waste disposal have not been given enough attention in some countries. For example, in the United Kingdom, a 1999 Parliamentary report (HL, 1999) stated that there are long-lived wastes "for which no long-term management policy has been decided." The wastes arising from both civilian and military nuclear programmes include spent fuel from pressurised-water reactors, depleted uranium, surplus plutonium and certain reactor decommissioning wastes. As a result, future storage and disposal needs are not well defined, and this has led to the "continued storage of hazardous materials in an essentially temporary state." The French safety authority has called attention to the problem of major waste categories for which no final disposal solution has been found, including waste from decommissioned reactors and long-lived low-level waste (DSIN, 1999: p. iv). Stabilisation of mine tailings, clean-up of uranium-ore spills and clean-up of old fuel cycle facilities are an issue in some countries.

The minimum expected cost of a national programme to dispose of high-level wastes is about one billion US dollars, whatever the quantity of waste involved (Table 16 and Figure 18). International co-operation on R&D related to waste management and disposal can help to share costs and reduce national expense. The relatively high minimum cost creates a strong economic case, especially among countries with small nuclear programmes, to seek the development of international waste disposal sites. This idea poses particularly difficult political issues. No government wishes to be seen as importing or exporting potential environmental dangers. Non-proliferation issues also are difficult to surmount. Nonetheless, given the high expense and slow pace of tangible progress in national high-level waste disposal projects, some governments might now find it worthwhile to reconsider the idea, taking into account national and international sensitivity to the idea of "exporting" nuclear wastes.

Several OECD government bodies have debated conditioning the construction of new nuclear power plants or the reprocessing of fuel on the availability of an operating facility for the disposal of high-level wastes. The idea was publicly debated and rejected in Canada, the United Kingdom and the United States. A variation has been that a ban should prevail until a programme clearly demonstrating the ability to dispose of waste has been devised and accepted. This policy was adopted by the Swedish government in 1976 and by the Swiss government in 1979. In Sweden, Parliament decided that a permit could be issued for new plants if the utility presented an agreement on reprocessing of the spent fuel, and a plan for safe final storage of the high radioactive waste. The Swiss government required nuclear generators to demonstrate the feasibility and safety of final disposal as a condition for the extension of plant operational licences beyond 1985. In most countries, a ban on new plant construction would have no immediate impact, since no new plants are planned, but it could constrain future plant construction if disposal sites were slow to be developed. On the other hand, high-level wastes must be dealt with regardless of the future of nuclear power. If there were a strong wish to build new nuclear stations, the policy could be an incentive to speed up the development of waste sites. It could also help to develop public confidence that no new environmental questions or problems would arise beyond those already known.

The ability to monitor and gain access to waste once it is in a permanent disposal site is seen as increasingly important to public acceptance of disposal plans. This would allow future generations to determine whether the site is still safe. Maintaining some access to the site could be useful for two reasons related to public acceptance. First, it would make it easier to correct problems if they arise. Second, it would allow future generations to apply new methods of waste management if better solutions become available. On the other hand, making the site *too* accessible might invite mischief or misuse of the wastes, such as recovery of plutonium for military purposes. The issue is as much a matter of public policy as a technical question.

If spent fuel is disposed in the facility, maintaining access to it could allow later recovery of the potential energy in uranium-238 and plutonium. Today's thermal reactors convert only a small fraction of the total energy available in nuclear fuel. Spent fuel still contains substantial quantities of energy that could be exploited in the future.

Emissions of radioactive elements from OECD civilian nuclear facilities, both routine and accidental, have been small. While accidents at nuclear facilities can and do happen (Table 22), no accident in an OECD country has released significant amounts of radioactive materials. On the basis of what is known today, radiation protection authorities are confident that public health effects have been too small to measure. The most important action governments can take in this area is to foster an industrial and regulatory environment that gives the highest priority to safety and adherence to radiation protection standards. This has been the policy of OECD governments since the inception of their nuclear power programmes. It merits continued emphasis.

Governments may find it useful to re-examine their regulations and practices concerning releases of radioactive elements from fuel cycle facilities and uranium mines. Since nuclear power plants have by now maintained their safe operating records for lengthening periods, antinuclear campaigns may increasingly concentrate on facilities other than power plants. Also, regulatory attention traditionally has been more focused on power plant design and operation, because of the potential for accidents and associated release of fission products. Yet reprocessing plants handle greater quantities of radioactivity and are subject to both industrial and nuclear accidents. The last three serious incidents at OECD nuclear facilities have been at fuel cycle facilities.

Climate Change

Climate change is one of the most important energy and environmental policy issues today. Except for Korea and Mexico, OECD countries have all committed themselves to reduce their emissions of greenhouse gases below 1990 levels. All OECD countries are exploring the measures available to reduce emissions of carbon dioxide. The electric power sector is important in the climate change debate because it is responsible for about one-third of emissions of carbon dioxide. Policy-makers are likely to focus on power generation as a convenient target for emissions reduction. Unlike other energy processes, carbon dioxide emissions from power generation are released in large quantities from a relatively small number of sites. Restrictions on emissions of greenhouse gases could increase the cost of generation using fossil fuels and so improve the economic competitiveness of generation options that do not emit greenhouse gases.

Nuclear power emits no carbon dioxide in operation and is therefore a current and potential contributor to greenhouse gas reductions, though it is not unique in this regard. Various other energy sources, including renewable energies, can also help to mitigate emissions from the electric power sector. Alteration of demand patterns and decreasing the intensity of energy use can also contribute.

Nuclear power has already played a major role in lowering the amount of greenhouse gases produced by OECD power plants (Figure 24) over the past 40 years. Without nuclear power, OECD power plant emissions of carbon dioxide would be about one-third higher than they are at present. This is an annual saving of some 1.2 billion tonnes of carbon dioxide, or about 10% of total CO_2 emissions from energy use in the OECD. If all OECD nuclear plants were to cease operating in the coming decades, this would add 10% to CO_2 reduction targets. Governments will need to consider how the outlook for nuclear power affects future CO_2 emissions.

A number of governments, including those of Canada, France, Japan, the United Kingdom and the United States, recognise the important role of existing nuclear plants in climate change policy. The Japanese government places great emphasis on expanding nuclear power as an important element in their strategy for reducing emissions of carbon dioxide.

Not all governments believe that nuclear power is an appropriate means to reduce greenhouse gas emissions. At the 6th Conference of the Parties (COP 6) to the United Nations Framework Convention on Climate Change held in November 2000, ministers from Austria, Denmark, Germany, Greece, Ireland, Italy and Sweden opposed the use of nuclear power projects in the Clean Development Mechanism[2]. They believe, on balance, that other environmental costs outweigh any potential benefits from the use of nuclear power to abate climate change. The debate at COP 6 did not result in any decision.

Capacity upgrades at existing nuclear plants help to reduce CO_2 emissions by displacing generation at fossil-fuelled power plants. Individual nuclear plants have increased capacity by 2 to 15%. Higher utilisation rates in existing plants also help. If average national utilisation of nuclear capacity in all OECD countries with capacity utilisation of less than 85% were to attain 85%, total carbon dioxide emissions would be reduced by an additional 100 million tonnes per year, or roughly 0.8% of total OECD emissions from energy use. This illustrative figure does not take into account the technical limit of nuclear plants or electricity system constraints, which would lower the potential savings. Increases in capacity and utilisation at existing nuclear plants are helpful in reducing CO_2 emissions, but have limited potential effect.

New nuclear power plants could provide a much larger source of emissions avoidance. A study by the OECD Nuclear Energy Agency (NEA, 1998c) concludes that a tripling of nuclear power capacity by 2050 would be feasible from the point of view of construction, financing, siting and land requirements, and uranium resources. It estimates, in this case, that nuclear power could annually avoid some

2. The Clean Development Mechanism is a mechanism that seeks to encourage climate-friendly projects in developing countries and to help minimise the overall cost of reducing emissions.

6.3 billion tonnes of CO_2 by 2050. This would avoid about one-third of total projected world CO_2 emissions from the energy sector.

Governments are seeking a cost-effective and politically feasible mix of measures to reduce emissions of greenhouse gases. Opinions vary on how nuclear power would compete economically among other potential policy measures. If nuclear power did cost the same as competing means of power generation, the incremental cost of reducing CO_2 emissions would be zero. Under these conditions, power generators would choose to build nuclear plants anyway, and no government action would be necessary.

If nuclear power were not the commercial option chosen by electricity generators, specific government action would be required in order to assure the construction of new nuclear plants. For example, governments could provide explicit subsidies for building new nuclear power plants, provide a protected market for nuclear generation, or establish market-based mechanisms that transfer the cost of CO_2 abatement to CO_2 producers. The last-named option is preferable if economic efficiency is also to be optimised.

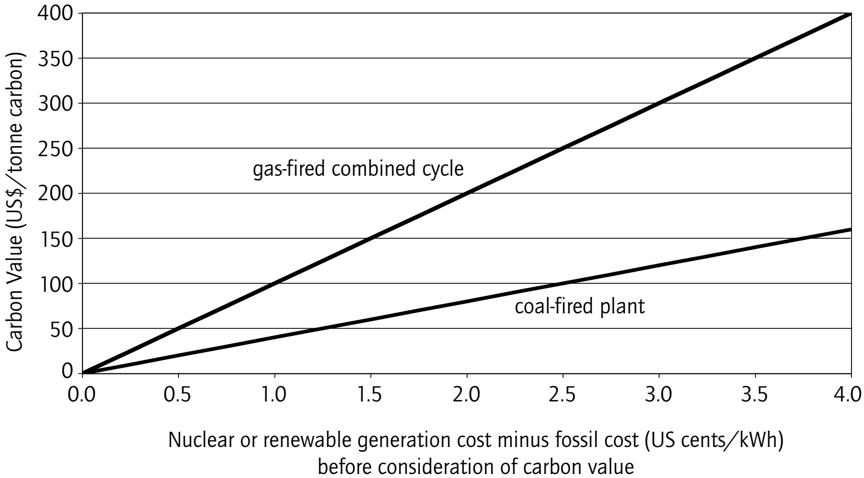
It is possible for governments administratively to select specific power generation options, including nuclear power, as an option to help reduce CO_2 emissions. It is unlikely, however, that administrative measures would reduce CO_2 emissions in the most cost-effective way. OECD Member governments have stated their wish to implement climate change policies that maintain economically efficient energy markets. This would favour policies that reflect the cost of CO_2 abatement in electricity generation and other sectors over administratively chosen options.

The difficulty in judging what measures are the most cost-effective is an important reason why many governments believe market-based policies for CO_2 abatement should be used. There are strong economic arguments in favour of allowing energy and other markets to determine an abatement cost or “carbon value”. Even in the absence of market-based mechanisms, restrictions on CO_2 emissions would implicitly set a carbon value. Regardless of how such a carbon value is determined, nuclear power generation would not be burdened with additional costs to avoid carbon dioxide production.

Within the power sector, a carbon value would increase the cost of generation from fossil-fuelled power plants compared to nuclear generation, renewables, and other generation technologies that do not emit carbon dioxide. Where nuclear is *not* the cheapest option, a carbon value would decrease the difference in cost between fossil-fuelled plants and nuclear plants. Given a large enough carbon value, nuclear power would become the cheapest generating option. As a rule of thumb, a \$1/tC carbon value increases the cost of gas-fired generation by 0.01 cents/kWh and coal-fired generation by 0.025 cents/kWh[3]. Figure 3 illustrates the relationship. For a given

Figure 3

Carbon Value at Which Nuclear or Renewables Become Competitive with Coal and Gas-Fired Plants



Source: IEA.

3. The rule of thumb calculation assumes the following: natural gas having a carbon content of 15 kg carbon per GJ is burned in a combined cycle of 55% efficiency; coal having a carbon content of 27 kg carbon per GJ is consumed in a plant of 40% efficiency.

difference in cost between gas- or coal-fired generation and nuclear generation (nuclear assumed to be more expensive) on the X-axis, the Y-axis shows the carbon value at which the fossil options increase in cost to the same as nuclear. Note that the same figures apply to renewables and other generation sources with no carbon dioxide emissions.

Many analyses of CO_2 abatement costs to meet the requirements of the Framework Convention on Climate Change estimate carbon values at between \$25/tonne and \$85/tonne of carbon. Some analyses suggest much higher values might be needed. For example, a 1998 report by the US Energy Information Administration (EIA, 1998) estimates that a carbon value of up to \$350/tonne could be reached to meet US domestic targets. Given a range of \$25 to 350/tonne, nuclear power could overcome a cost handicap compared to coal of 0.6 to 8.8 cents/kWh. It would overcome a cost handicap compared to natural gas of 0.3 to 3.5 cents/kWh. In the OECD study on electricity generating costs, when nuclear generation is estimated to be more expensive, the maximum difference in generation cost compared to coal is about 0.5 cents/kWh and compared to gas about 2 cents/kWh (OECD, 1998). So there is a range of plausible circumstances in which effort to reduce emissions of greenhouse gases could alter the competitive balance between new nuclear power plants and other generating options.

Some proponents of nuclear power have argued that the contribution of nuclear power plants to reduce emissions of carbon dioxide be recognised through specific mechanisms in emissions trading regimes. For example, the International Nuclear Forum, an informal grouping of nuclear trade associations, proposed (INF, 1999) that climate change policies should include "distribution of emission allowances in global electricity sectors based on *electricity generated* to ensure an emissions trading system that is non-discriminatory of non- and low-emitting technologies" (emphasis added). In itself, providing credits to generating plants that do not emit greenhouse gases merely results in a redistribution of money from emitters to non-emitters, while having no effect on the total absolute levels of emissions. Emissions trading works efficiently provided all emission sources are adequately covered by the system. As nuclear generation is not a source of carbon dioxide, it would not be constrained by an emissions cap and therefore would not warrant the distribution of emissions credits. From an economic standpoint, nuclear power would start off at an advantage compared to fossil fuel generation sources.

In the long run, other technologies could offer the same climate change advantages as nuclear generation. Renewable energy could improve its technical and economic performance to provide electricity, without CO_2 emissions, at a cost competitive with coal or gas. Inexpensive electricity storage helps to overcome the problem of intermittence of some renewables, especially solar and wind. More efficient fossil-fuelled generation technologies and less expensive techniques for carbon sequestration could become competitive options. New technologies in the transportation or commercial sectors could equally affect the economic balance. Thus, while nuclear power is a potential contributor to mitigation of greenhouse gas emissions, it is one among other technologies whose costs and technical performance are also likely to change over time.

Air Pollution

Nuclear power plants emit negligible amounts of sulphur dioxide, nitrogen oxides, particulate matter or trace metals (Table 23). This is a major tangible benefit of nuclear power generation.

Pollution control regulations have steadily become more stringent in OECD countries. More stringent air pollution control regulations on fossil-fuelled power plants will come into effect in early 2002 in the United States. Revisions to the European Large Plant Combustion Directive and a new protocol to the Convention on Long-Range Transboundary Air Pollution are expected to come into effect within several years. The trend will continue and will tend to improve the economic position of nuclear power compared to fossil-fuelled power.

As pollution control regulations become more stringent, systems to control pollution from fossil-fuel combustion will become more expensive.

This is likely to have a greater effect on older fossil plants, which may become more expensive to operate or which may be shut down, while nuclear plants remain unaffected. More stringent regulations are unlikely to have a substantial near-term impact on the relative cost of *new* fossil and nuclear plants, because regulations already require new fossil plants to be equipped with effective pollution control equipment. Incremental cost increases due to pollution control regulations are not likely to greatly increase overall pollution control costs by very much. If attitudes towards conventional pollution radically shift in light of new concerns about the environment or health, this might cease to be true.

Issues for Government Action

Wastes

- *Give the highest priority to implementing realistic, broadly-accepted programmes for high-level waste disposal, including disposal of spent fuel considered as waste.*

- *Make steady, step-by-step progress in implementing ongoing waste programmes, thus building confidence in their adequacy. Make sure, more than in the past, that there are ample opportunities for consultation and public review of waste disposal plans. Waste programmes should be designed to take into account the ethical, health, economic and political concerns of all interested parties, especially those directly affected.*

- *Continue to work towards resolving all outstanding issues of waste disposal, not just those connected with high-level wastes. Consider the important benefits of cleaning up all radioactively contaminated sites, even if not related to civilian nuclear power. This should be done not only to secure long-term environmental* *benefits, but also to build trust in the methods for dealing with the environmental problems caused by radioactive materials.*

- *If spent fuel is disposed of in geological disposal facilities, make sure it is feasible in the future to retrieve the spent fuel in order to recover its unused energy value. For both spent fuel and high-level wastes, consider such retrievability as a matter of public policy and not as a matter of purely technical debate.*
- *Support and strengthen international co-operation on R&D related to radioactive waste disposal.*

Climate Change and Air Pollution

- *Carefully consider the potential contribution of nuclear power to limit carbon dioxide emissions and fossil fuel airborne emissions and its role in future abatement strategies.*

Safety Regulation

OECD countries have always regarded high standards of nuclear plant safety as a fundamental requirement of nuclear development programmes. Few serious nuclear accidents have occurred in OECD nuclear power plants, and these had no significant public health consequences from radiation, according to nuclear safety and radiation protection authorities. The main high-level policy issue for nuclear safety regulation is therefore how to make sure that it is both effective and cost-efficient. Governments must also consider their role in maintaining or strengthening public confidence in safety authorities.

Growing numbers of countries have undertaken programmes to reduce regulatory burdens and improve the quality and cost-effectiveness of those regulations that remain (OECD, 1997). Improvements in regulation can boost the productivity of industries and improve the quality and range of products and services. The benefits of regulatory reform can be observed not just in economic regulation, but also in safety regulation and other social regulations. The interest in regulatory reform of the 1990s coincided with the introduction of competition in the electricity markets of most OECD countries.

Nuclear regulatory authorities must therefore adapt both to the call for greater regulatory effectiveness and to the new conditions of electricity market competition. By mid-2000, the nuclear regulatory authorities in Canada, France, Germany, Japan, Spain, Sweden and the United States were involved in ongoing programmes to improve their effectiveness or organisation. Safety regulators must adapt to changing plant technical operation and commercial arrangements within the nuclear generation industry. A significant challenge for governments is judging the effectiveness of a regulatory organisation and justifying its operating budget (NEA, 1998a: p.34).

In the United States, the Nuclear Regulatory Commission has undertaken a programme to reform and improve its safety regulation. It intends to apply more objective, timely, safety-significant criteria in assessing performance. By developing and applying "risk-informed" and "performance-based" regulations, it wishes to make sure that regulations are related to the magnitude of risks and that they maintain safety in practice. One element of some programmes to improve nuclear safety regulation is to reinforce the responsibility of facility operators. A 1999 report by the Japanese Nuclear Safety Commission on the criticality accident at Tokaimura (NSC, 1999) emphasised that the primary role of ensuring nuclear safety must rest with the operator.

In some countries, the nuclear industry has criticised the lack of predictability and consistency of nuclear regulation. Regulatory authorities have already responded, in some cases, by changing their regulations and administrative procedures. In the United States and Germany, licensing procedures for future plants have been modified to improve this consistency of application and their ability to stand up to legal challenge after operating permits have been issued.

Electricity market competition will lead to stricter application of the principle that regulatory authorities should limit the scope of their actions to plant features and operations that protect the public and workers. Plant owners will wish to reinforce their ability, without undue regulatory intervention, to make decisions on how best to protect plant investment. Nuclear facility owners will seek increased independence in determining the commercial framework for plant operation, including, for example, ownership, corporate alliances or operating agreements.

The effectiveness of nuclear safety regulators is closely tied to the openness and independence of their actions, characteristics to which governments have given greater attention over time.

Regulatory measures that are hidden or hard to access undermine safety. Greater openness should help safety experts access all the relevant information to make sound decisions and help to improve public understanding of nuclear power in general (see below). There is wide agreement that regulatory proceedings should be open to public scrutiny and that regulatory documents should be widely and easily available. In many countries there is insufficient interaction between regulatory bodies and the public (NEA, 1999b). Governments have supported the development of cost-effective means of disseminating information on nuclear safety regulation, particularly through the Internet. Many nuclear regulatory authorities already have begun using this medium.

Ensuring the independence of nuclear safety regulators is a recurring theme throughout OECD countries. Not all OECD countries have sufficient guarantees that safety regulators can remain independent of short-term political influence, commercial pressures, promotional organisations and anti-nuclear organisations. Many countries have taken specific actions to enhance the independence of nuclear safety regulators (Table 26), including six countries that did so in the 1990s. The reform proposals of the French nuclear safety regulation, (published in draft form under the title “Transparency, Safety and Radiation Protection Act”), aim to separate more clearly nuclear regulation from promotion. The Canadian reform law proclaimed in

May 2000 reinforced the independence of the nuclear regulator and provided new compliance and enforcement powers. In April 2000 the Japanese Nuclear Safety Commission was moved from within the Science and Technology Agency (STA) to the Prime Minister's Office as an interim measure and its staff was increased from 20 to 92. Further changes are expected in 2001.

Nuclear safety regulators are confronted with two objectives that must be reconciled:

- Increasing interaction with the public and disseminating information on facility performance and regulatory actions.

- Ensuring that nuclear facility operators take primary responsibility for safety, for example by "self-regulation" which tends to reduce reporting requirements and notification of actions with minor safety significance.

The first objective emphasises the flow of information and dialogue with the public on regulatory issues. This tends to increase the importance of providing easily understandable measures of satisfactory safety performance and immediate explanations of any operating plant anomalies. The second objective emphasises the importance of safety goals and the responsibility of plant operators in meeting them. Compliance, while still fundamental, varies in short-term importance according to the safety significance of the regulation or standard.

A final issue is the need for scrupulous adherence to established regulations. The highest standards are not effective if nuclear facilities and operators do not comply with them. Governments cannot assume that the existence of a safety authority and satisfactory safety records to date guarantee continued safe operation. Recent and historical accidents at OECD nuclear facilities illustrate that constant vigilance and strong government support of nuclear safety institutions is essential to ensure safety in practice.

Businesses may not comply with safety regulations for a variety of reasons. These include failure to understand the law, lack of commitment to the objectives that lie behind the law or to the rules chosen to secure those objectives, perception that regulatory procedures are unjust, high costs of regulation, or failure of regulatory enforcement (Braithwaite, 1993). The problems that arose in Europe in 1998 with respect to a shipment of radioactive waste appear to have been caused by a lack of industry commitment to radiation protection standards. Despite long knowledge of the problem, the industry and some radiation protection authorities did not act to correct it because some felt the rules were unnecessarily stringent. Some nuclear regulatory frameworks have been criticised as too complex and detailed, and therefore impossible to apply consistently. Complacency about meeting the requirements of specific regulations may develop if there are no safety incidents or problems for long periods. Yet lack of adherence to established regulations, even if public health is not in immediate danger, damages trust in the safety authority and the industry.

Issues for Government Action

- *Make sure that regulatory authorities have adequate resources, visibility and authority to meet the need for greater regulatory effectiveness and electricity market competition. Sustain an industrial and regulatory environment that gives the highest priority to safety and adherence to radiation protection standards. Industry and regulators must fully accept, implement and enforce rules as written, or work together to improve them so that high levels of compliance can be attained.*

- *Support efforts to improve nuclear safety regulation while still ensuring high standards of protection. Give priority to simplifying safety regulations and improving their cost-effectiveness.*

- *Assure the maximum degree of independence for nuclear safety regulatory authorities, consistent with national practices for the control of government institutions. Regulators should be institutionally separate from industrial support organisations and should be designed to limit the scope for political interference in regulatory decisions.*

▶▶▶ *While allowing for continuous advancements in techniques and knowledge related to safety, support administrative procedures that provide stable and predictable regulatory processes.*

Policy Issues for Governments Wishing to Retain Nuclear Power as an Option

This section considers issues that must be addressed by governments wishing to see that nuclear power is available if desired. Nuclear power could help to mitigate the OECD's increasing reliance on fossil fuels and to address future environmental problems, particularly those related to air pollution and climate change. For these reasons, and others, a number of OECD governments wish to retain the use of nuclear power as an option for the future. In the few OECD countries where new nuclear power plants are expected to be built in the coming decades, this option will automatically be retained. However, the lack of orders for new power plants in all but a few countries causes concern among some governments about the availability of nuclear power to meet future energy and environmental challenges. Nuclear power's role could shrink in the coming years.

The long-term future of nuclear power will be shaped by a number of issues. Prominent among them are economics, energy security, the environment, and safety regulation. If governments are satisfied that these issues support or pose no fundamental obstacles to the long-term availability of nuclear power, there still remain areas where government policies could help to improve the foundation for future nuclear power development. Nuclear power must be considered in a broad energy context and within overall energy strategies, including the contribution of other non-fossil energy technologies. Long-term sustainable development should also be considered in decisions on nuclear power.

Policies Affecting the Operation of Current Plants

Leaving aside changes in policy towards nuclear power, plant lifetime is the single most important determinant of nuclear capacity and generation in the coming decades. One important and inexpensive policy which governments can adopt to ensure the availability of the nuclear option is to remove any unnecessary obstacles to keeping current plants operating.

Governments can help to keep current plants operating by, for example, supporting reform of safety regulation to make sure that it is fully cost-effective, while still preserving safety. They can encourage safety regulators to simplify procedures for extending the operating period of existing plants. They may wish to support research and development relevant to plant life extension. Actions that reduce the cost of infrastructure borne by generators can help nuclear plants to continue operating.

Public Trust in Policies

As noted, nuclear facilities generally attract substantial public opposition. Increasing opposition to the siting of new nuclear facilities has developed alongside growing public resistance to the implementation of large projects of any type, such as airports, refineries or other industrial facilities. This is known as the "nimby" (not in my back yard) problem. The difficulty of siting new nuclear facilities is particularly acute in most countries.

There are numerous environmental and anti-nuclear organisations devoted to blocking nuclear power development or phasing it out. The existence of moratoria or restrictions on construction of nuclear plants in many countries (Table 30) is an important institutional factor affecting prospects for nuclear development. Governments wishing to keep nuclear power as an option must build public support for their policies. Public opinion also has an international dimension that governments must consider.

The prominence of public opinion as a challenge to nuclear power may be related to the energy market context of recent years, featuring an abundance of energy at reasonable prices. In this context, the need for nuclear energy seems less imperative than it did during the oil shocks of the 1970s. The public may be less willing to accept nuclear power when other energy sources, which are perceived to be less threatening, are available at low cost. If energy prices increase due to the restrictions on emissions of greenhouse gases or to simple growth in energy demand relative to supply, public attitudes towards nuclear power could become more favourable.

There is no consensus on how to improve public opinion on nuclear power, or to what degree "improvement" is really needed. Opinion polls show a wide range of public attitudes. The International Nuclear Societies Council, in a comprehensive review of the issues, concludes that "there is no single guaranteed method for winning public acceptance" (INSC, 1998).

Past efforts to gather public support for nuclear power have used analysis and intellectual approaches to assure the public that nuclear power was a beneficial energy option. Certainly, it may be helpful to communicate the positive aspects of nuclear power, especially its contribution to energy security, low environmental impact from airborne emissions, and its natural resource benefits. However, this type of factual and technical communication has probably been over-emphasised. The nuclear industry has tended to assume that nuclear energy issues are too difficult for non-specialists to understand. Some believe that improving the public's technical understanding of nuclear risks and enhancing their ability to weigh them against other risks is the key to improving public support for nuclear power. Much research, however, indicates that attitudes towards nuclear power (for or against) "will not be quickly or easily changed by improving 'technological literacy' or improving the communication of technical assessments showing the risks of nuclear power generation and nuclear waste disposal to be minuscule." (Slovic, 1998). At best, the reliance on factual or "rational" communication is incomplete. The underlying values and beliefs and the "authenticity" of participants involved in discussion of the issues are also important (Andersson *et al.,* 1998). "Authenticity" refers to the idea that participants in public debates accurately express their true views and do not hide their motives or facts.

Government information campaigns are thus insufficient alone. They also carry certain risks. Over-emphasis on public information campaigns may be counterproductive if government is perceived to be the "propaganda arm" of the nuclear industry. Thus, while governments have a legitimate role in informing the public, they must act carefully to avoid such problems.

Some analyses have found that government communication programmes can best support constructive public participation by providing transparency to the decision-making process. This means that programmes should help those affected by the decision (the "stakeholders") to increase their appreciation of all the issues involved, not only issues related to safety and technical efficiency but also those related to values and norms in society. Government authorities and programmes are more effective when they provide stakeholders with channels for dialogue, through which they can challenge those proposing a nuclear project to provide both technical explanations *and* proofs of a project's consistency with values and norms in the community.

Policies to address the *sources* of negative attitudes are helpful. In a broad sense, more positive public opinion must be based on improved public trust in utilities, government, regulators, and others responsible for nuclear matters. Strengthening public understanding and acceptance of nuclear power would involve:

- Separating civilian nuclear power production from military issues to the maximum extent and strengthening safeguards to prevent misuse of civilian nuclear materials.

- Increasing the openness of communication about nuclear issues to dispel the perception of secretiveness.

- Basing government financial support for nuclear power, if any, on clearly defined and accepted public benefits.

- Improving the effectiveness of nuclear safety regulation and its implementation.

- Demonstrating continued safe operation of nuclear facilities and resolving issues of waste disposal.

- Demonstrating economic benefits on the same basis as other generation technologies.

Governments should refrain from suggesting that nuclear power (or any other source of energy) is perfectly safe. This was a conclusion of the Japanese Nuclear Safety Commission in their report analysing the 1999 accident at the Tokaimura plant (NSC, 1999). If the safety of nuclear power is overstated, public reaction to accidents that *do* occur is extremely negative. A French study for the European Union's ExternE project on externalities noted that "at this time, there is no general consensus on a methodology to assess the external costs of severe nuclear reactor accidents." (Dreicer *et al.,* 1995: p. 3). In other words, there is no consensus on how to compare the potential environmental impact of nuclear plant accidents with the environmental costs of other power plants or to weigh them against nuclear power's environmental benefits. Therefore, portraying the possible environmental or health effects of accidents as "zero" or as "known with certainty" to be negligible is not convincing and erodes credibility.

The introduction of the International Nuclear Event Scale (INES) has helped to foster public understanding of the level of safety attained in nuclear plants. Introduced in 1990, the scale is a tool to communicate consistently to the public the safety significance of reported incidents and accidents at nuclear installations. Like the Richter scale for earthquakes, it is designed to convey, in a single number, the severity of an event. No civilian accident within the OECD has been classified as a "serious" or "major" accident (level 6 or 7) with significant off-site impact.

Openness is an essential ingredient to foster public trust in nuclear power. As expressed by the French Prime Minister Lionel Jospin at a parliamentary colloquium on energy policy, the future of nuclear power must be based on the end of the "culture of secrecy" (Jospin, 1998).

Availability of Infrastructure and Industrial Capability

Some governments and the nuclear industry are concerned about the availability of specialised infrastructure and industrial capability to support nuclear power programmes. Governments must consider whether any special measures to support infrastructure or industry are needed to ensure that nuclear power is available as a future option. They must also decide who should bear the cost of such measures.

The areas of concern are (NEA, 1996d):

- Industrial ability to fabricate specialised nuclear components.
- Educational programmes and availability of qualified manpower.
- Research and development.
- Regulatory bodies.

These issues are common concerns within the nuclear industry (e.g. Michael *et al.,* 1999). Shrinking infrastructure undoubtedly poses challenges. But while it is clear that some elements of nuclear infrastructure have decreased according to some measures, it is not clear that they have shrunk or will shrink below minimum levels to support future needs. After a long period of growth from the 1960s to the 1980s, nuclear power has stabilised. Future needs are difficult to define because of the uncertain timing and strength of any future revival of nuclear power growth.

The nuclear industry remains large. Whereas it was once oriented towards construction of new plants, it is now oriented towards the operation and support of existing plants. Also, the increasing efficiency of many industrial activities and the automation of some functions have reduced the need for certain industrial capabilities. Many specialised companies exist to provide support for operation and maintenance, fuel management, computer support, testing services and other nuclear services. Industrial capability to supply decommissioning services has also grown steadily as the number of retired plants has grown. This capability involves sophisticated remotely controlled machines and robots to enter and work in high radiation fields. There has been an effort to develop plant designs and systems that do not rely on equipment uniquely suited to nuclear service. Such nuclear-quality components have always been very expensive, yet, in some instances, they may not be needed to maintain high levels of plant safety. As specialised nuclear components are eliminated, ordinary industrial-quality components can be used.

Adjustments among equipment suppliers began to occur when orders for new plants dropped off sharply from their peaks 20 years ago. The number of Western European manufacturers of heavy nuclear components dropped from twelve in the late 1970s to only two in 1996 (OECD, 2000: p. 102). Recently, the pace of consolidation among reactor suppliers has quickened, with the purchase by British Nuclear Fuels Limited of Westinghouse in 1998 and ABB Nuclear in 2000. The French supplier Framatome and the German supplier Siemens merged their nuclear businesses in 2000. Consolidation and alliances among suppliers help them to maintain commercial strength. On the other hand, utilities and governments are faced with the problem of maintaining a competitive supply market as the number of participants decreases.

Preserving a specific pool of human talent is much more difficult than preserving engineering data. The average age of those working in the nuclear industry has steadily increased. In coming years, the nuclear industry will need to replace many retiring workers. Nuclear educational programmes have decreased in size and in number in response to diminished employment prospects for nuclear graduates. These trends are of concern to the nuclear industry, which has recognised the need to maintain an adequate supply of human talent fast enough to support its activities. Industry and some governments are concerned that educational programmes may not be able to provide trained individuals within the needed time to make up for retirements. Many companies have taken an active role in making sure that they have access to qualified personnel through training programmes, support of educational programmes, and scholarships.

Maintaining the required level of competence and staffing to ensure nuclear plant safety could also prove to be a major challenge both for plant operators and for regulators. There can be no compromises with safety, nor should there be any need to make them. Nuclear facility operators must continue to place safety as their highest priority and allocate resources accordingly. Governments must make sure that nuclear safety regulators have the means to verify plant safety. This includes the necessary budget, people, training, knowledge base and research. If regulators feel that the low level of nuclear activity threatens their ability to verify safety, they need to act to correct this or make the government aware of the constraints preventing them from doing so. Since governments hold safety as a top priority in OECD nuclear plants, there should be no impediment to obtaining the resources needed for effective safety regulation.

Government expenditure on nuclear research and development has dropped substantially in most countries since the 1970s (Figure 28). Nuclear power still remains the predominant area of government spending on energy R&D in the OECD as a whole (Figure 27). The number of research and test reactors has dropped, though many remain in operation. Continued research on nuclear technologies and on resolving current problems will help to maintain some parts of nuclear infrastructure.

As long as substantial numbers of nuclear plants continue to operate, there will be an industrial base and human capital from which to draw. Many existing facilities will be operating well beyond 2020. A trained, highly skilled workforce will continue to be available to support current plant operation, including engineers, regulatory personnel, researchers, managers and others.

Governments can work co-operatively with the nuclear industry and utilities to minimise any impediments to providing supporting infrastructure. This could include eliminating legal barriers to sharing information or facilities among suppliers or generators so long as such sharing does not raise anti-trust issues.

In the past, governments have played an important role in developing the infrastructure needed for nuclear power development. Some fuel cycle facilities, services to the nuclear industry, research institutions and programmes are still funded by governments. However, the maturation of the industry and the strong revenue base of existing nuclear plants make it unlikely that similar support would be given for any future growth in nuclear power.

In summary, governments need to assess carefully what policies are needed, if any, to help the nuclear industry meet the challenges to infrastructure and industrial capability posed by trends in industry, education, and research and development. Government financial support can be extended if there is a clear public policy need that cannot be met through normal operation of the industry. If governments believe that the ability to develop rapidly a programme of new plant construction were essential in the near term, there would be a case for government policies to support such a capability.

Technology Developments and R&D

Governments wishing to keep nuclear power as an option may have an interest in supporting technology developments that make new plants more competitive and more attractive to investors. This is particularly true if the decision to build new nuclear plants must be made in competitive energy markets that do not fully take into account external costs and benefits. If advanced nuclear fission technologies were available that are both cost-competitive while further improving safety, proliferation-resistance and waste management characteristics, nuclear power would be better placed for the future. Much work has already been undertaken on advanced conventional nuclear power plant designs, which can be considered commercial or near-commercial. Some work is also under way on new reactor designs; for the most part, these designs are farther away from commercial viability. In some cases, a prototype or demonstration plant needs to be built.

Nuclear technology development would attract substantial sums of money if higher fossil energy prices or more severe environmental constraints increased fossil generation costs. The energy policy issue is whether, in the absence of such changes in energy markets, increased government funding of such developments is needed, when balanced against other energy R&D needs. This issue is related to the infrastructure discussion in the preceding section: continued research on nuclear technologies can help to maintain part of the nuclear infrastructure, particularly educational programmes and student interest.

International Co-operation

Declining national budgets for nuclear programmes increase the value of international co-operation. Governments have already recognised that nuclear power development is becoming less national and more international. There is growing international co-operation in nuclear infrastructure, safety regulation, industry and R&D that can help to reduce the cost of public and private nuclear activities. Governments should seek opportunities to strengthen international co-operation in nuclear power.

Governments may wish to consider actions to support more cost-effective nuclear infrastructure through international co-operation. Many nuclear programmes were developed from a largely national perspective, often aiming for a high degree of self-sufficiency. Knowledge, experience and research facilities can be shared among countries to maintain access to nuclear infrastructure while reducing its cost.

International co-operation on research and development can reduce the cost of developing new nuclear technologies. Co-operative R&D programmes have been successfully pursued in the past, including work on demonstration or prototype reactors. An international research consortium, for example, developed the Superphénix fast breeder reactor. There is also scope for collaboration on basic nuclear science. It must be acknowledged, however, that there are practical constraints on international R&D co-operation because of commercial considerations. Much nuclear technology is in the hands of organisations faced with competitive markets for their products.

International co-operation on safety regulation can help to establish compatible national conditions for nuclear power development and competition. Harmonisation of safety standards and procedures can be useful in four ways. First, by helping countries to recognise and draw on the best features of different regulatory practices, it can improve the effectiveness of national regulation. Second, it can contribute to public confidence that the safety performance of plants meets internationally recognised standards. Third, harmonisation can help to reduce differences in the cost of compliance with safety standards. Nuclear generators competing across national borders will find this relevant. Finally, co-operation can reduce the cost of equipment and services from nuclear suppliers and in licensing reactor technologies. Suppliers can then design systems or provide services that are standardised for the countries whose regulations have been harmonised. Lower development costs can be spread over greater sales, and ongoing costs may be lower. Harmonised licensing requirements could make new reactor designs faster and cheaper to gain approval.

International organisations, particularly the OECD Nuclear Energy Agency and the International Atomic Energy Agency, play an important role in helping to co-ordinate and share the results of national efforts related to nuclear power. The Nuclear Energy Agency is the primary forum for OECD countries to co-ordinate nuclear technical matters. It is engaged in work on nuclear safety, radiation protection, research and development, law, technology and other areas. The NEA maintains an extensive databank of scientific and engineering information and has undertaken other initiatives, such as the development of an Internet R&D database, to improve the accessibility of results from nuclear research projects around the world. The International Atomic Energy

Agency has a broader membership and broader scope of activities, including non-power-related uses of nuclear materials and nuclear non-proliferation safeguards. The International Atomic Energy Agency and the Nuclear Energy Agency have joint programmes related to research and development. The IAEA is investigating the potential for strengthening co-operation on R&D in nuclear technologies. Other international organisations help to maximise the benefits of nuclear programme co-ordination across many countries.

Over time, a substantial international legal framework for co-operation on nuclear power and the regulation of nuclear materials has been developed. It includes agreements on accidents, safety, transportation, wastes, civil liability and the non-proliferation of nuclear weapons. Among the relevant conventions are:

- Vienna and Paris Conventions and Protocols on Civil Liability for Nuclear Damage (1960 onwards).
- Treaty on the Non-Proliferation of Nuclear Weapons (1970).
- Convention on Early Notification of a Nuclear Accident (1986).
- Convention on the Physical Protection of Nuclear Material (1987).
- Convention on Nuclear Safety (1996).
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (1998).

The treaty creating the European Atomic Energy Community (Euratom) was signed in 1957. The two basic objectives of the Euratom Treaty were to ensure the development of the basic installations necessary for nuclear energy in the Community and to ensure that all users in the Community receive a regular and equitable supply of ores and nuclear fuels. Euratom provided strong support for the initial development of nuclear power and uranium supply in Europe. Over time, national programmes and policies have taken on greater importance. A growing divergence of views among the member states of the European Union with regard to nuclear policy has also tended to reinforce the primacy of national policies. A French Senate committee report (de Montesquiou, 2000) describes the evolution of Euratom and notes that, in some respects, it has been overtaken by the changing EU legal and institutional framework.

Predictability and Stability of Nuclear Policies

Governments can help to maintain nuclear power as an option by fostering a predictable and stable policy framework. Predictable and stable policies help to reduce uncertainty and risk for those considering investments in new nuclear plants or supporting businesses. One example is to implement policies that define and limit the scope for administratively imposed changes in expected long-term liabilities. In some countries, governments and regulatory authorities have revised the licensing procedures to reduce uncertainty and to lessen the possibility of licence rejection after large investments have been made. Stability cannot, of course, be pursued in a purely administrative context, since the normal functioning of democracy can lead to changes in policy. Furthermore, policy stability that leads to inflexibility or to the exclusion of innovation would be counterproductive.

Electricity market competition may prove helpful in promoting nuclear policy stability. In the past, when there was a call for a nuclear facility to be closed down, plant owners could, if forced to do so, ultimately yield to the pressure because a monopoly utility could pass on the costs to consumers. Electricity consumers, not plant owners or governments, bore the cost of nearly all major OECD nuclear facilities (with two exceptions) closed for non-economic reasons (Table 29). Such arrangements will be difficult in competitive electricity markets, where there is no automatic mechanism for covering the cost of lost investments in generation or related facilities.

Private ownership of nuclear facilities may also help promote policy stability. Private owners will not quietly accept abrupt changes in policy direction if they reduce the value of their facilities. They will demand compensation if government policy forces them to take on new legal obligations or investments. Other factors being equal, compensation requiring debate in an open political forum is less likely to be granted than if compensation can be agreed administratively, without public debate.

International co-operation helps to promote stability of nuclear policies. When countries or government nuclear organisations enter into international agreements and programmes, they are often bound to respect their engagements over a period of years. An orderly withdrawal from international engagements can take a number of years. This is not to suggest that international commitments should be used to thwart changes in domestic policies. Rather, if they are made as natural elements of domestic programmes, they will tend to brake abrupt shifts in policy.

Issues for Government Action

Evaluation of Nuclear Power

▸▸▸ *Consider nuclear power in connection with overall energy strategies, including other non-fossil energy technologies.*

▸▸▸ *Consider long-term sustainable development in decisions on nuclear power.*

Policies Affecting the Operation of Current Plants

▸▸▸ *Consider removing any unnecessary obstacles to the continued operation of existing facilities. Support the expeditious handling of regulatory safety reviews for existing power plants or of facilities that support the ongoing operation of plants. Similarly, retroactive application of changes in safety regulation should be encouraged only where past requirements are clearly inadequate.*

Public Trust in Policies

▸▸▸ *Strive to be open in all policy decisions. Eliminate the "culture of secrecy" where it still exists. Any direct government financial support, such as subsidies or provision of no-cost services or* *facilities, should be indicated in clearly identifiable government accounts.*

- *Ensure that nuclear policy decisions are part of a fully democratic process. This means not relying upon purely administrative decisions, taken without public debate, to support nuclear power development. The need for consultation and public review of policy decisions is especially important in the area of high-level radioactive waste disposal.*

- *Government-sponsored communication programmes can help to inform the public about nuclear power, but should not be over-emphasised. When undertaken, their objective should be broader than that of conveying facts. They should be designed to help those affected by nuclear-related decisions to expand their appreciation of all the issues involved, i.e., issues related not only to safety and technical efficiency but also to values and norms in society, including environmental values.*

- *Refrain from suggesting that nuclear power (or any other source of energy) is perfectly safe. The environmental effects of potential nuclear accidents should neither be portrayed as zero nor as known with certainty to be negligible.*

- *Although an absolute separation of military and civilian nuclear facilities may not be possible, in the interest of public acceptance, do not use civilian power plants for the production of military materials.*

Research and Development

- *Consider a re-evaluation of current expenditures for R&D on new designs, with due regard to current public and private R&D efforts and funding.*

- *Make sure that policies supporting nuclear R&D are complementary to overall energy strategies and that the level of public R&D spending is appropriate.*

International Co-operation

- *In light of shrinking overall government R&D budgets, make sure that there is adequate international co-ordination of nuclear research in programmes supported by public money. Consider how international R&D collaboration could accelerate development of new concepts and make the most of the available R&D resources. Co-operation on prototype or demonstration plants may be of interest.*

- *Consider actions to maximise sharing of knowledge, experience and research facilities among countries to facilitate availability of nuclear infrastructure while reducing its cost. Consider how international harmonisation of safety standards could be improved.*

- *Ensure that nuclear power programmes and policies take appropriate advantage of the international framework for nuclear law.*

Policy Issues for Governments Wishing to Phase Out Nuclear Power

Some countries are considering phasing out the use of nuclear power. Governments may consider that no new plants should be built, or they may wish nuclear plants to cease operation sooner than would be the case if they closed according to the criteria of plant owners. The latter situation is called an "accelerated phase-out." Accelerated phase-outs engender costs above those incurred for a replacement of power generation capacity according to commercial economic criteria. Nuclear plant owners bear some of these costs. Once established, the use of nuclear power alters many features of national energy supply and other areas of the economy. The environmental performance of power generation is affected, notably through a decrease in the emission of airborne pollutants and carbon dioxide and the production of radioactive wastes. All these issues need to be taken into account in phase-out policies.

Economic Issues

The main economic issue is timing. If no new nuclear plants are built, there will be a natural phase-out as plants retire. This could take several decades, according to the age distribution of nuclear plants and their economic performance. There are no particular financial implications to this process, as investments for new plants would be required in any case. But if governments want an accelerated phase-out, plant owners will seek compensation for their lost revenue. New investments will be required sooner than otherwise, drawing resources away from other areas of the economy. The need for new investment would tend to increase electricity prices, possibly affecting industrial competitiveness or macroeconomic performance. An accelerated phase-out can also threaten the ability of generators to accumulate adequate reserves to cover their long-term liabilities from plant decommissioning and waste disposal, depending on the arrangements for building those reserves.

The closure of a nuclear plant can have a large effect on the local economy. Money flowing to the local economy for labour and supplies decreases and skilled nuclear plant workers whose jobs are lost may not find new employment in the area. Local governments can lose a substantial source of tax revenue. The Group of Municipalities with Nuclear Facilities, a European organisation, stresses the importance of nuclear facilities in the economies of the member municipalities (GMF, 2000). An accelerated phase-out makes the problems more acute because the local economy may not have enough time to readjust.

Replacement Energy

In the case of an accelerated phase-out, there must be sufficient physical plant capacity or transmission capacity for increased regional trade to replace the lost output from nuclear plants. An accelerated phase-out also forecloses the use of certain generation or demand-side technologies that might otherwise have become economic in several years. The economic, technical, environmental and other characteristics of replacement plants need to be considered regardless of the time scale.

In the near term, renewable energy cannot make up for closed nuclear plants. Non-hydro renewables are generally available only on a small scale. Typically, they provide intermittent, rather than baseload supply. Large-scale hydroelectric power could replace nuclear plants, but siting, environmental issues and the time needed to build a hydroelectric project are substantial impediments. Within OECD countries, few new large hydroelectric installations are likely to be built. Thus, fossil fuels are the main alternative to replace reduced nuclear output in the short term.

Obtaining replacement electricity from imports could pose political problems. Domestic consumers might find it difficult to accept that domestic electricity supply should be decreased, with a short-term loss of jobs, in favour of foreign production. This issue depends heavily on the size of nuclear power's contribution to the domestic economy and on the speed of the phase-out. It also depends on the progress towards open, regional electricity markets and increased trade in electricity.

Environmental Implications

Environmental performance is a key characteristic of plants built to replace nuclear plants. If an accelerated phase-out is pursued, fossil-fuelled plants will generally substitute for nuclear plant output. The airborne emissions of replacement fossil-fuelled plants need to be considered. The effect of closing nuclear plants on emissions of CO_2 is an issue. These emissions will tend to increase unless renewable energy sources or demand restraints make up for the lost nuclear output.

Countries must find suitable solutions for nuclear waste regardless of any phase-out policy. Table 24 indicates that there are considerable quantities of spent fuel in all countries with nuclear power plants. This spent fuel, and other wastes, must be properly disposed of regardless of the future operation of nuclear plants.

A phase-out could, however, affect the timing and the capacity of centralised waste disposal facilities. If a phase-out brings production of new wastes to an end sooner than would otherwise happen, planning and progress for a national waste facility might be encouraged sooner. Power plant owners might push for waste disposal solutions that reduce or limit the planning or economic uncertainty of waste disposal. A phase-out policy might also remove certain political obstacles to establishing final waste disposal plans. Waste disposal facilities could be seen as dealing with an existing matter (previously generated nuclear waste) rather than as a way of facilitating the continuation of the nuclear industry. The ultimate size of the disposal facility might also be smaller in the case of a phase-out, since waste production might be stopped earlier.

Supporting Businesses and Trade

Domestic suppliers of nuclear services, equipment and fuel and their patterns of trade are likely to be affected by a phase-out. Nuclear fuel production businesses can be affected unless they are able to replace lost domestic business through additional business in international markets. Domestic manufacturers of nuclear equipment can also lose an important market. The shift from nuclear generation to other forms requires time to change employment patterns and skills. Trade unions have clearly made known their concerns about closure of nuclear plants because it can lead to high unemployment in the region around the facility affected. An accelerated phase-out could affect electricity trade patterns, depending on the geographical distribution of nuclear plants and on the country’s ability to replace lost nuclear generation with domestic production or demand reductions.

It is also possible that a phase-out decision may be accompanied by legislation forbidding other nuclear activities. Such prohibitions could have direct consequences for supporting businesses and trade.

Experience in Sweden and Germany

The debates on the phase-outs in Sweden and Germany have considered all the issues above. Economic and environmental considerations have been the most important issues related to implementing the phase-outs. Trade unions, industrial groups, and electricity consumer groups have expressed concern that the premature closure of nuclear plants could harm their national economies and could lead, in the short term, to additional emissions from fossil-fuelled plants. The competitive electricity markets in both countries make the cost of prematurely closing nuclear facilities more transparent to consumers. This, in turn, tempers the willingness and ability of governments to implement rapid phase-out policies.

The possible source of replacement energy is a complex issue in Sweden, where nuclear power supplies about 45% of total electricity generation. The 1997 parliamentary decision on a Sustainable Energy Supply calls for more efficient energy use, electricity conservation, conversion from electricity and supplies of electricity from other energy sources to compensate the loss of electricity generation from closed nuclear plants. The bill provides for long-term investments in the development of energy-efficient technology and new electricity production from renewable energy sources – biofuels, wind power and small hydroelectric power plants. One condition for the closure of the second unit of the Barsebäck nuclear power plant is that the electricity production loss can be compensated through the addition of new sources and decreased consumption of electricity. The parliamentary decision stated the second unit should be closed prior to 1 July 2001 if the loss of electricity could be compensated. A written communication from the government was presented to Parliament in October 2000. In this communication the government reported that the conditions for closing the reactor have yet to be fulfilled. It should therefore not be closed before 1 July 2001. Closure of the reactor should be possible by no later than the end of 2003, according to the government's assessment. Based on this written communication, the

Parliament will decide whether or not the conditions for closure of Barsebäck's second reactor before 1 July 2001 have been fulfilled.

Nuclear power and hydroelectricity together supply over 90% of Sweden's total electricity. Thus, most of Sweden's electricity generation produces no airborne emissions of any kind. The Swedish electricity research group Elforsk found that increased imports from Denmark and Germany and increased production from the Karlshamn oil-fired power station were the most likely sources of electricity to replace lost output from the Barsebäck reactor (Hovsenius, 1997). They estimated that an additional 10 000 tonnes of sulphur dioxide and 5 000 tonnes of nitrogen oxides would be produced regionally if both Barsebäck units were out of operation in 2001. Further negative environmental effects could be expected if other nuclear reactors were closed quickly.

The owner of the Barsebäck nuclear plant strongly resisted the decision to close the first unit of the plant by 1 July 1998. It lost a challenge to the legality of the decision and subsequently agreed on compensation. The compensation agreement was approved by Parliament in May 2000. The agreement was costly for Swedish taxpayers. Trade unions and Swedish industrial associations have generally been critical of the phase-out policy, citing the potential impact on employment and industrial competitiveness. According to industrial groups, the operating cost of Swedish nuclear plants is lower than all other sources in the Scandinavian interconnected system, except hydroelectric power and industrial co-generation.

In Germany, the 1998 political decision to seek the accelerated phase-out of nuclear power was accompanied by a long period of negotiation with industry. An important element of the phase-out policy was that it should entail no costs to the government. Consequently, a central issue of debate and negotiation with nuclear generators has been the economic consequences of the policy. Industry has consistently argued that the phase-out deprives it of future revenues and leads to the need for new investment. The lifetime of individual power plants is a key issue, since this varies according to the economic characteristics of the plants and their potential for refurbishment. The industry has argued that a flexible approach is needed rather than fixed lifetimes.

The Parliament sought to identify options for replacement power in a plan called "Energy Dialogue 2000". The plan seeks to identify replacement energy sources that do not increase emissions of carbon dioxide. As of early 2000, few concrete proposals had been identified. International trade issues and industrial competitiveness are, as in Sweden, among the controversial areas.

Actual implementation of the phase-out policies in Sweden and Germany has proved a difficult process. In Sweden, after some 20 years of political debate, the first concrete steps towards a phase-out were taken with the closure of one unit of the Barsebäck plant. But energy savings hoped for by the framers of the implementing legislation, which are necessary to proceed with further closures, have yet to materialise. Defining fair compensation to the plant owner was difficult. In Germany, the process has been undertaken much more recently, but has revealed the same issues. In the short term, it appears that the constraints placed on the phase-out programmes in both countries cannot all be satisfied. While replacement sources of power can be identified, they lead to increased imports of electricity or to substantial new investments, as well as increased carbon dioxide and fossil pollutants.

Issue for Government Action

▸▸▸ *Assess the costs and benefits of phasing-out nuclear power, including implications for the environment, the national energy balance and radioactive waste disposal. Evaluate the costs to the owners of nuclear facilities and consider how those costs will be borne among electricity consumers, taxpayers and facility owners. The results of those assessments should be published.*

Nuclear Power in Non-OECD Countries

The growth of nuclear power in OECD countries is expected to be limited in coming years. Most new nuclear capacity is expected to be built outside the OECD, mainly in China and India. This trend has three key policy implications for OECD Member governments:

- The safety performance of nuclear plants outside the OECD will be of growing relevance for the protection of public health and the environment and for public views on nuclear power within the OECD.
- Over time, the industrial capability to build nuclear plants could shift towards non-OECD countries.
- Ensuring the adequacy of non-proliferation measures grows in importance.

As larger numbers of nuclear plants operate outside OECD countries, the possibility of an accident in a non-member country tends to increase. Yet a serious accident outside the OECD could affect future prospects for nuclear power *everywhere*. The Chernobyl accident illustrated this. Therefore, OECD governments have an interest in helping non-member countries to establish and maintain effective nuclear safety regulatory systems. Governments can pursue bilateral approaches to strengthen safety regimes or multilateral approaches, such as the IAEA Convention on Nuclear Safety.

Over time, the location of companies and organisations with expertise and knowledge in nuclear power could shift. North American and European suppliers could become less strong in comparison with Asian or Russian suppliers. Diminished strength of some OECD suppliers could mean that any renewal of nuclear growth might depend on non-OECD suppliers, at least for an initial period. The main policy issue is one of timing, as in the case of infrastructure discussed above. Some governments might also consider energy security to be a factor because of the need to rely upon foreign or non-OECD suppliers of equipment or services.

As non-member countries increase their use of nuclear power, OECD countries must also consider the strength of the international arrangements to ensure non-proliferation. As at present, multilateral and bilateral approaches can be followed.

The wish to promote safety and to avoid proliferation has motivated a number of OECD countries to strengthen co-operation on civilian nuclear matters with Russia, with countries of the former Soviet Union and with other non-OECD countries operating Soviet-designed reactors. Together these countries have, by far, the largest nuclear capacity outside the OECD. With nuclear generation capacity of some 20 GWe, Russia has a substantial nuclear industry and infrastructure. Since the break-up of the Soviet Union, Russian organisations have increasingly sought to compete with Western companies in fuel supply, equipment, services and other areas of nuclear technology. The country is developing a scheme to reprocess spent fuel and possibly to store spent fuel and wastes from OECD and other countries. Since 1992, the G7 group of countries has supported projects to improve the safety of Soviet-designed reactors in non-OECD countries, especially a number of older reactors in Bulgaria, Lithuania, Russia, Slovakia and Ukraine. The European Union provides assistance for improving nuclear safety to countries of the former Soviet Union through the Tacis programme. The European Union provides similar assistance to Central and Eastern European countries through the Phare programme. Nuclear plant safety has been an issue in discussions on the accession of several of these countries to the European Union. Clearly, the countries of the former Soviet Union are important in the world's nuclear industry and its future development.

China and India today have the most active nuclear development programmes outside the OECD, though their programmes are still relatively small compared to those of most OECD countries. As of 1999, China had about 2 GWe of capacity in two nuclear plants and plans to bring more than 4 GWe into operation by 2004. The Chinese have worked closely with Western equipment suppliers and have also begun to develop indigenous industrial capability. India had about 2 GWe of capacity in 1999, but in a larger number of small units (about 200 MWe each). India has emphasised the development of domestic heavy-water technology and hopes to add an additional 2 GWe by 2008.

Issue for Government Action

- *Promote dialogue and information exchange with non-OECD countries over safety issues and best practice. For example, by encouraging nuclear safety regulators to meet regularly.*

Nuclear Non-Proliferation

From the beginning of nuclear power development, a major concern has been that civilian nuclear materials or technologies could be diverted to manufacture nuclear weapons. For this reason, a number of international mechanisms and organisations were created to minimise the risk of civilian nuclear power contributing to the proliferation of nuclear weapons. The most important international agreement, to which 187 countries are party, is the Treaty on the Non-Proliferation of Nuclear Weapons. The fact that so many countries are party to the treaty is remarkable. It entered into force in 1970 and, as result of its important and demonstrated role in non-proliferation, was extended indefinitely in 1995. Parties to the treaty which have no nuclear weapons agree not to develop nuclear weapons and accept international safeguards on all their nuclear material. The application of such safeguards is one of the primary responsibilities of the International Atomic Energy Agency. Moves to strengthen IAEA safeguards resulted in 1997 in the adoption of a model "Additional Protocol". States are now in the process of signing protocols additional to their existing safeguard agreements, based on this model protocol. Four regional treaties covering Latin America, the South Pacific, South-East Asia and Africa outlaw nuclear weapons in the zones defined by the treaties. The treaties provide for monitoring. Various bilateral mechanisms also exist to help realise non-proliferation objectives.

So-called "full-scope" safeguards are required of parties without nuclear weapons. These impose conditions on the export of sensitive nuclear materials, equipment and technologies, including a condition that exported goods be placed under IAEA safeguards. All major suppliers of sensitive nuclear technologies require safeguards from their customers as a condition of nuclear exports and many require that recipient countries accept safeguards on their fuel cycle facilities as a condition of supply.

It is unlikely that any OECD country wishing to develop or expand the domestic use of nuclear power would forgo that option as a matter of non-proliferation policy. Domestic policies towards nuclear weapons are essentially independent of domestic policies towards nuclear power. Three OECD countries already have nuclear weapons, so there would be no issue of domestic proliferation in those cases. Other OECD countries have committed themselves not to develop or possess nuclear weapons, regardless of their use of civilian nuclear power. That commitment is maintained through strong public institutions and a chain of accountability that effectively separates domestic civilian and military use of nuclear energy.

For OECD countries, the main energy policy issue related to non-proliferation is the fact that proliferation issues contribute to public concern about nuclear power. Even though domestic proliferation of nuclear weapons is not an issue, some believe that nuclear power programmes are indirectly contributing to the spread of nuclear weapons elsewhere. To the extent that nuclear weapons and nuclear power are linked in debate, increasingly critical public attitudes towards nuclear weapons tend to reduce support for nuclear power.

It is clear that governments cannot be complacent about ensuring non-proliferation. A few large countries are not parties to the Non-Proliferation Treaty, and some of them have nuclear power programmes. Two non-parties, India and Pakistan, carried out nuclear test explosions in 1998, and it is generally conceded that a third, Israel, possesses nuclear weapons. It is noteworthy that the original five countries with nuclear weapons obtained them through dedicated military programmes rather than through nuclear power programmes. Still, some countries have expressed concern about civilian nuclear power programmes in countries that *have* joined the Non-Proliferation Treaty, implying a lack of confidence in at least some aspects of the treaty's implementation. The growth of nuclear power outside OECD countries could increase opposition to OECD civilian nuclear programmes if governments do not strongly link that expansion to maintenance of strong non-proliferation policies.

Governments must make every effort to ensure that the existing non-proliferation arrangements are strengthened and improved. OECD governments and industry must be fully resolved to minimise the possibility that domestic and foreign nuclear programmes can be used to support the spread of nuclear weapons. The International Atomic Energy Agency and other organisations provide an international forum for further discussion and development of strong non-proliferation actions. Governments should continue to support these organisations in their non-proliferation work. Certain technical choices in power plant design or fuel cycles could help make civilian nuclear technologies more resistant to misuse for military purposes. Some governments are supporting nuclear research and development on civilian power technologies that make proliferation more difficult.

Issues for Government Action

- *Continue to monitor closely the adequacy of non-proliferation measures.*

- *Continue to support efforts to extend and increase the effectiveness of the non-proliferation regime. Make sure that the relevant national and international organisations, especially the International Atomic Energy Agency (IAEA), have adequate* *resources and are suitably equipped and structured to carry out their missions.*

- *Given that non-proliferation issues contribute to public concern about nuclear power, consistently and regularly emphasise the commitment to preventing the spread of nuclear weapons in connection with civilian nuclear power development.*

CHAPTER 3

AN INTRODUCTION TO NUCLEAR POWER IN THE OECD

The Development of Nuclear Power in OECD Electricity Supply

Early Development

Nuclear reactors for civilian electricity production have been in use in the OECD since 1956, when the 50 MWe Unit 1 of the Calder Hall Station began operation in the United Kingdom. As with some other industries, such as the development of gas turbines for military aircraft, civilian nuclear electricity production had its origins in military programmes. Nuclear military programmes were carried out by the United States, the United Kingdom and France, countries that had intensive government programmes in the 1950s to develop nuclear technology for use in atomic weapons, for which enriched uranium, plutonium and other nuclear materials were needed. Nuclear reactors for the production of these materials were built and provided the first experience with nuclear technology.

The programme with the most profound effect on the development of civilian reactor technology was the development of the nuclear submarine programme in the United States. Its goal was to design and produce compact nuclear reactors allowing extended autonomy for submarines. The results were pressurised water and boiling water reactor designs which now account for most of OECD nuclear plant capacity. These reactors required enriched uranium, of which the

United States had a ready supply from enrichment plants built for military purposes. Surplus enrichment capacity at US plants was large enough to meet OECD demand for civilian nuclear reactor fuel until 1973, when the first of the enrichment plants developed under the 1970 Treaty of Almelo opened in the Netherlands.

France and the United Kingdom did not have free access to enriched uranium, as the United States forbade its export until 1956. After 1956, any country purchasing enriched uranium from the United States had to agree to extensive inspections to verify that the material was not being used for military purposes. As a result, the French and British nuclear power programmes initially took a design approach that did not depend on enriched uranium. Rather, they focused on gas-cooled reactors that could use natural uranium. The British Magnox reactor and subsequent advanced gas-cooled reactor designs were the result of this effort in the United Kingdom, where they remain in use today. The first commercially operated power reactor in the United Kingdom also produced plutonium for military purposes. The French development effort also resulted in gas-cooled reactors. After 1969, the development of gas-cooled reactors was dropped in favour of pressurised water reactors. The last of the early French gas-cooled plants was closed in 1994.

Canada was able to pursue a different path to nuclear power development because it had access to heavy water. Production capacity for heavy water had been developed during World War II for nuclear weapons projects and was available for civilian nuclear power development. The Canadian design effort resulted in a reactor using heavy water and, like the French and British designs, natural uranium.

The then Soviet Union developed two types of nuclear plants for civilian electricity generation, beginning in 1954. The first was a unique design of the type used at the Chernobyl plant ("RBMK") and the second was basically similar to the pressurised water design of the United States. The initial reactor of this latter type was put into operation in 1964 in Russia. Three nuclear plants using Soviet pressurised-water reactor technology were ultimately built in countries now belonging to the OECD.

The design work of the 1950s produced operating nuclear power plants in Canada, France, Germany and the United States by 1962. By 1969, a total of ten OECD countries had placed commercial nuclear power plants into service (Table 2). In a little over a decade, commercial nuclear capacity grew from zero to 20 GWe. All but three of these first ten commercial plants were based on US designs, either built by US companies or built under licence to them. Later on, German, French and Swedish companies built a total of eight units in Europe, outside their home countries. Reactors of Soviet design were among the last to be introduced in OECD countries. Of the last four countries to introduce nuclear power, all but Mexico used pressurised water reactors of Soviet design.

The appearance of nuclear power in the 1960s coincided with a period of rapid economic growth and rapid growth in electricity demand. Many governments embraced nuclear power as a means to meet this rapid growth economically while also promoting domestic technical capabilities and developing an alternate energy supply. All the basic reactor concepts in use today were developed in government programmes. Many nuclear power programmes were supported financially by national governments, as was the case in other industries such as conventional electrical generation equipment or steel-making. Canada, Germany, France, Japan, the United Kingdom and the United States all supported the construction of multiple prototype nuclear power plants for civilian electricity production. France and Germany each constructed nine prototype reactors and the United States built 14. Belgium, Sweden and Switzerland had programmes which resulted in single prototype reactors. Government subsidies or other financial support, such as tax reductions, also aided early commercial plants. For example, in the United States, the Atomic Energy Commission had a “Power Demonstration” programme from 1955 to 1962 that provided capital subsidies for new nuclear power plants.

In the 1960s, the average annual growth rate of nuclear generation was about 40%, starting from a low base. In the 1970s, it increased rapidly at an average of 27%. Nuclear capacity reached a 10% share

Table 2

First Commercial Nuclear Power Plants in the OECD

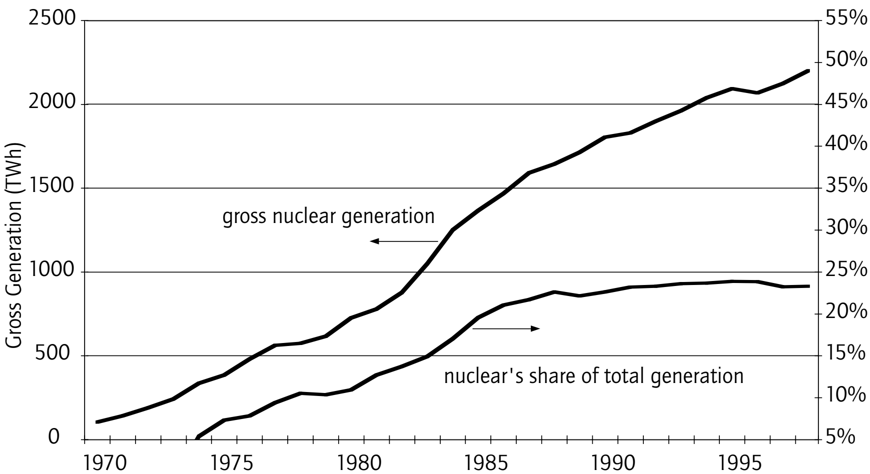
	Plant Name	Gross Capacity (MWe)	First Year of Operation
United Kingdom	Calder Hall	60	1956
United States	Dresden 1	200	1960
Italy	Trino Vercellese	270	1964
Germany	Gundremmingen	250	1966
France	Chooz A1	320	1967
Canada	Douglas Point	220	1967
Spain	José Cabrera	160	1968
Netherlands	Dodewaard	59	1968
Japan	Tokai 1	166	1969
Switzerland	Beznau 1	380	1969
Sweden	Oskarshamn 1	462	1971
Belgium	Doel 1	420	1974
Korea	Kori 1	587	1977
Finland	Loviisa 1	500	1977
Austria	Tullnerfeld *	724	1978
Hungary	Paks 1	460	1982
Czech Republic	Dukovany 1	440	1985
Mexico	Laguna Verde 1	675	1990

** The Tullnerfeld plant was completed but never entered into commercial operation.*
Notes: Definition of the first "commercial" power plant varies according to source. This table uses the convention adopted by the CEA, except for the United States. Most countries had developmental or experimental reactors in operation before those noted in this table.
Sources: CEA, 2000; AEC, 1974; IEA.

of total electricity generation by the end of the 1970s (Figure 4). However, a number of factors in the 1970s were to change the prospects for later growth in new capacity. The oil shocks of 1973 and 1979/1980 increased the cost of generating electricity from petroleum products and triggered a re-evaluation in many countries of their energy security situation, prompting policies to diversify the fuel mix away from oil. The oil shocks increased awareness of nuclear power's value for energy security. The higher cost of generating electricity from oil also improved nuclear power's competitive position. Both oil shocks slowed economic growth and reduced the expected growth in electricity demand. Thus there was less need for new capacity of *any* type. Various factors, including increasing capital costs of nuclear plants, higher cost of capital and the expectation of high uranium prices, tended to increase the cost of nuclear generation and reduce its competitive advantage. There was a serious accident at the Three Mile Island

Figure 4

OECD Nuclear Electricity Generation and Generation Share, 1970 to 1999



Source: IEA, Electricity Information 2000.

nuclear plant in the United States in 1979. This also had an important influence on nuclear plant development.

The 1980s and 1990s saw continued growth in nuclear capacity and generation, as new plants ordered earlier started operation. The rate of increase slowed. Orders for new plants continued only in Korea, France and Japan (see below). In the 1980s, the growth rate of nuclear generation slowed to 12% and in the 1990s fell to 3%. Nuclear power's share of total electricity generation levelled off at about one-quarter by 1990.

At an international level, institutions to foster nuclear power development have been put into place within the OECD and Europe. Euratom, the International Atomic Energy Agency and the OECD Nuclear Energy Agency were all established in 1957. Euratom participated in a joint power reactor programme with the United States, resulting in three early commercial reactors in Italy, France and Germany. The OECD Nuclear Energy Agency sponsored early development reactor projects: in Norway, the Halden project, and in the United Kingdom, the Dragon project. These institutions helped to monitor and promote co-operation in nuclear energy matters and, in the case of the International Atomic Energy Agency, to monitor the use of nuclear materials.

OECD governments signed various treaties to support nuclear power development. The Paris Convention, signed in 1960 by OECD Member countries, limited the civil liability of nuclear plant operators for damage from plant accidents. Protocols to the Paris Convention and the Brussels Convention, signed in 1963, further defined the international regime for limiting civil liability for nuclear damage. The Treaty on the Non-Proliferation of Nuclear Weapons was signed in 1968. This aimed to ensure that civilian nuclear technology was not used for military purposes. It made the IAEA responsible for inspecting facilities for compliance with the treaty. The Treaty of Almelo was signed by Germany, the Netherlands and the United Kingdom in 1970 to develop and exploit uranium enrichment plants for non-military purposes. This treaty fostered the joint development of technology and reserved the right of state enterprises to develop industrial-scale centrifuge enrichment plants. Many other treaties followed in the 1970s and later.

Ordering Patterns[4]

The pattern of orders for nuclear power plants broadly followed the pattern of government support and interest in nuclear power during the early years of its development. Orders for nuclear power plants expanded in the late 1960s and early 1970s, when the first commercial plants had been in operation for some time and confidence had developed in the technology. The 1970s were the heyday of nuclear plant ordering. By 1980, however, a combination of factors stopped orders for new plants in all but three countries of the OECD. The first oil shock of 1973 and the second one in 1979/1980, which coincided with the accident at Three Mile Island which had an important influence on nuclear plant development.

Considering nuclear plant orders that were not subsequently cancelled, 60% of OECD nuclear plant gross capacity was ordered before the first oil shock in 1973. Another 20% were ordered in the five years from 1974 to 1979, and the remaining 20% were ordered in 1980 or later, almost entirely in France, Japan and Korea. In Austria, Hungary, Italy, Mexico, the Netherlands, Switzerland and the United States, there were no lasting orders for nuclear plants after 1973. Most other countries placed the remainder of their nuclear plant orders from 1974 to 1979. These countries are Belgium (70% of gross plant capacity ordered), Canada (39%), Finland (31%), Germany (37%), Spain (26%), Sweden (23%) and the United Kingdom (18%). In Germany and the United Kingdom, one single-unit plant was ordered in each country in 1980.

The only countries in which significant new orders for nuclear plants were placed after the second oil shock of 1979 were the Czech Republic (at the time Czechoslovakia), France, Japan and Korea. In each of these

4. Statistics in this section are based upon data in CEA, 2000.

countries, two-thirds or more of total plant capacity was ordered after 1973. France, Japan and Korea are the only three countries of the OECD to sustain nuclear plant orders beyond 1980. France's last nuclear plant order was placed in 1993, while utilities in Japan and Korea have placed orders for new plants within the last two years.

The capacity of plant orders cancelled after 1973 was significant. The United States presents a special case; the capacity of cancelled US nuclear plants was one-third greater than the capacity of nuclear plants finally built. In other OECD countries, the total of nuclear plant cancellations, all of which came after 1973, was roughly 20% of the capacity of plants finally built. This includes 11 000 MWe of nuclear plant capacity cancelled in countries that do not have any operating plants today: Italy, Luxembourg, Poland and Turkey.

In summary, 60% of current OECD nuclear plant capacity was ordered before 1973. A further 20% was ordered between the two oil shocks. The remaining 20% were ordered after 1979 in France, Japan and Korea. The equivalent of 20% of plant capacity was cancelled after 1973, excluding the United States. If the United States is included, the equivalent of 55% of OECD plant capacity was cancelled after 1973.

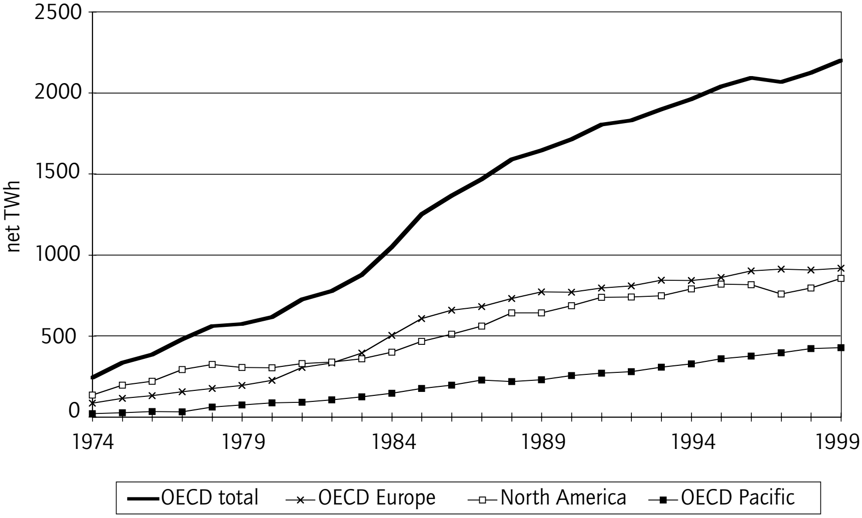
The Current Role and Features of Nuclear Power in OECD Electricity Supply

Nuclear Generation, Capacity and Share in Electricity Generation

Figure 4 shows clearly the overall rise of nuclear in the OECD since its first appearance in the late 1950s. In 1998, nuclear generation reached 2 000 TWh and its share of total OECD power generation was almost one-quarter. The growth in nuclear power generation by OECD region is shown in Figure 5.

Figure 5

OECD Nuclear Electricity Generation by Region, 1974 to 1999



Note: Czech data included as from 1993; Korean data included as from 1994.
Source: IEA, Electricity Information 2000.

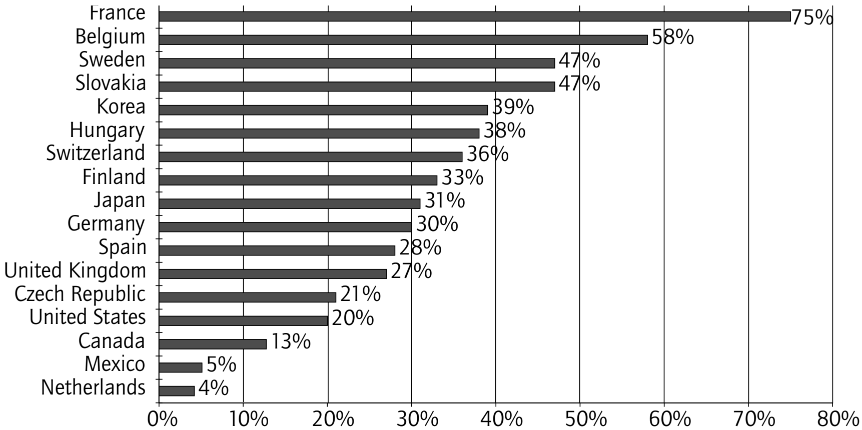
The picture by country, however, shows significant variations. Nuclear power's share of national generation varies from less than 7% in Mexico and the Netherlands (each having only one nuclear plant in 1998) to over three-quarters in France. In Belgium and Sweden, nuclear plants provide about half of total electricity generation. In Hungary, nuclear generation accounts for 38%, in Korea for 37%, in Switzerland for 40%, and in all other OECD countries for 32% or less. Figure 6 shows the situation graphically.

Installed nuclear capacity was 300 GWe in 1998[5]. In round figures, North America and OECD Europe had about 125 GWe each and OECD Pacific had 50 GWe (Figure 7 and Table 3). Nuclear plants represent

5. Unless specified otherwise, capacity and generation figures refer to net values.

Figure 6

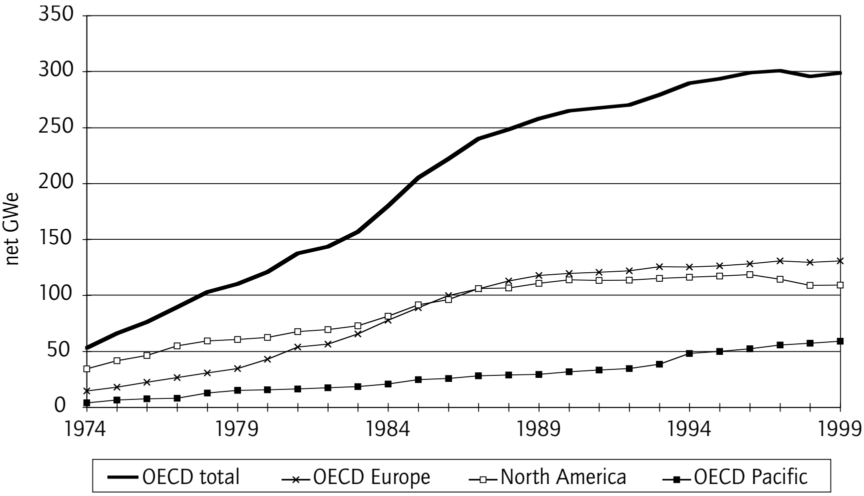
Nuclear Power's Share of Net Electricity Generation in OECD Countries, 1999



Source: IEA, Electricity Information 2000.

Figure 7

Net OECD Nuclear Generation Capacity, 1974 to 1999



Note: Czech data included as from 1993; Korean data included as from1994.
Source: IEA, Electricity Information 2000.

Table 3

Net OECD Nuclear Power Production and Capacity, 1998

	Units*	Production (TWh)	Capacity (GWe)	Share of National Production (%)	Share of National Capacity (%)
Australia					
Austria					
Belgium	7	43.9	5.7	55	37
Canada **	14	67.5	10.6	12	10
Czech Republic	4	12.4	1.8	20	12
Denmark					
Finland	4	21	2.6	31	16
France	58	368.5	61.7	76	55
Germany	19	153	22.3	30	20
Greece					
Hungary	4	13.1	1.8	38	23
Iceland					
Ireland					
Italy					
Japan ***	53	313.5	45.2	32	18
Korea	14	85.2	12.0	37	25
Luxembourg					
Mexico	2	8.8	1.3	5	3
Netherlands	1	3.6	0.4	4	2
New Zealand					
Norway					
Poland					
Portugal					
Spain	9	56.7	7.3	30	15
Sweden	12	70.5	10.1	46	31
Switzerland	5	24.4	3.1	40	19
Turkey					
United Kingdom	35	95.1	12.6	28	17
United States	104	673.7	97.1	19	12
OECD total	**345**	**2 010.9**	**295.8**	**23**	**15**
North America	120	750	109.0	17	12
OECD Pacific	67	398.7	57.3	28	16
OECD Europe	158	862.2	129.5	30	19

Grey entries indicate no operating commercial nuclear power plants.
** Unit data as of 31 December 1998.*
*** Canadian capacity data exclude 7 non-operating units at Bruce A and Pickering A.*
**** Japanese data include the Tokai 1 Magnox nuclear plant (154 MWe), permanently closed in March 1999.*
Sources: IEA, Electricity Information 2000; *NEA,* Nuclear Energy Data 1999.

about 15% of total OECD installed capacity. They have been at this level for the last ten years. Nuclear plant capacity is distributed in 345 reactor units at about 160 plant sites. On average there are slightly more than two units per plant site in the OECD.

Sixteen OECD countries produce electricity in nuclear power plants. One-fourth of these countries, the United States, France, Japan and Germany, account for three-fourths of all OECD nuclear power generation (Table 4). On a world scale, these countries are also the four largest producers of nuclear electricity.

Table 4

Net OECD Nuclear Power Generation Ranked by Country, 1998

	Production (TWh)	Capacity (GWe)	Share of OECD Nuclear Production (%)
United States	673.7	97.1	34
France	368.5	61.7	18
Japan	313.5	45.2	16
Germany	153.0	22.3	8
United Kingdom	95.1	12.6	5
Korea	85.2	12.0	4
Sweden	70.5	10.1	4
Canada	67.5	10.6	3
Spain	56.7	7.3	3
Belgium	43.9	5.7	2
Switzerland	24.4	3.1	1
Finland	21.0	2.6	1
Hungary	13.1	1.8	<1
Czech Republic	12.4	1.8	<1
Mexico	8.8	1.3	<1
Netherlands	3.6	0.4	<1

Source: IEA, Electricity Information 2000.

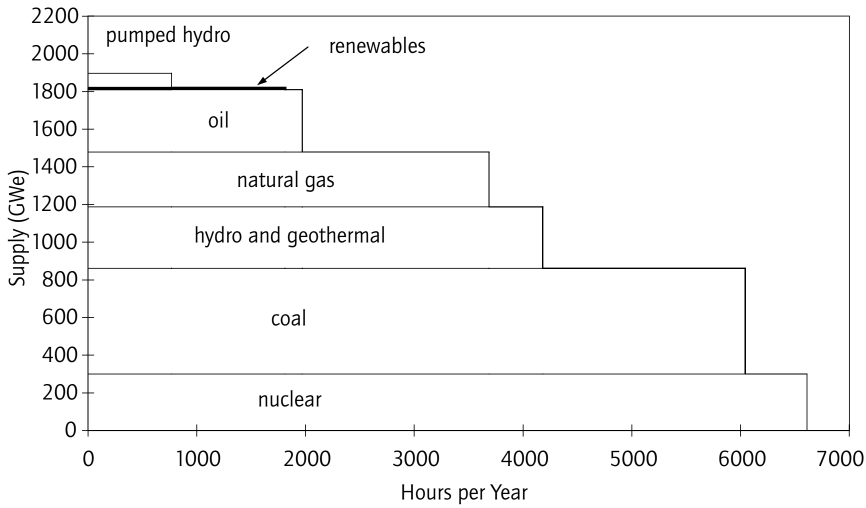
Nuclear Power's Role in Electricity Generation

Even though nuclear power plants account for only 15% of installed power generation capacity in the OECD, they provide about one-quarter of total electricity generation. This is because nuclear power plants are used almost exclusively for continuous power production at their rated capacities, i.e. baseload power production. Owing to relatively low operating costs, nuclear plants are generally used whenever they are available. On average throughout the OECD, nuclear power plants have the highest utilisation rate of any type of plant. This is illustrated by the OECD electricity supply curve, shown in Figure 8. This shows the gigawatt contribution of each energy source to electricity supply over the equivalent annual operating hours of each source.

The exception to the general rule of strict baseload operation is France, where nuclear power plants provide such a high proportion of the load

Figure 8

OECD Electricity Supply Curve, 1998



Note: Multi-fuel capacities assigned to each respective fuel are IEA Secretariat estimates.
Source: IEA Electricity Information 2000.

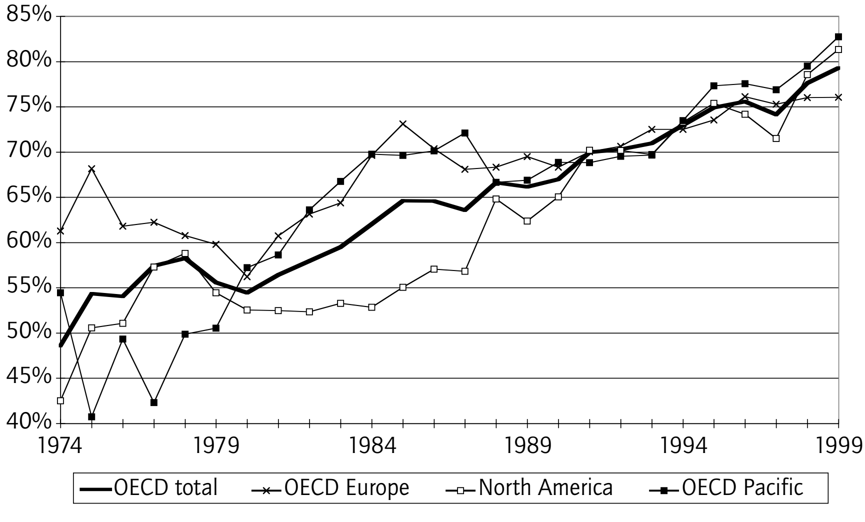
that load-following operation is typically used. The output of nuclear power plants is adjusted to match the total system load. With this variable operation, French nuclear plants have an average lifetime utilisation rate of about 66%.

Hydroelectric plants are economically operated at all load levels (baseload, load-following, and peak) depending on the characteristics of the water supply. Figure 8 represents production time for OECD hydroelectric plants on average.

Nuclear plant utilisation has increased steadily over the last two decades, as shown in Figure 9. Average utilisation rates (capacity factors) have increased from about 50% in 1974 to 78% in 1998. The highest lifetime-averaged utilisation rates at individual utilities are

Figure 9

Nuclear Plant Gross Capacity Factors, OECD Regions, 1974 to 1999



Note: Capacity factor calculated as total annual nuclear generation divided by (8760 times nuclear generation capacity in GW).
Source: IEA, Electricity Information 2000.

generally between 75 and 80% (NEI, 2000: p. 22), although some newer plants or units have reached up to 85%.

Plant Technology Types

The four basic types of nuclear plant in commercial operation in the OECD are pressurised water reactors (PWRs), boiling water reactors (BWRs), gas-cooled reactors, and heavy water reactors. These are all so-called "thermal" reactors, because the neutrons within the reactor core are slowed by moderators to reach a "thermal" speed. A small number of "fast" reactors have been tested over the years, but today there are no commercially operating fast reactor plants. Table 5 summarises the reactor types and their shares in commercial nuclear generation capacity in the OECD.

Table 5

Nuclear Plant Types in the OECD

Reactor Type	Acronym/Name	Country of Initial Development	Share of Commercial OECD Capacity (%)
Pressurised water	PWR	USA	65
Pressurised water	VVER	Soviet Union	1
Boiling water	BWR	USA	26
Gas-cooled	Magnox and AGR	UK	4
Heavy water	Candu	Canada	4
Fast	breeder	various	0

Sources: CEA, 2000.

Pressurised water reactors are by far the most commonly installed type. They account for nearly two-thirds of total OECD nuclear capacity. Together with boiling water reactors, they account for about 90% of net installed nuclear capacity in the OECD. Pressurised water reactors developed in the Soviet Union are also known by their Russian acronym, VVER. Of the plants with pressurised water reactors, only three are VVER plants. These are located in Dukovany in the Czech Republic, Loviisa in Finland, and Paks in Hungary.

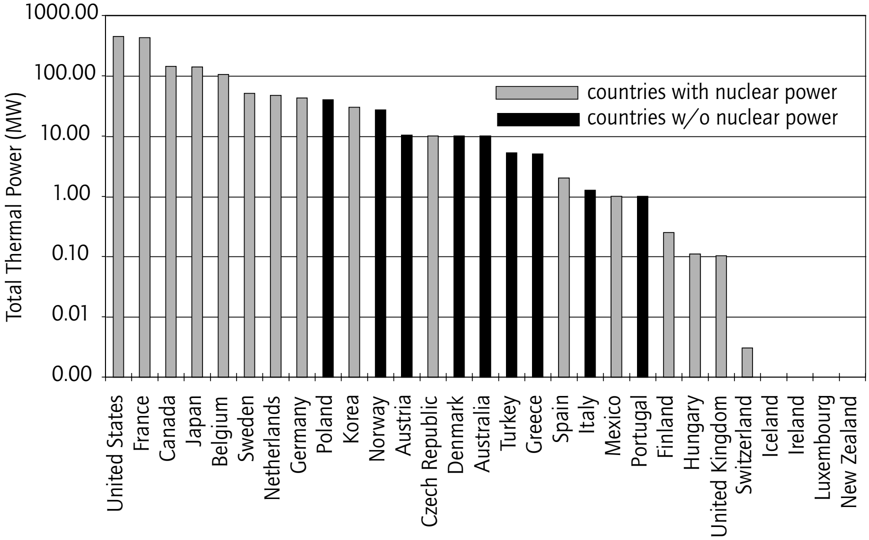
Gas-cooled reactors in commercial operation today are of two British designs, the Magnox and the advanced gas-cooled reactor (AGR). Gas-cooled reactors operate only in the United Kingdom. All the pressurised heavy water reactors are of Canadian design, the Candu reactor. Heavy water reactors operate only in Canada, with the exception of the Wolsong plant in Korea.

There are two currently operating, electricity-producing reactors in the OECD which do not fall in one of the four basic categories. There is one fast reactor, Phénix, in France. Its primary use is to explore options for better consumption of plutonium and for a transmutation of long-lived radioactive materials. A unique Japanese reactor, the Fugen plant, fulfils a similar research role, particularly for the use of mixed oxide fuel. It uses both heavy water and light water for reactor operation.

The growth of operating nuclear power plants has been accompanied by a development of test and research reactors in every country of the OECD except Iceland, Ireland, Luxembourg and New Zealand (Figure 10). These reactors contribute to commercial nuclear power by providing training and support for research and development. In addition, many are used to produce isotopes with beneficial uses in industry, medicine and other areas. On average, OECD countries have 5 MW capacity (thermal power) of test and research reactors for each gigawatt of installed nuclear electric capacity. However, there is no strict relationship between the capacity of test and research reactors and the capacity of operating power reactors. Nine countries have operable test and research reactors, but no operating nuclear power plants. Belgium, France and the Netherlands have above-average capacity in test and research reactors, while Germany, Japan and the United States have less than the average.

Figure 10

Thermal Capacity of OECD Operable Test and Research Reactors



(Note logarithmic scale)
Notes: French capacity does not include the Phénix or Superphénix reactors. Japanese capacity does not include the Fugen or Monju reactors. Thermal power is the amount of energy released as heat. Test reactors may also be capable of electricity production.
Source: NEI, World Nuclear Industry Handbook 2000.

Nuclear Fuel Supply and Facilities

Nuclear Fuel Supply

The raw energy commodity for nuclear power production is natural uranium. In its commercial form it is as uranium oxide, or yellowcake. There is no other major civilian use for uranium apart from electricity production. Therefore, uranium mining activity and uranium prices depend substantially on nuclear power generation.

Uranium was mined in 23 countries in 1998. OECD countries provided about half of the world's supply in the 1990s (Table 6). Within the OECD, Canada, Australia, the United States and France are the largest producers, accounting for about 90% of total OECD production in the 1990s. Canada alone provides half of OECD supply. Outside the OECD, Kazakhstan, Namibia, Niger, the Russian Federation, Uzbekistan and South Africa are the largest producers.

From the beginning of commercial nuclear power till the mid-1980s, the OECD was self-sufficient in uranium production. In fact, production substantially exceeded reactor requirements, reaching a maximum excess of some 15 000 tonnes a year in 1980. However, a drop in

Table 6

OECD Uranium Production by Country

	Total Uranium Production, 1990 to 1998 (tonnes)	Uranium Production, 1998 (tonnes)
Canada	90 120	10 922
Australia	33 189	4 910
United States	19 855	1 810
France	13 275	507
Czech Republic (1)	9 367	610
Other OECD (2)	10 118	329
OECD Total	**175 924**	**19 088**
OECD Share of World Total	**52%**	**55%**

(1) Prior to 1993, includes production from the Czechoslovak Federal Republic.
(2) Belgium, Hungary, Germany, Portugal and Spain.
Note: See sources for detailed estimates and data limitations.
Sources: NEA, Uranium 1997 – Resources, Production and Demand, *Table 6;*
NEA, Uranium 1999 – Resources, Production and Demand, *Table 9.*

uranium prices in the early 1980s led to sharply reduced uranium production, so that by 1990 neither the OECD nor the world as a whole produced enough uranium to satisfy current requirements. In recent years, world annual reactor requirements have exceeded world annual mine production ("primary sources") by roughly 25 000 tonnes. The deficit has been met from "secondary sources" of uranium, that is, existing stockpiles of both natural uranium and enriched uranium. Russian uranium supplies have been the largest source in the 1990s, followed by reductions in OECD inventories. Thus, it is difficult to analyse a "self-sufficiency" of the OECD in primary uranium production because the world as a whole is currently in deficit.

Over the next few years, world uranium production is difficult to predict because of several factors:

- The size of accumulated stockpiles of both natural and enriched uranium is not accurately known.

- Non-traditional suppliers to the world market may increase their exports. These potentially major new suppliers include China, Kazakhstan, the Russian Federation and Uzbekistan.

- Surplus uranium and plutonium from Russian and US military programmes will enter the uranium market over the next few years, effectively displacing natural uranium production. The timing and size of annual releases of this military material is not certain.

- Uranium trade between some countries of the former Soviet Union and some OECD countries is subject to quotas or other restrictions.

Given these factors, the period during which primary uranium production falls substantially short of annual reactor requirements is likely to continue (UI, 1998: p. 152). The Uranium Institute, the industry group that monitors uranium supply and demand, believes that the nuclear fuel market will be adequately supplied until 2020, considering all primary and secondary sources of uranium supply. They expect that "a significant fraction of requirements will be met from secondary sources which have their origin in military nuclear programs". The US Energy Information Administration estimates that, by 2001, 20% of the world's commercial uranium requirements could be met by defence surplus materials (Szymanski, 1998). By 2010, enriched uranium from Russian military surplus could supply about 50% of the US market for uranium for commercial nuclear power plants. Another important factor noted by the Uranium Institute is that uranium "production is becoming increasingly concentrated in a small number of large mines in a limited number of countries, particularly Australia and Canada" (UI, 1998: p. 8).

Today's estimated reserves of uranium are given in Table 7. They are categorised according to the definitions of reserve certainty and cost defined in *Uranium 1999 – Resources, Production and Demand* (NEA, 2000c). OECD countries have estimated reserves of 1.2 million tonnes considering known and directly inferred uranium resources recoverable at a cost of $40 per kilogram or less. Actual reserves of uranium available at $40 per kilogram or less are likely to be smaller because two countries with major reserves, Australia and the United States, only provide estimates of reserves at a cost of $80 per kilogram or less. Uranium prices in the 1990s were $20 to $40 per kilogram.

OECD countries have reserves of nearly 2 million tonnes of uranium, or 43% of estimated world reserves, when considering known and directly inferred uranium resources at a cost of $130 per kilogram or less. If reserves of lower certainty and unknown cost are considered, the total within OECD countries doubles, but accounts for about only one-third of world reserves. Because the associated extraction cost for these reserves is three to four times the price of uranium on world markets in the 1990s, the reserve estimates at $130 per kilogram greatly exceed today's commercially exploitable reserves.

Uranium 99 estimates the world requirement for uranium in 2000 as 64 kt/yr. Reasonably assured world reserves of uranium are equivalent to about 30 to 50 years of consumption at this rate of use, depending on uranium extraction price. If total resources at a cost of $130 per kilogram are considered, including additional hypothesised resources noted in Table 7, world reserves of uranium are equivalent to about

250 years of consumption. These estimates do not take account of the use of uranium stockpiles, reprocessing of fuel from existing reactors or fuel produced in breeder reactors.

Table 7

Estimated OECD Uranium Reserves

	Estimated Resources[1] of $40/kg U or less (thousand t U)	Estimated Resources[1] of $130/kg U or less (thousand t U)	Hypothesised Resources[2] including Resources of Unknown Cost (thousand t U)
Australia	754[3]	910	0
Canada	372	433	850
United States	106[3]	355	2 613
Denmark	0	43	60
Czech Republic	0	30	189
Hungary	0	19	13
France	12[3]	15	0
Spain	0	14	0
Sweden	0	10	0
Turkey	0	9	0
Portugal	0	9	7
Germany	0	7	74
Greece	1	7	6
Japan	0	7	0
Italy	0	6	10
Mexico	0	2	13
Finland	0	2	0
Finland	2	0	0
OECD Total	**1 247**	**1 877**	**3 835**
OECD Share of World Total	**54%**	**43%**	**33%**

(1) Estimated resources include unadjusted totals of "reasonably assured resources" and "estimated additional resources, category I" for all reported assessments. (2) Hypothesised resources include "estimated additional resources, category II" and "speculative resources". They are termed "undiscovered conventional resources" in the source document. (3) Includes estimates for resources of cost $40 to $80/kg U. Estimate of resources of $40/kg U or less is not available.
Note: See NEA source document for detailed estimates and data limitations.
Sources: NEA, Uranium 1999 – Resources, Production and Demand, *Tables 2, 3 and 5;*
US data from USDOE, Uranium Industry Annual 1999, *DOE/EIA-0478(99), Annex B.*

Fuel Preparation Facilities

This section summarises the capacity of facilities around the world for preparing nuclear fuel. Unlike fossil fuels, nuclear fuel must be specially processed and placed into engineered fuel assemblies before it can be used in power plants. The facilities for preparing nuclear fuel are themselves essential parts of the nuclear fuel supply chain. Similarly, special facilities are needed for processing and storing nuclear fuel after it has been used, so-called spent fuel. Nuclear generation capacity is consequently tied to the processing capacity of these related fuel cycle facilities. At present, this relationship does not constrain nuclear power generation, because most parts of the chain have excess capacity compared to requirements for current fuel use in power plants.

Also unlike fossil fuels, few parts of the supply of nuclear fuel have been highly competitive. Many of the key facilities needed for producing nuclear fuel and for processing spent fuel are owned by governments and were developed either for specific nuclear power development programmes or for strategic or military reasons. Furthermore, few facilities are needed to supply the entire set of OECD reactors, because nuclear fuel is a relatively concentrated energy source. Finally, some nuclear fuel facilities, notably those that fabricate fuel assemblies, tend to provide services closely linked to plants designed by specific vendors.

For these reasons, facilities for nuclear fuel supply are more closely linked to electricity production than are most fossil fuel production facilities. There is no civilian market for nuclear fuel apart from nuclear electricity production.

The steps required to prepare nuclear fuel from natural uranium are known in the industry as conversion, enrichment and fuel fabrication (see Annex III). Tables 8 to 10 summarise OECD and world capacities in uranium conversion, uranium enrichment and fuel fabrication facilities. There are four large uranium conversion plants and eight uranium enrichment plants in the OECD. The United States and France dominate OECD production, with over 50% of total production capacity in all three fuel production steps. Outside the OECD, Russia possesses over 95% of

Table 8

OECD and World Uranium Conversion Capacities for Production of Light Water Reactor and AGR Fuel, 1999 (Yellowcake to Uranium Hexafluoride Only)

	Sites	1999 Capacity (tonnes/year)
Canada	Blind River/Port Hope (1)	12 500
France	Malvesi/Pierrelatte (2)	14 000
Japan	Ningyo-Toge	120
UK	Springfields	6 000
US	Metropolis works	12 700
OECD Total		**45 320**
Russia	Angarsk	18 700
Others	Brazil, South Africa	790
Non-OECD Total		**19 490**
World Total		**64 810**

(1) Capacity of Port Hope uranium hexafluoride production; (2) Figure does not include 350 tonne U/year capacity for conversion of reprocessed uranium.
Sources: NEI, 2000; Cameco Corporation.

uranium conversion and enrichment capacity. Fuel fabrication facilities are more widely spread within the OECD, as they do not require the same heavy investment as do conversion and enrichment facilities. They are tailored more closely to individual reactor designs, since fuel assemblies must meet the specific mechanical and physical constraints of individual reactors. The only countries without fuel fabrication facilities are those in which there are five or fewer nuclear units in operation.

Fuel preparation facilities for pressurised heavy water reactors and gas-cooled reactors are located in Canada and the United Kingdom,

Table 9

OECD and World Uranium Enrichment Capacities, 1999

	Sites	Technology	1999 Capacity (thousand swu*/year)
France	Pierrelatte	diffusion	10 800
Germany	Urenco Gronau	centrifuge	1 100
Japan	Rokkasho, Ningyo-Toge	centrifuge	950
Netherlands	Urenco Almelo	centrifuge	1 500
UK	Urenco Capenhurst	centrifuge	1 800
US	Paducah, Portsmouth	diffusion	19 200
OECD Total			**35 350**
Russia	Ekaterinburg, Tomsk-7, Krasnoyarsk-45, Angarsk	centrifuge	19 000
Others	Argentina, China, Pakistan, South Africa	various	725
Non-OECD Total			**19 725**
World Total			**55 075**

** swu means "separative work unit".*
In the OECD, about 4.3 swu's are required for each tonne of uranium contained in light water reactor fuel.
Sources: NEI, 2000; Urenco Limited.

respectively, the two countries where commercially operating plants of these designs were initially developed. Korea also possesses a fuel fabrication facility for its pressurised heavy water reactors.

At 1998 rates of nuclear electricity production, the OECD is self-sufficient in enrichment and fuel fabrication, as shown in Table 11. There are at present ample margins in these two areas. Furthermore, the requirement for enrichment capacity is expected to be lower than suggested in Table 11

Table 10

OECD Nuclear Fuel Fabrication Capacities, 1999

	Light Water Reactor Fuel (1) (tonne heavy metal/yr)[2]	Candu Fuel (tonne heavy metal/yr)	Magnox and AGR Fuel (tonne heavy metal/yr)
Belgium	435		
Canada		3 250 (3)	
Czech Republic	–		
Finland	–		
France	1 340		
Germany	650		
Hungary	–		
Japan	1 684		
Korea	400	400	
Mexico	–		
Netherlands	–		
Spain	250		
Sweden	600		
Switzerland	–		
United Kingdom	158		1 460
United States	3 900		
OECD Total	**9 417**	**3 650**	**1 460**

(1) Light water reactor fuel fabrication capacity includes 193 tonne HM/yr for fabrication of fuel with reprocessed plutonium.
(2) HM means "heavy metal", generally uranium or plutonium.
(3) Data from NEI, 2000, p. 207.
Note: Table does not include fabrication capacity for fast reactor fuel.
Sources: NEA, Nuclear Energy Data 2000, *Table 8.*

because of the availability of surplus enriched uranium and plutonium from military stockpiles. The equivalent of some 100 million separative work units is expected to become available over the next 15 to 20 years from this source. This compares with OECD annual enrichment capacity of about 35 million separative work units (swu's). Roughly 85% of OECD enrichment capacity is in France and the United States and uses gaseous diffusion technology. Other plants around the world generally use centrifuge technology, which has lower construction and operating costs.

Fuel fabrication capacity is probably even greater than suggested by Table 11, particularly for the production of fuel for light water reactors. Anderson (1998) estimates that capacity is double demand.

Conversion capacity within the OECD, on the other hand, appears to be below current requirements. This is similar to the situation in raw uranium production. Also, most imports of uranium from countries of

Table 11

Total OECD Fuel Production Capacities and Estimated Requirements, 1999

Production Step	Annual Unit	OECD Production Capacity	Estimated Requirement (1)
Conversion (2)	tonnes uranium	45 320	55 000
Enrichment	'000 sep. work units	35 350	28 000
Fuel fabrication	tonnes heavy metal		
• Light water reactors (3)		9 417	6 000
• Candu reactors		3 650	2 000
• Magnox and AGR		1 460	< 500

(1) Rounded values; IEA Secretariat estimates, assuming fuel production entirely from natural uranium. Estimated enrichment requirement from NEA, Nuclear Energy Data 2000.
(2) Conversion to uranium hexafluoride only.
(3) Includes production capacity for fuel with reprocessed plutonium.
Sources: NEA, Nuclear Energy Data 2000, *Table 8; NEI, 2000; Cameco Corporation.*

the former Soviet Union have already been converted to uranium hexafluoride. This tends to reduce the need for uranium conversion capacity within the OECD.

Although not a nuclear fuel, heavy water is needed for the operation of heavy water reactors. An initial inventory of heavy water is required, as well as small quantities each year to replace heavy water lost during operation. A 700 MWe Candu reactor requires about 460 tonnes of heavy water for its initial fill (0.65 tonne per MWe capacity) and less than 0.5% of this inventory must be replenished yearly. There are heavy water production facilities in Canada (capacity of about 800 t/yr) and the United States (190 t/yr).

Reprocessing and MOX Facilities

Reprocessing is the treatment of used nuclear fuel to extract the uranium and plutonium. The separated elements can be recycled into

Table 12

OECD Plants for Reprocessing Spent Reactor Fuel

	Plant Name and Company	Start-up Year	Capacity (tonne/year)
Fuel for light water reactors			
France	La Hague UP2 &UP3, Cogema	1976	1 600
Japan *	Tokaimura, JNC	1981	90
United Kingdom	THORP, BNFL	1994	850
Total			**2 540**
Fuel for Magnox reactors			
United Kingdom	Sellafield Magnox, BNFL	1964	1 500

** The Tokaimura reprocessing plant has been out of service since 1997, when an accident occurred.*
Sources: NEI, 2000, p. 209; Japan Nuclear Fuel cycle Development Institute (JNC).

reactor fuel as mixed oxide or "MOX" fuel (for a fuller description, see Annex III). Current OECD capacity for reprocessing fuel from light water reactors is about 2 500 tonnes/year (Table 12). One large plant at La Hague in France accounts for over half of total OECD capacity. In Japan, an 800 tonne/year reprocessing facility at Rokkasho is scheduled to open in 2005.

Plutonium extracted from spent fuel or unused nuclear weapons can be mixed with uranium fuel to produce "mixed-oxide" or "MOX" fuel. Up to half of the fuel supplied to pressurised water reactors can consist of

Table 13

OECD Production Plants for Light Water Reactor MOX Fuel, 1999

	Plant Name and Company	Start-up Year	Nominal Capacity in 1999 (tonne HM[1]/year)	1999 Production (tonne HM)
Belgium	Dessel P0, Belgonucléaire	1985[2]	35	38
France	Cadarache, COGEMA	1990[3]	35	40
	Melox, COGEMA/Framatome	1995	115	101
United Kingdom	Sellafield MDF[4], BNFL	1994	8	8
	Sellafield MOX Plant[5], BNFL	1998	120	–
Total			**313**	**187**

(1) HM means heavy metal: plutonium plus uranium.
(2) The Dessel plant began operation in 1973, producing fuel for fast breeder reactors. It began producing MOX fuel for light water reactors in 1985.
(3) The Complexe de Fabrication des Combustibles Cadarache began operation in 1963 producing fuel for fast breeder reactors, and began producing MOX fuel for light water reactors in 1990.
(4) MOX Demonstration Facility.
(5) The Sellafield MOX plant continued with start-up operations, using uranium only, throughout 1999. Actual MOX production capacity was zero.
Sources: NEI, 2000, pp. 207-208; IEA; French Government.

mixed-oxide fuel. A higher fraction could be obtained for reactors specifically engineered to accept this fuel. To prepare a uranium-plutonium mixture suitable for use in civilian nuclear reactors requires specialised chemical processing plants.

There are five plants for the production of MOX fuel for light water reactors in the OECD, with total production of about 300 tonnes/year (Table 13). In round figures, this represents about 5% of annual nuclear fuel requirements in the OECD.

As of December 1999, there were 33 reactors in Belgium, France, Germany and Switzerland using MOX fuel. They represent about 10% of commercial nuclear plants in the OECD. At present, MOX fuel use is dominated by French plants (half of the total number) and German plants (a third of the total). There are plans for using MOX fuel in additional French and Swiss reactors, and also in nine Japanese reactors in the coming years. The US Department of Energy has designated six US reactors to use MOX fuel derived from surplus military plutonium, though the timetable is uncertain.

CHAPTER 4

THE ECONOMICS OF NUCLEAR POWER

Introduction

This chapter addresses the commercial economics of nuclear power plants. It reviews the operating costs of nuclear power, followed by its capital costs. Safety, plant decommissioning and waste disposal costs, and the cost of uranium and nuclear fuel are then explored. The chapter ends with conclusions on the prospects for existing and new nuclear plants. These conclusions should be read in conjunction with the broader policy assessment in Chapter 2.

The economics of nuclear power are not just an issue of commercial decision-making; they depend heavily on the wider economic and policy framework. Whilst electricity market reform is encouraging the trend towards commercial decision-making on the basis of economic efficiency, other energy policy priorities, in particular environmental policy, are increasingly important.

Four existing OECD publications are relevant to this discussion and provide further insights:

- “Nuclear Power Economics and Technology: An Overview” (NEA, 1992).
- “ The Economics of the Nuclear Fuel Cycle” (NEA, 1994).
- “Nuclear Power: Sustainability, Climate Change and Competition” (IEA, 1998).
- “Projected Costs of Generating Electricity” (OECD, 1998).

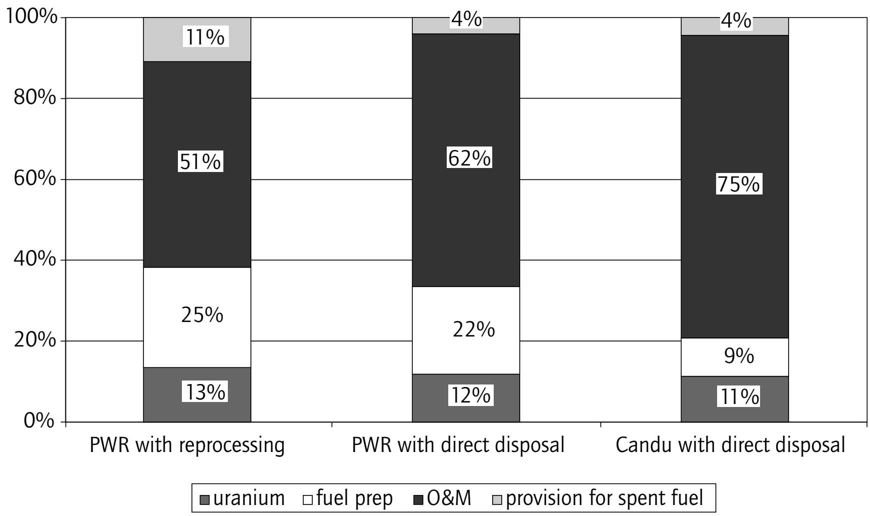
The Operating Costs of Nuclear Power

The Components of Operating Costs

The cost structure of nuclear power generation makes it very well suited for baseload power generation. Nuclear plants have high capital costs and operating costs similar to coal-fired plants, given historical and current prices for coal. Normally, they are operated at full capacity whenever they operate. The main operating costs of nuclear plants are nuclear fuel, operations and maintenance (O&M), provisions for spent fuel management and disposal, and provisions for final closure of the plant (decommissioning). Figure 11 illustrates the shares of these components for pressurised water reactors and Candu reactors. The

Figure 11

Illustrative Composition of Nuclear Plant Operating Cost



Notes: Shares vary greatly by country, plant, and year. These values exclude capital additions and are based on levelised cost shares at a 10% discount rate. Provisions for plant decommissioning costs are typically estimated at less than 1% of ongoing operating costs.
Sources: IEA, using data in NEA, 1994; OECD, 1998.

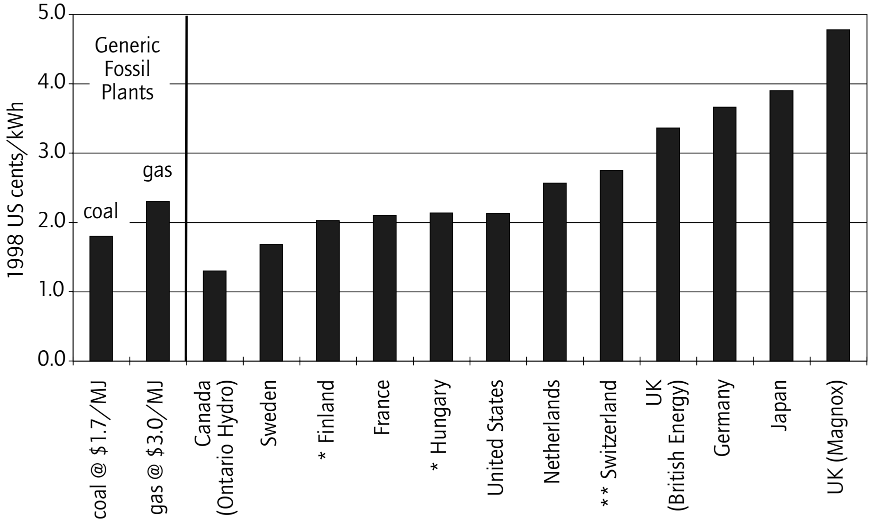
shares of each component vary by plant type and country, and depending on whether or not spent fuel is reprocessed before disposal. The shares have also varied considerably over time in some countries. O&M typically accounts for one-half to two-thirds of operating costs in pressurised water reactors and, of this amount, personnel is the largest single component. Nuclear fuel accounts for roughly one-third of operating costs, most of which go into fuel preparation. In Candu reactors, O&M accounts for three-quarters of the total operating cost, and nuclear fuel only one-fifth.

Provisions for spent fuel management and disposal and for decommissioning are included as operating costs because the plant typically cannot continue to operate without regular payments to spent fuel and decommissioning funds. Provisions for spent fuel management account for roughly 10% or less, and provisions for decommissioning account for less than 1%. However, both these components can vary widely depending on the regulatory requirements and the period of time over which provisions must be collected. One study estimates that current (non-levelised) provisions for wastes and decommissioning account for about one-quarter of operating expenses (Hensing *et al.,* 1997) in France and Germany. Provisions for spent fuel management and decommissioning are the most uncertain components of operating costs, since experience with both has been limited. If spent fuel is reprocessed to recover plutonium, both fuel and provisions for spent fuel will account for a larger share of operating expenses than in the case of direct disposal of the fuel. Candu reactors do not require fuel with enriched uranium, so their fuel costs account for a smaller share of operating costs than in pressurised water reactors.

The operating costs of existing nuclear plants make them generally competitive with fossil-fuelled plants. Figure 12 shows the average operating cost of nuclear plants in selected OECD countries, along with generic values for coal-fired plants and gas-fired combined cycles. It should be emphasised that average cost figures do not indicate how individual nuclear and fossil-fuelled plants actually compare in cost in given markets. But they do suggest that the majority of nuclear plants in

Figure 12

Average Operating Costs of OECD Nuclear Plants



* *Costs for Finland and Hungary include capital expense.*
** *Cost for Switzerland based on the Gosgen and Leibstadt nuclear power plants only.*
Note: Operating costs exclude repayment of capital, interest or ongoing capital requirements (major refurbishment or repair).
Sources: IEA, from published data. Netherlands data provided by Borssele nuclear power plant.

OECD countries have operating costs in line with those of their fossil fuel competitors. Coal-fired plants cost approximately 2 cents/kWh, and gas somewhat more (depending strongly on local natural gas prices). Nuclear plants are generally in the same range. In countries with higher nuclear operating costs, competing non-nuclear plants may also have higher operating costs. For example, Japanese power plants, including nuclear plants, have high operating costs compared with OECD averages.

Results from a 1998 OECD study on electricity generating costs (see OECD, 1998; see also Paffenbarger and Bertel, 1998) project low future operating costs for nuclear plants compared to coal-fired and gas-fired plants. Figures given in this report (Table 14) are invariably lower than for current nuclear plant operating costs.

Table 14

Projected Operating Costs of Power Plants (US cents/kWh)

	Nuclear	Coal	Gas
Canada	0.8	1.9	2.2
Finland	1.5	2.3	3.0
France	1.5	3.3	3.9
Japan (1)	3.2	3.2	4.0
Korea	1.4	2.3	3.7
Spain	1.9	2.9	4.1
Turkey (2)	1.3	0.9	2.7
United States (3)	1.5	1.4	2.0

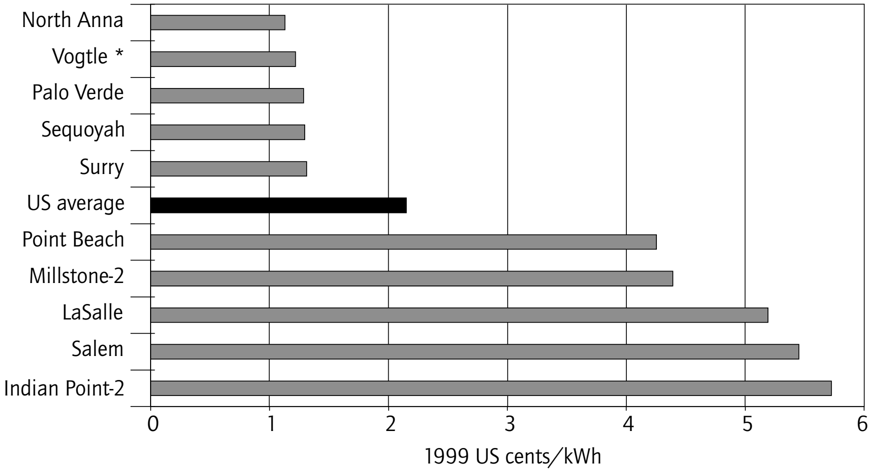
(1) Japanese costs for gas-fired plants assume zero natural gas price escalation.
(2) Turkey has no operating nuclear power plants.
(3) US nuclear plant costs are based upon a design expected to be available by 2005.
Notes: Costs are projected for commercially available power plant designs entering service in 2005. These costs include O&M and fuel cost.
Source: OECD, 1998.

Operating Cost Differences

It should be noted that there are large differences in operating costs, both across countries and within countries. In Nordic nuclear plants, generally acknowledged to be among the most cost-effective in the world, operating costs are below 2 cents/kWh. In the higher range, including plants in Germany and Japan, average operating costs are over 75% higher. Within the United States, average operating costs over the period 1997 to 1999 varied by a factor of five (Figure 13). Fourteen plants had operating costs below 1.5 cents/kWh, while 14 plants had operating costs above 2.6 cents/kWh.

Figure 13

Best and Worst Operating Expenses of US Nuclear Power Plants, 1997-1999



** Average relates to 1997-1998 only.*
Source: NW, 2000.

Improving Technical Performance

Nuclear plant technical performance is a major factor in both operating costs and in the use made of nuclear plants in electricity production. There has been a world-wide trend towards improved technical performance of nuclear plants since the late 1980s. Learning must account for a good part of this, as the industry has matured. Competition reinforces the trend in many areas because improved technical performance is essential to reducing operating costs.

An important measure of performance is the plant utilisation rate (capacity factor), the fraction of time that a plant is used at its full capacity. This has been steadily increasing (Figure 9) in OECD countries. In the best performing plants, annual capacity factors have exceeded 90%. Their maximum value is limited by the need for periodic refuelling and maintenance activities. Some plants have extended the time between outages for refuelling in order to increase capacity factors. While 12 months between refuelling outages is a typical interval, 18 months is now the norm in some plants.

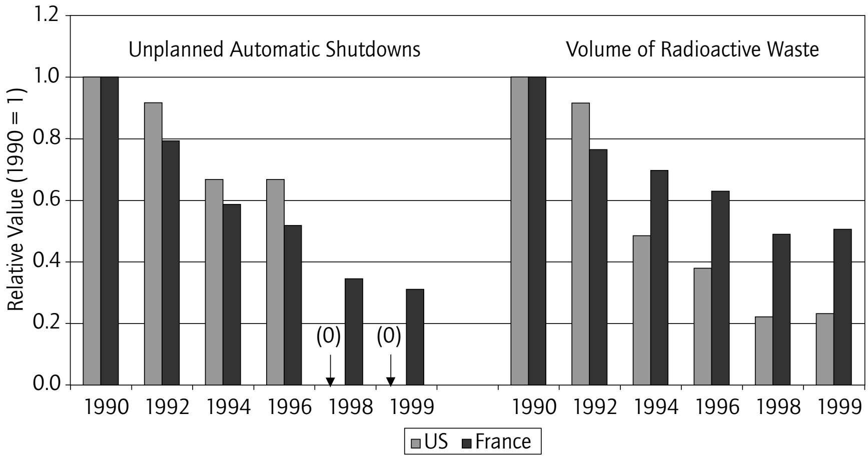
Other technical factors that have shown continued improvement are:

- Number of unplanned automatic shutdowns.
- Volume of radioactive waste produced.
- Time for plant refuelling.
- Energy utilisation of nuclear fuel (known as "burnup").
- Thermal efficiency.
- Radiation exposure of plant workers.

As an example of improving trends, the first two of these values are shown in Figure 14 for US and French nuclear plants. As technical

Figure 14

Selected Nuclear Plant Performance Trends in France and the United States, 1990 to 1999



Notes: Lower values imply lower cost of operation. The volume of radioactive waste in the United States is for pressurised water reactors.
Sources: NN, 2000; Électricité de France.

performance continues to improve, nuclear power's economic performance will continue to improve with it. The ability to sustain the gains of recent years and to push them farther will be important to nuclear power's future competitiveness.

The Capital Costs of Nuclear Power

Not including interest paid during construction, current designs of nuclear plants have capital costs of roughly \$2 000/kWe, compared to \$1 200/kWe for coal-fired plants and \$500/kWe for combined-cycle gas turbines. Capital costs typically account for 60 to 75% of nuclear power's total generation cost, while in coal plants they are only about 50% and in gas-fired plants they can be 25% or less.

Estimated capital costs for new nuclear plants vary by country, as shown in Table 15. The major factors in variability across countries for plants of similar technologies and size include:

- Labour cost.
- Domestic prices for material and equipment.
- Institutional and regulatory framework (for example, see "Safety Costs" below).
- Infrastructure.
- Site-specific conditions.
- Cost of capital (discount rate).
- Time to develop operating plants.
- Ability to take advantage of economies of scale, economies of scope and standardisation.

The cost of capital for plant construction directly affects the financing charges accrued while building a nuclear power plant. The cost of capital represents the rate of return that must be paid to attract

Table 15

Capital Cost Estimates for New Nuclear Power Plants

				Total Capital Cost	
	Plant Type	Plant Net Capacity (MWe)	Overnight Capital Cost ($/kWe)	discount rate = 5% ($/kWe)	discount rate = 10% ($/kWe)
Canada	Candu	1 330	1 697	2 139	2 384
Canada	Candu	1 762	1 518	1 878	2 053
Finland	BWR	1 000	2 256	2 516	2 672
France	PWR	1 460	1 636	1 988	2 280
Japan	BWR	1 303	2 521	2 848	3 146
Korea	PWR	1 000	1 637	1 924	2 260
Spain	PWR	1 000	2 169	2 540	2 957
Turkey	PWR	1 000	1 968	2 274	2 552
Technology Expected to Be Commercially Available by 2005-2010					
United States	PWR	1 300	1 441	2 079	2 065

Source: OECD, 1998.

investors to a project, including holders of both debt and equity. For purposes of project evaluation, their costs are equivalent to the discount rate, since they represent the return that could be earned by investing in similar projects.

The investment cost of *all* power generation projects increases as discount rates increase. But the cost of electricity from capital-intensive power generation technologies such as nuclear power and hydroelectric plants increases more steeply. In the OECD generating cost study (OECD, 1998), doubling the discount rate from 5 to 10% increased the levelised cost of nuclear electricity by between 40 and 70%, with an average of about 50%. By contrast, the average increase in the cost of coal-fired generation was 28%, and for gas-fired combined cycles it was 12%. Nuclear power is more competitive when builders have access to capital at low cost.

In practice, the effect of the discount rate on the choice of generation technology may not be clear-cut, though it is important in determining the absolute cost of electricity. The 1998 OECD generating cost study shows that the cheapest generating option was unaffected by the choice of discount rate (10% vs 5%) in about half the countries analysed. Furthermore, the discount rate can influence the overall cost of generation in opposing senses. Higher discount rates increase the financing costs of plant construction, but minimise the present value cost of major plant repairs, waste disposal and plant decommissioning. These expenses can be substantial, and they generally occur after a long period of plant operation.

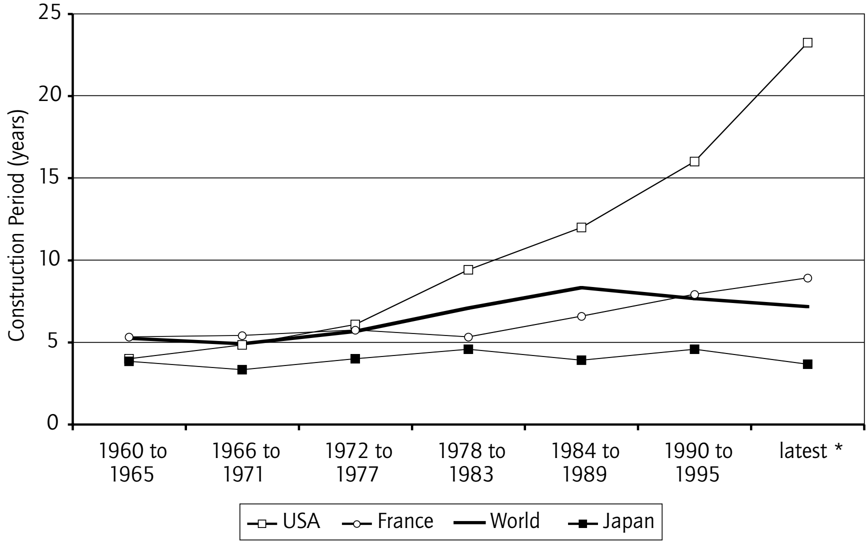
The time needed to develop an operating plant is relevant because financing charges usually accrue during the period of planning and construction. The longer the time needed to bring a project to fruition, the larger the accumulated financial charges.

The time needed for pre-construction activities, including siting and licensing, has increased over the years. More importantly, considering the impact on cost, the average time needed to build nuclear plants has also increased (see Figure 15). In the 1960s, five years or less was typically required to build a plant. By the 1990s, the world average had risen to nearly eight years. But these averages conceal wide variations. Japanese nuclear power plants have consistently taken less than five years to build.

The last US nuclear plant was ordered in 1973. The 33 nuclear units that came on line in the last half of the 1980s and the 4 units in the 1990s all experienced long construction periods, delays and even periods of project suspension. The financial condition of some utilities, public opposition and regulatory scrutiny after the Three Mile Island

Figure 15

Average Construction Time for Nuclear Plants



** The latest data points are France – 2000 (a single plant, Civaux 2); Japan – 1996; USA – 1996 (a single plant, Watts Bar 1); world – 1998.*
Notes: Average construction time is for plants connected to the electrical network in the time intervals indicated.
Source: IAEA, Reference Data Series No. 1, 1999, *Table 14.*

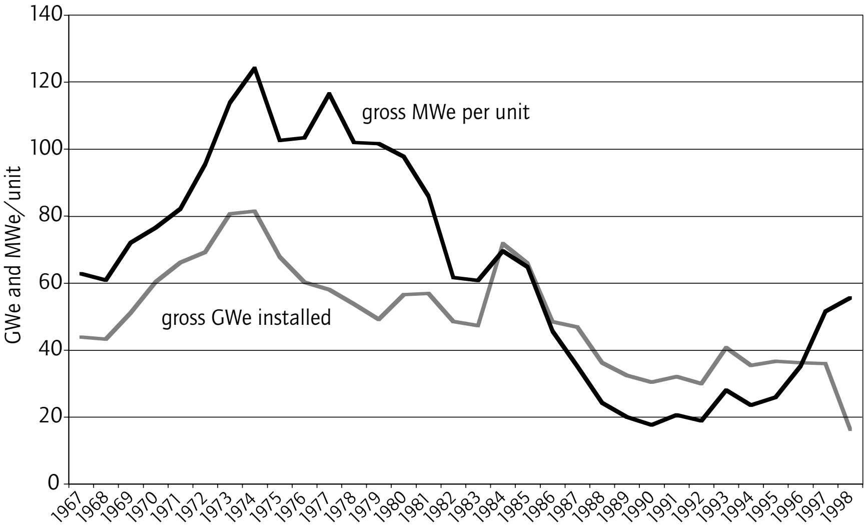
accident and other factors led to average construction times of over 12 years for plants completed from 1984 onwards. Other OECD countries with construction times above the world average after 1984 were Germany (9 years), Mexico (15 years), Spain (9 years), Switzerland (10 years) and the United Kingdom (11 years).

One traditional approach to reducing power plant capital cost (in $/kWe) has been to pursue economies of scale in power plant construction. A second approach has been to build a series of plants or units in succession. A third approach has been to design standard plants that may be built in different locations with minimal changes. These approaches allow certain engineering, licensing, administrative, procurement and other costs to be divided among a number of projects. All three approaches are being explored for future nuclear plants (NEA, 2000a), and they could be important factors in reducing the capital costs of nuclear power plants.

There are, however, major challenges. Actual plant construction in some countries has not always realised the expectation that net economies of scale can be achieved when total investment costs are considered. Experience in some countries also indicates that operating costs in larger plants have risen because of greater complexity of design. The characteristics of OECD electricity markets may pose the greatest challenge to realising the potential gains from economies of scale, series construction and standardisation. Most OECD electricity markets are not growing fast enough to accommodate single large plants or a

Figure 16

Electricity Capacity Additions and Average Unit Size in OECD Countries, 1967 to 1998



Note: The average unit size is the average gross capacity of all power plant units put into service in a given year, including baseload, intermediate-load and peaking plants.
Source: IEA, using the Utility Data Institute power plant database.

programmed series of plants as easily as they might have done in the past. Large plants can take many years to reach full utilisation, unless they replace retiring units. Since the mid-1970s, both total annual additions to generating capacity and average unit sizes installed in OECD power plants have been dropping (Figure 16). The 1990s saw a partial reversal in the trend towards smaller unit size, but units remain less than half the size of those built during the period of large capacity growth. Competitive markets will favour plant sizes better matched to expected load growth. Plant sizes will remain closer to the equivalent annual load growth of just a few years rather than to that of 20 or 25 years. This provides a better match with financial risks and reduces system reliability risk, and hence the need for higher reserve margins.

Safety Costs

The principal goal of safe plant operation is to minimise the possibility that radioactive materials escape into the environment, either through routine activities or as the result of an accident. Safety regulation provides a means of ensuring and verifying that this goal will be met. As with the regulation of other potentially harmful substances, the more stringent the limits on releases of radioactive materials, the higher the costs of meeting those limits. The *nature* of regulation applied to ensure safe operation of nuclear facilities also has an influence on cost.

Safety regulation of nuclear power plants and other parts of the nuclear energy chain affects the cost of nuclear power production in key areas:

- Capital cost.
- Operation and maintenance cost.
- Cost of ongoing capital expenditures.
- Licensing.
- Plant decommissioning and waste disposal.

Nuclear plants have elaborate and costly systems to ensure plant safety. Many systems not exclusively devoted to ensuring safety perform safety functions as well. Various estimates suggest that a substantial fraction of nuclear plant capital cost is attributable to nuclear safety. Forsberg and Reich (1991) suggest that up to 60% of the capital cost of nuclear power is related to health, safety and the environment. Because of the many systems devoted to ensuring nuclear plant safety, and the high proportion of safety-related costs in nuclear power plants, overall capital costs are strongly influenced by the specific requirements of nuclear safety regulation.

Differences in nuclear regulatory requirements have been identified as a major factor influencing the difference in capital costs of nuclear plants between countries. One study found that the main factor explaining high overnight capital costs in Germany compared to France was the complicated process of reviewing and granting operating licences in Germany (Ferroni *et al.,* 1998). More stringent safety regulation can contribute to higher cost because of requirements for redundant components, additional safety systems and stronger structures.

Many link the increasing capital costs of nuclear power plants brought into service in the 1980s and 1990s to the more stringent safety regulations that followed the accidents at the Browns Ferry (1975) and Three Mile Island (1979) nuclear plants in the United States. In the wake of these accidents, nuclear regulatory authorities in many countries revised a large number of specific requirements on nuclear plant construction and operation. They developed and applied new methods of assessing plant risk, and found that improvements and additional systems were needed to increase safety levels. Spokesmen for the nuclear industry, particularly in the Unites States, may have overstated the impact of safety regulation on capital costs. At the same time that safety regulations were changing, many new power plants were coming on line. Utilities and manufacturers discovered that a number of generic problems not directly related to safety required technical changes and improvements. Thus capital costs were increasing regardless of safety-related cost increases. In light of international comparisons and cost trends in individual countries, it is generally accepted that safety provisions are an important determinant of plant capital costs (Gilinsky, 1992).

The impact of safety regulation also seems clear in O&M costs and ongoing capital expenditures at existing nuclear plants. Two studies have traced high O&M costs in Germany to more stringent safety regulation, compared to Sweden or France (Bröcker and Hansson, 1996; Hensing *et al.,* 1997). Requirements for greater redundancy in German plants add to O&M costs because there are greater numbers of components to maintain. More extensive requirements for inspection and testing of plant components further add to German O&M costs compared to Sweden. Relatively high staffing levels in the United States have been traced to regulatory requirements. Regulatory actions and enforcement of safety rules have been strongly correlated to the increases in real operating and maintenance costs in the United States over the period 1975 to 1992 (EIA, 1995). The US Energy Information Administration estimated that these costs accounted for an annual absolute increase in O&M costs of $9/kW of plant capacity over this period. Rust and Rothwell (1995) found that US nuclear power plants became substantially less profitable owing to the change in regulatory regime following the Three Mile Island accident in 1979: over 90% of the expected discounted profits from continued operation of existing nuclear plants were lost in the period after 1979 because of higher operating costs.

Ongoing capital expenditures can be directly affected by regulatory requirements. The regulatory actions immediately following the accident at Three Mile Island have been linked to expensive capital projects to improve plant safety at existing plants. An increase in ongoing capital expenses was not observed in all countries, because not all regulatory regimes required extensive plant modification of plants already licensed and in operation.

Safety regulators have required nuclear plants to close for extended periods or to delay the start of initial operations in order to improve plant systems, operations or management. Some plants have been abandoned because of concerns about their safety, coupled with the expected cost of improvements to correct deficiencies. Outages required for meeting the requirements of nuclear regulation can entail substantial costs apart from the direct costs of correcting the problems, such as replacement power or finance costs.

Licensing costs can be high for nuclear plants. Plant operators and builders applying for a licence are required to show that the plant meets all relevant safety regulations. Exhaustive, detailed and highly technical studies must be carried out to establish this to the satisfaction of regulators. In some countries, the process has been open to legal challenge after construction has begun, further increasing costs. In Germany, the autonomy of the Länder led to differing licensing requirements within the country. The use of courts to resolve disputes over licensing issues also contributed to costs higher than they would have been otherwise. Some countries, including Canada, Finland, Spain and the United States, issue nuclear plant licences valid for fixed periods. Licences must be renewed at the end of the period. Thus re-licensing costs may be relevant in some countries.

Plant Decommissioning and Waste Disposal Costs

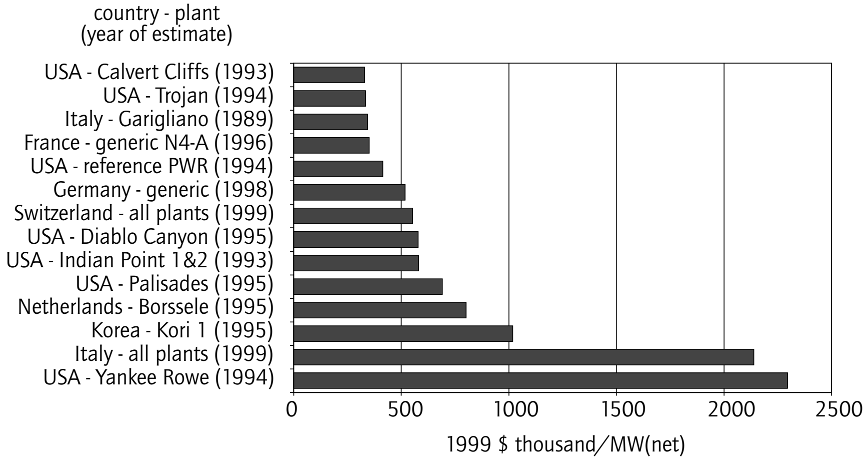
The costs of permanently closing nuclear facilities and for disposal of nuclear wastes are important in evaluating nuclear power economics. Both plant decommissioning and waste disposal expenses are large in absolute terms, although life-cycle analyses of nuclear power production usually find the estimated present value costs to be small. This is because the costs occur far in the future, beyond the end of a plant's operating lifetime. Discounting expenditures 30 or more years into the future reduces their present value by something between one-fourth to one-twentieth or less of their current cash cost, depending on the discount rate used. Nonetheless, such costs remain important considerations in evaluating nuclear power economics because they are highly variable, depending on regulatory and technical requirements, and because their actual scales have not been confirmed in practice. While the basic principles and methods for decommissioning and waste disposal are well documented, no country has a complete, proven concept of all the facilities and operations that will be necessary. There is considerable uncertainty inherent in any cost estimate for a project expected to occur in the distant future.

Plant Decommissioning Costs

Current estimates for plant decommissioning (closure) costs are variable, but are typically $300 to $500 million per unit, not including fuel. Pacific Gas & Electric, a US utility, has estimated the permanent closure of its two-unit, 2 200 MWe Diablo Canyon plant to cost $1.2 billion. Figure 17 shows that the estimated costs of plant

Figure 17

Estimates of Plant Decommissioning Costs for Light Water Reactors, Excluding Disposal of Nuclear Fuel



Notes: Cost estimates converted using the US exchange rate for the year in which the estimate was made, then adjusted to 1999 dollars using the US GDP deflator. US estimates generally include interim fuel storage and handling costs. Italian estimate for all plants (1999) includes disposal of nuclear fuel.
Source: IEA Secretariat, from published sources.

decommissioning per unit of capacity are also variable. The difference between lowest and highest estimates can approach a factor of ten for different plants. Decommissioning costs for plants below 100 MWe in size can reach $4 000/kWe.

The variability of estimated plant closure costs has been of concern to the industry; provisions for future liabilities are not known with certainty and, therefore, possibly inadequate. An NEA study of the reasons for variability of cost estimates concluded (NEA, 1991a) that they were attributed to:

- Exchange rate variations.
- Confusion between current and discounted monetary units.
- Physical differences between different plant types.
- Differences in legal and regulatory policy frameworks.
- Differences in unit input costs (labour, services) and their future evolution.

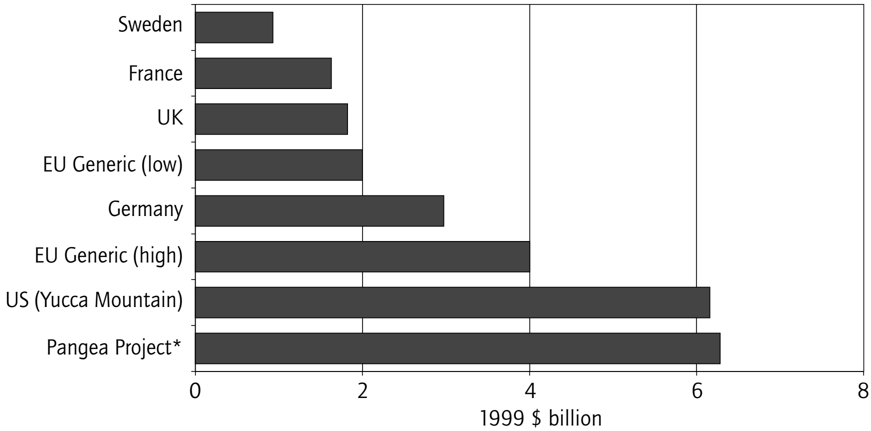
A UNIPEDE group concluded (UNIPEDE, 1998) that the "scope" of the estimate was the single most important factor accounting for variability. "Scope" in this context means the cost items included or excluded in an estimate. For example, some estimates do not include the cost of planning, licensing, or the storage, handling and disposal of spent fuel. Other factors identified by the UNIPEDE group were similar to those reported by the NEA. The importance of scope has been recognised to the degree that the NEA, the International Atomic Energy Agency, and the European Commission are developing a standard list of decommissioning cost items to improve the comparability of cost estimates.

Waste Disposal Costs

Cost estimates vary considerably for high-level waste disposal facilities (Figure 18) and for programmes (Table 16). Facility costs include amounts required for the development and construction of

Figure 18

Present Value Cost Estimates for Developing and Constructing High-Level Waste Disposal Facilities



** The Pangea waste disposal concept has been proposed by a company and is strongly opposed by the government of the proposed host country, Australia, whose policy prohibits the importation and disposal of other countries' radioactive waste.*

Notes: Estimates are discounted values pertaining to facilities of different scope and capacity but developed over similar time scales. Estimates for Pangea and EU facilities include overnight capital cost only. Others include R&D, design, licensing and construction. The IEA Secretariat estimated discounted costs of development and initial construction of the Yucca Mountain facility using data in USDOE (1998).

Sources: IEA Secretariat calculations based on Drasdo (2000); McCombie et al. *(1999); USDOE (1998); European Commission.*

underground waste disposal repositories. Overall programme costs include facility costs as well as operation of the facility, monitoring, closure, and non-site-specific research and development. The costs of high-level waste disposal will vary depending upon the ultimate arrangements adopted. Some of the main factors affecting cost are:

- Regulatory limits on risks of public exposure to radioactivity.
- The fuel cycle: direct disposal versus reprocessing.
- Timing of waste disposal after the end of plant operation or removal from plant.

- Waste treatment steps, including possible nuclear treatment (transmutation).
- Location of waste facilities in relation to the earth's surface: deep geological disposal or monitored storage at the surface.
- Physical characteristics of the chosen site, especially if underground.
- Location of waste facilities: domestic site or in another country.
- Financial support to communities hosting waste sites.

Disposal costs are significantly lower for low-level waste than for high-level waste. Low-level waste disposal accounts for only a small fraction of total life-cycle electricity cost. Low-level waste could account for about one-third of the cost of decommissioning (NE Institute, 1998: p. 9). Cost estimates for the disposal of low-level and intermediate-level wastes are based on actual experience with most parts of the disposal

Table 16

Cost Estimates for Encapsulation and Disposal of High-Level Waste

	Type of Waste	Total Cost (million 1996 $)	Cost per Unit Volume (thousand $/m^3)
Belgium	reprocessing waste	900	270
Canada	spent fuel	9 786	101
Finland	spent fuel	855	326
France	reprocessing waste	7 087	506
Germany	spent fuel, reprocessing waste	5 174	108
United Kingdom	reprocessing waste	1 912	630
United States	spent fuel	110 249	124

Source: Stevens (1998).

process except final closure of waste disposal facilities. There is again a wide variation in costs among countries. Total projected, undiscounted costs vary from \$1 000/m^3 of low-level waste in the Czech Republic and the United Kingdom to around \$8 000/m^3 in Belgium and Japan (NEA, 1999a: Fig. 5.1). The increasing difficulty of siting waste facilities and more stringent rules for their operation are expected to increase disposal costs. In the United States, costs for disposal of low-level radioactive waste escalated at an average of 13% per year during the period 1980 to 1995 (Taylor and Zeyher, 1996).

Provisions for Future Liabilities

All OECD governments require owners of commercial nuclear power plants to make financial provisions to cover the cost of future liabilities related to the disposal of radioactive wastes and plant decommissioning. The specific requirements imposed on nuclear plant owners to accumulate provisions for future liabilities vary, and they are important in evaluating nuclear power economics.

A report by the OECD/Nuclear Energy Agency discusses the differing national requirements for dealing with future liabilities of nuclear power plants (NEA, 1996a). The role of governments varies in assuring the management of funds and the responsibility of implementing disposal of the different forms of radioactive waste arising from nuclear power production. Accounting methods, tax treatment and the means of guaranteeing funds also vary widely. These differences have substantial effects on the timing and size of cash flows required to accumulate provisions and on the potential for growth of provisions from the return on financial investments. Some utilities must account for provisions on the basis of current values, while others must use the expected net present value of the liabilities. When using the current value method, provisions accumulate more rapidly. For a given liability, they require higher cash annuity payments. Provisions may be accumulated with a fixed annual payment, or as a function of electrical production, fuel discharge or other values. The type of investments allowed using provision funds also affects total cash requirements, because financial returns vary according to asset types. Governments may not allow provisions to be placed in riskier investments with higher returns, and thus limit the potential rate of growth of the provisions.

Tax treatment of liability funds affects their financial returns. The German government's proposals in 1998 and 1999 to tax spent fuel management funds caused considerable concern among nuclear utilities, who said this would significantly reduce the profitability of nuclear generation. The German finance ministry estimated in May 1999 that changes to the taxation of reserves for future liabilities would cost utilities about $7 billion over ten years (FT, 1999). Utilities estimated the impact of the changes to be twice as large.

Electricity market competition will affect both the technical and financial aspects of plant decommissioning funding. It will tend to reduce the cost of decommissioning through technical improvements. It is likely to put pressure on governments and regulators to establish plant decommissioning requirements that limit open-ended risk in the future. Utilities will strongly resist requests to bear the cost of any stricter closure standards applied retroactively. Regulators may tend to increase the total money collected for plant decommissioning, since they cannot rely on automatic pass-through of the costs to electricity consumers. They may also consider the possibility of faster accumulation of funds. Owners of nuclear plants may wish to proceed more quickly with plant decommissioning than required by regulation in order to limit future liabilities and cost uncertainty.

Electricity market competition will put pressure on those responsible for waste management to improve the efficiency and cost of services for handling, processing and storing spent nuclear fuel and radioactive wastes. Historically the arrangements for dealing with used fuel have been driven by political, administrative and regulatory considerations. Cost is likely to become a more important consideration in future.

To the extent that competition causes some nuclear plants to close before they have accumulated enough money to pay for all their liabilities, competition introduces the question of how to pay for unfunded plant decommissioning and waste disposal expenses. Paying for unfunded liabilities of closed or bankrupt companies is not a problem unique to nuclear power, but the potential size of nuclear liabilities is larger than in most other industries. As in other industries, some combination of public funding and funding by consumers can be used, as decided by political process. The transition to competition reveals the companies where the issue of under-funding must be addressed. Measures to make sure that liabilities are fully covered can be made part of policies regarding payment for stranded costs. This was the case in the United Kingdom, where funds from the Non-Fossil Fuel Levy were used to finance under-funded plant decommissioning and waste disposal expenses. Given the expected competitiveness of nuclear plants in terms of operating costs, the threat of premature closure and consequent under-funding of decommissioning costs does not appear to be great.

Uranium and Nuclear Fuel Costs

Historical Developments

In contrast to fossil fuels, the cost of the raw commodity, uranium, is not the main determinant of generating costs. Table 17 gives fuel cost components for pressurised water and Candu reactors. Nuclear fuel, including spent fuel disposal or reprocessing, typically accounts for less than 15% of total generation costs (up to 25% at lower discount rates). Of this amount, uranium cost accounts for only 20 to 30%. The price of nuclear fuel is most dependent on the cost of nuclear fuel *services*: conversion, enrichment, fuel fabrication and final processing. For heavy water reactors, where conversion and enrichment are not necessary, uranium still accounts for only about half the delivered price of fuel.

Historically, prices of nuclear fuel to utilities have not followed the same patterns as those of fossil fuels. Although the late 1970s and

Table 17

Levelised Nuclear Fuel Cost Components, Pressurised Water and Candu Reactors

	PWR %	Candu %
Uranium	35	54
Conversion	4	n.a.
Enrichment	40	n.a.
Fuel fabrication	21	46

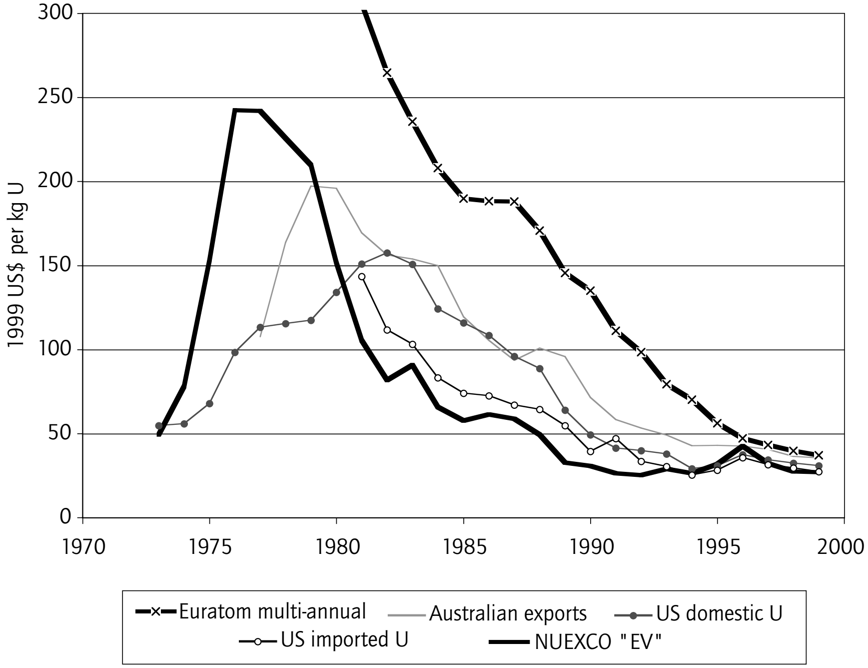
n.a. : not applicable.
Note: PWR values are at a 5% discount rate.
Source: NEA, 1994.

early 1980s saw relatively high uranium prices, fuel prices began falling well before the 1986 oil price countershock.

Figure 19 shows trends in real uranium price since the 1970s, based on a mix of long-term and spot market purchases reported by several sources. Uranium prices differed by a factor of over two throughout the 1980s, but began to converge in the 1990s. Real prices have declined substantially, from over $150/kg contained uranium in 1980 to about $30/kg U in 1996, based on 1990 dollars. The convergence and decline of prices in different markets reflects the gradual movement towards a more integrated world uranium market and increased spot market sales. Uranium prices have declined steadily because of the availability of large sources of "secondary" or stockpiled uranium, the entry of former Soviet Union countries into the international uranium market and supplier concentration, among other factors. Figures 20 and 21 show trends in prices for conversion and enrichment services. Note that these prices do not represent real OECD averages (as do those of Figure 19). Rather, they are nominal estimates in individual markets calculated using different averaging and sampling methods.

Figure 19

Real Uranium Prices in the OECD, 1973 to 1999



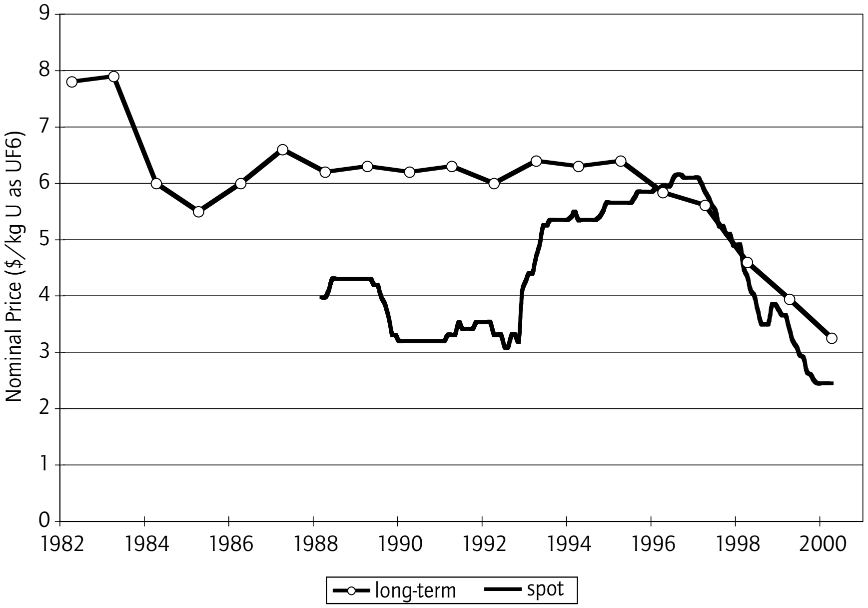
Notes: Euratom prices deflated by OECD Europe GDP deflator. All others deflated by US GDP deflator. Euratom prices are based on multi-annual contracts. Others reflect a mix of spot and multi-annual contract prices.
Sources: ABARE (1999); EIA (2000); Euratom (1999).

They merely give an indication of nuclear fuel services tendencies in recent years.

Until about 1995, prices of long-term contracts for conversion services, as reported by the French fuel services provider Cogema, were relatively steady, from 1.5 to 2 times an indicative spot price. Following the closure of a large US conversion plant (Sequoyah) in 1992, conversion overcapacity was reduced somewhat. Long-term and spot prices have tended to converge and, more recently, both have been decreasing in

Figure 20

Long-Term and Spot Price of Uranium Conversion Services, 1982 to 2000



Sources: TradeTech (2000); Cogema (long-term conversion prices before 1996).

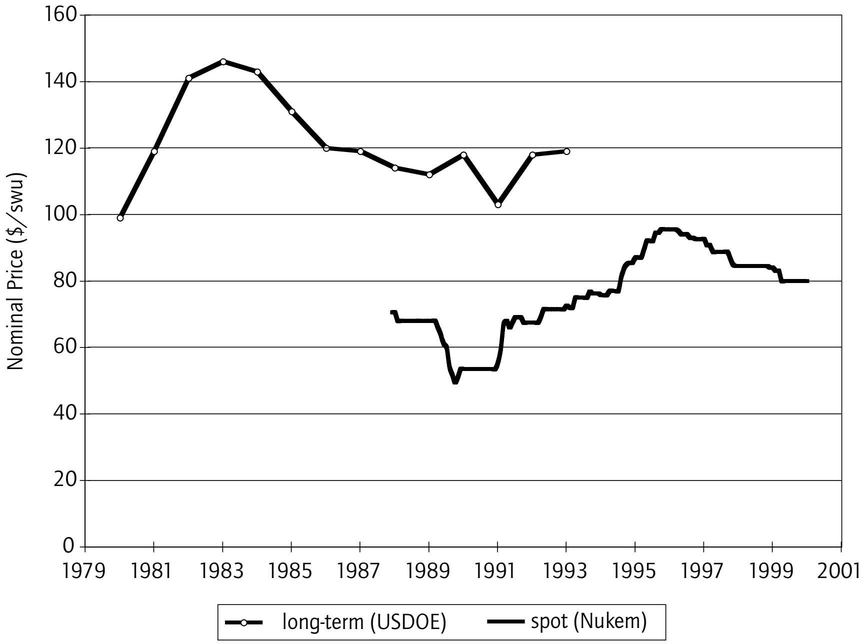
response to the expected arrival of uranium from dismantled nuclear weapons. The conversion market is today a relatively competitive component of the fuel services chain.

Future Prospects

In the coming decade, there need be no concern about the availability or price of fuel cycle services. The general tendency in all parts of the nuclear fuel supply chain is towards the introduction or further development of competition. This, combined with the excess capacity in most parts of the fuel supply chain, suggests that prices will remain

Figure 21

Long-Term and Spot Price of Uranium Enrichment Services, 1980 to 2000



Note: swu ("separative work unit") is a standard measure of uranium enrichment services.
Sources: Nukem (2000), US Department of Energy.

stable or continue to decline. Nuclear competitiveness is not likely to suffer in the near term because of nuclear fuel price rises.

However, the long-term evolution of uranium prices is difficult to predict. There are two key uncertainties. First, nuclear fuel markets have not been fully competitive and are strongly influenced by political decisions. Second, there has been a persistent imbalance in uranium production versus consumption.

The markets for uranium and nuclear fuel supply services have, on the whole, generally not been fully competitive. This is because certain parts of the nuclear fuel supply chain were or continue to be operated by government entities, political decisions can strongly influence supply and costs and there are legal and technical constraints to the emergence of competitive markets. Uranium enrichment has been in the hands of government entities since the beginning of nuclear power. The United States Enrichment Corporation, the dominant supplier with about a third of the market for enrichment services, was privatised only in 1998. The Euratom Supply Agency has the exclusive right to conclude uranium supply or procurement contracts, including enrichment, within the European Union. It exercises this right through formal approval of supply or procurement contracts entered into by commercial entities. Both the United States and the European Union restrict the supply of uranium and the provision of conversion services from states of the former Soviet Union. The United States has agreed to purchase enriched uranium from stocks of highly enriched uranium in former Soviet states. Furthermore, long-term demand projections in the OECD depend strongly on political decisions regarding the continued operation of existing plants and the construction of new ones. The heavy involvement of governments in supplying fuel services introduces an element of political risk.

There has been a historic lack of supply-demand balance in the uranium market. Until the late 1980s, the market was characterised by oversupply, mainly owing to a lower-than-expected growth rate for nuclear electricity generation. After 1990, total world uranium production fell below annual requirements and net stock drawdowns have been 20 000 tonnes or more since 1992. The absence of a long-term equilibrium makes forecasting commodity prices difficult.

An overcapacity in enrichment services has put downward pressure on contract prices, but uncertainties in the enrichment market have tended to increase spot prices since 1991. The 1998 privatisation of the United States Enrichment Corporation, while competition increased among suppliers, is likely to lower prices in the near term as in the availability of surplus military stocks.

The market for fuel fabrication services has in the past been very segmented by reactor type and country, and tightly linked with the vendor of the power plant in which the fuel is used. Fuel fabrication prices vary by a factor of three in Japanese, European and North American markets (Lannegrace, 1998). It is apparent, however, that the market for fuel fabrication services has become more competitive, especially for the supply of fuel for light water reactors, as suppliers are beginning to provide fuel for use in systems not based on their own designs. Persistent overcapacity in fuel fabrication means that prices of fuel fabrication are likely to drop and exhibit less variation by region. The size of the price difference in fuel fabrication services between Europe and the United States has been narrowing quickly in recent years (Anderson, 1998). European prices dropped by some 25% in real terms between 1996 and 1998.

There are relatively few facilities in some parts of the fuel supply chain, so the loss of a single facility could have a big impact on supply. Four facilities provide virtually all OECD uranium conversion capacity (Table 8). Three large plants (Table 9) account for about 85% of OECD enrichment capacity.

Financial Risks of Nuclear Power

Builders and owners of nuclear facilities face financial risks related to the technology of, and the special regulations applied to, nuclear facilities. Risks affect nuclear economics because project evaluations take them into account along with the directly quantified costs of construction and operation. The higher the likelihood that a financial risk will occur in practice, the closer its value to an ordinary cost.

Table 18 lists the major risks for nuclear projects. They include the same types of risks as for other large industrial projects, categorised as non-political or political/regulatory. Because nuclear power plants are capital-intensive, the absolute value of money at risk is large, but is of the same general scale as for other large industrial facilities such as

Table 18

Financial Risks in Nuclear Power Projects

Type	Risk	Examples
Non-Political	**Construction**	
	construction delays	strikes; accidents; management problems
	increased construction cost	sub-standard design; construction errors
	generic defect	steam generator replacement; stress corrosion cracking
	Operating	
	poor plant performance (high cost per kWh)	early gas-cooled plants
	catastrophic failure	Three Mile Island (US nuclear power plant)
	fuel price increase	mid-1970s
	lower revenue than expected	low electricity demand; low electricity price (competitive markets only)
Political/Regulatory	**Construction**	
	construction delays	changes in regulatory requirements; delays in regulatory approval; public protests
	plant modifications required	control room modifications; addition of new systems
	Operation	
	more restrictive permits	equipment retrofits required
	plant shutdown required	Millstone (US power plant)
	denial of permits	see Table 29
	government failure to bear costs	US high-level waste disposal
	changes in requirements for plant decommissioning or spent fuel	accelerated plant closure required; storage of spent fuel required at plant site

Source: IEA.

terminals for liquefied natural gas, refineries, chemical plants or mines. What has differed for nuclear projects, compared to non-nuclear projects, is:

- The large fractions of initial capital investment at risk.
- The greater probability of encountering certain risks in practice.
- The greater risks posed by technology-related issues.
- The greater risks posed by regulatory and political actions.

Risks have, however, differed greatly by country.

Box 1 sets out the issues in more detail. In summary, risks related to technology and those related to regulation and political decisions have been the two main financial risks in nuclear power projects. Technology-related risks should, in principle, be lower in the future because of learning and maturation. Plant designers can avoid leaps in technology that introduce unforeseen technical and safety issues. Regulatory risks are also likely to be lower because of learning, improved procedures for licensing and limitations on the recourse to retroactive application of new regulations. The potential for reducing regulatory risks depends heavily on the system of nuclear plant safety regulation in place in individual countries. Political risk remains a highly variable risk component whose future evolution is difficult to predict.

Box 1

Financial Risks of Nuclear Power

In the 1970s and 1980s, the technology of nuclear power production was still immature. Plant size increased rapidly before operating results from smaller plants were fully assimilated. Two notable plant accidents in the United States in the 1970s (at the Browns Ferry and Three Mile Island plants) and others elsewhere led to a reconsideration of certain technical design assumptions. Generic faults appeared after the earliest plants had been in operation for some time. These factors raised costs for nuclear plants because of technological issues. Nuclear plants cost more than other technologically mature plant types.

The initial period of technological development is complete. The industry has drawn many lessons from past experience. It is unlikely that the same degree of technological risk will be encountered in future projects based on commercially proven plant designs. The nuclear industry is confident that existing nuclear technologies are mature and that financial risks from technological issues will be minimal for future plants. Though probably smaller than in the past, risk from technological problems still exists, as for any plant. For example, the latest series of French N4 reactors introduced in the 1990s have encountered a generic problem of cracking in their safety-related heat removal systems. Other recent French plants have had problems of leak-tightness of the structure housing the nuclear reactor.

Financial risk from regulatory and political sources is the other broad category of risk that affected nuclear economics in the past. The predictability of nuclear safety regulation has been a key issue in some countries. Nuclear investments were committed on a given regulatory basis, this basis changed, and the new regulatory requirements were applied retroactively, in many cases increasing construction or operating costs substantially. Examples include more costly requirements for protection against earthquakes, back-up power in case of a lack of network power, in-depth protection against the possibility of a core meltdown and control systems with better operator interfaces. The speed of nuclear plant development placed difficult burdens on nuclear plant regulators, who were learning at the same time as the power industry itself. Regulators in some cases slowed the pace of granting individual permits in order to consider safety problems that had not previously been fully examined.

Nuclear facilities other than nuclear power plants are also affected by regulatory risk. An attempt to develop a new enrichment plant in the United States was abandoned in 1998, because, according to the developer, the licensing process did not "operate *in a predictable, efficient, and timely manner" (Jensen, 1998). Louisiana Energy Services, the developer, spent seven years and some $34 million before abandoning its effort. A new mixed oxide fuel plant in Hanau, Germany, was abandoned, after even greater expenditures, for similar reasons.*

Plant operators or safety regulators may need to close nuclear facilities until they are in full conformity with regulatory requirements. Plants have been closed, sometimes for long periods, in order to satisfy the safety concerns of owners or of nuclear regulatory authorities. This would be a rare event in most other industries, but in the nuclear field it has been more frequent and continues to be so.

As with technological risks, regulatory risks will probably be lower than in the past because of greater experience and knowledge on the part of regulators and plant operators. Some countries have introduced mechanisms to reduce regulatory risk. For example, the United Kingdom has a system of submitting pre-construction reports to the safety authority. This reduces the likelihood of later changes in regulatory requirements. Germany and the United States have modified licensing procedures to reduce regulatory risk.

Legal or political challenges to plant operation can increase financial risk. Even if nuclear facilities meet regulatory requirements, their operation has often been challenged on the interpretation of those requirements or on wholly separate issues. For example, the Mülheim Kärlich power plant in Germany has not been allowed to operate since 1988 because of lengthy legal disputes over the adequacy of its licence. Local, regional or national political authorities have sometimes forbidden nuclear plant projects. Austria and Italy both required the closure of existing, operable nuclear plants. The Shoreham nuclear plant in New York State never opened, although it was ready to operate, because local authorities did not wish to establish emergency evacuation plans for the surrounding area. Some countries have adopted policies to phase out the use of existing nuclear plants. The probability of political intervention in nuclear projects is clearly higher than for other industrial ventures.

The possibility of realising lower revenue on a nuclear plant investment owing to unforeseen market conditions or market risk is the same for nuclear projects as for any other type of power plant. Baseload electricity demand may not grow as quickly as expected. In the case of competitive electricity markets, electricity prices may be lower than expected. The difference for nuclear plants is that, for a given plant output, the total investment at risk in a nuclear project will typically be larger. This feature is relevant to the magnitude of total financial risk, but not to the probability of encountering it.

The Changing Economic and Policy Context

The economics of nuclear power has so far been examined without discussion of key changes in the wider economic and policy framework within which decisions about operating and building nuclear plants will be taken. Two fundamental changes in recent years are electricity market reform and the steadily growing importance of environmental policy for the energy sector.

Electricity Market Reform

The introduction of competition in the electricity supply sector is an increasingly important factor in nuclear power economics. OECD governments are now deeply engaged in the process of liberalising their electricity markets. The main objective is to improve economic efficiency through lower costs, and to lower electricity prices for consumers. The fundamental shift is from a situation where consumers purchased electricity from a monopoly supplier to a situation that permits end consumers to choose their electricity supplier from competing companies. Table 19 shows the current status of electricity market reform in OECD countries.

One consequence of market liberalisation is that generating companies no longer have a guaranteed market and must examine more carefully the costs and anticipated revenues from the sale of electricity. For existing plants, revenues from electricity sales must be sufficient to cover operating costs. For new plants, revenues must be adequate to cover total generation costs, including the investment costs of the plant. Competition provides generating companies with incentives to reduce their costs and to increase their revenues.

Other Energy Policy Priorities

The promotion of economic efficiency through competition is not the only policy objective being applied to electricity markets by OECD governments. Governments are increasingly conscious of the need to

Table 19

Status of Electricity Market Reform in OECD Countries with Nuclear Power Plants

	1999 Nuclear Generation Share (%)	Retail Market Opening %	
		2001	2003
Belgium	58	35	100
Canada	12	100*	100*
Czech Republic	21	0	40
Finland	33	100	100
France	75	33	35
Germany	31	100	100
Hungary	38	0	36**
Japan	36	30	40
Korea	43	***	***
Mexico	5	0	0
Netherlands	4	35	100
Slovakia	47	0	0
Spain	31	54	100
Sweden	47	100	100
Switzerland	36	****	****
United Kingdom	29	100	100
United States	20	100*	100*

** Wholesale markets are open. Retail market opening at provincial/state level varies from 0 to 100%.*
*** Proposed.*
**** Planned market opening over the period 2001-2009.*
***** Planned market opening over the period 2001-2007.*
Sources: EU Commission and IEA.

ensure costs or benefits to society that do not have a market price attached to them ("externalities") are taken into account in commercial decisions. Indeed, electricity market liberalisation highlights the need to ensure that externalities are properly incorporated into decision-making. By definition, externalities are not incorporated in market decisions unless governments take specific actions.

Two key externalities are environmental protection and energy security, which have traditionally been important to OECD governments and remain so. In fact, environmental protection is steadily increasing in importance. For nuclear power, this is especially relevant. On the one hand, the disposal of radioactive waste has a negative impact on nuclear power economics. On the other hand, the threat of climate change from carbon dioxide emissions works in favour of nuclear power.

These and other policy issues and the implications for nuclear power were explored more fully in Chapter 2. It should be emphasised that the wider economic and policy context is critical to any assessment of the prospects for nuclear power, which will not be determined solely by the specific commercial and financial considerations that have been explored in this chapter.

The Economic Prospects for Nuclear Plants

The Prospects for Existing Plants

The prospects for existing plants are subject to a number of policy factors that will interact with commercial decisions, as discussed in Chapter 2. The following assessment focuses on the economic and commercial dimension.

Operating costs are the major determinant of the competitiveness of existing plants. As noted earlier, the operating costs of existing plants make them generally competitive with fossil-fuelled plants. There has been a worldwide trend towards improved technical performance of nuclear plants which is a key to reducing their operating costs. There are, however, large differences in operating costs both across countries and within countries, so generalisations must be considered with care.

As well as operating costs, other commercial factors will play an important role in the future of existing plants. The first is capital additions. The need for capital expenditures must be considered in the economics of existing plants. Plant owners may undertake capital improvement for several reasons:

- To reduce operating costs and improve competitiveness.

- To increase the output of the plant.

- To carry out projects necessary for the continued safe operation of the plant.

Increasing the capacity of existing plants can provide "new" capacity without incurring the full costs for a new, complete facility. Increased output of existing plants reduces unit operating costs, and the investment to increase plant capacity is often quite small compared to the construction of new power plants. Competition reinforces an existing trend towards capacity upgrades. In Spain, for example, an extra 4% (220 MWe) of nuclear plant capacity was added between 1995 and 1997 from steam generator and turbine upgrades. An additional 7% is expected to be added by 2004. Swedish boiling water reactor power plants using nuclear systems designed by the company ABB have been upgraded to provide a total additional capacity of 600 MWe (Olsson and Haukeland, 1997). US plants designed by Combustion Engineering have increased their capacities by from 2.5 to 15%.

The need to replace steam generators in plants using pressurised water reactors has been the most common refurbishment project requiring large capital expenses in existing plants. The net capacity by which steam generators have been replaced in OECD countries reached 43 GWe in 1999, or 23% of the total capacity of plants with pressurised water reactors. This figure is projected to increase to

65 GWe and 34% of capacity by 2004 (CEA, 2000). Steam generator replacements usually cost from $100 to 200 million, with an average (in 1998 dollars) of $145 million (EPRI, 1997). Other major costs involve replacing reactor or steam system components, replacing control systems and improving safety systems.

There is a strong economic motivation to extend the lifetime of existing nuclear plants in competitive markets. Comparing both investment costs and total generation costs of alternatives, it will in many cases be more attractive to keep existing plants operating than to build new capacity. A regulatory examination or formal licence renewal is needed to extend plant lifetime, the incremental cost of which can be the equivalent of $10 to 50/kWe. Major capital additions or refurbishment are typically in the range of $100 to 300/kWe. These options are still less expensive than the investment cost of new combined-cycle gas turbine power plants, coal power plant refurbishment or new coal-fired power plants. By extending plant lifetime, nuclear plant owners may also delay expenditures on plant decommissioning and associated waste disposal. The difficulties of siting new power plants of any kind add to the advantage of continued operation.

In recent years, many nuclear plants reaching 25 to 30 years of service have been evaluated for continued operation, often in the context of renewal or extension of operating licences. These evaluations suggest that many existing plants can technically continue operation for 40 years of service or longer (Table 20).

As the average age of nuclear plants continues to increase in OECD countries, capital expenditures are likely to be an increasingly important factor in determining the competitiveness of existing plants. As plants age, major repairs or upgrades can be required for them to continue operating. One US study estimated that each additional year of average plant life causes the average annual capital expenditure to increase by $2 to 4/kWe (EIA, 1995). This compares to an average annual capital expenditure in US plants of about $30/kWe in 1993. As plants age, utilities will be faced more frequently with the need to

Table 20

Examples of Recent Nuclear Plant Lifetime Evaluations

	Plant Name	Plant Type	Original Expected Operating Period (years)	Current Expected Operating Period (years)
Finland	Olkiluoto 1&2	BWR	40	60
	Loviisa 1&2	VVER	30	40
Japan	Kepco plants	PWR	40	60
	Tepco plants	BWR	40	60
United Kingdom *	Calder Hall 1-4	Magnox	40	50
	Chapellcross 1-4	Magnox	40	50
United States	Arkansas 1	PWR	40	60
	Calvert Cliffs 1&2	PWR	40	60
	Oconee 1-3	PWR	40	60
	Hatch 1&2	BWR	40	60

** All other British Magnox plants, except one, have been approved for operation of up to 40 years.*
Sources: IEA; utility statements, Finnish Ministry of Trade and Industry.

evaluate the economics of continued operation through a licence review or formal licence extension.

Although capital additions can help existing nuclear plants compete in electricity markets, the need for heavy capital expenditures can also be an important factor in decisions to shut down plants permanently. Of the commercial nuclear plants that have shut down to date for economic reasons, the need for new investment was often an important element of the decision. This was the case in six of the eight large nuclear plants closed in the United States between 1985 and 1998.

A second factor in the future projects of existing plants is consolidation of ownership. In search of operating efficiencies and stronger commercial structures in competitive electricity markets, nuclear plant owners will increasingly:

- Consolidate and create consortia.
- Create nuclear management companies.
- Sell their nuclear units when they own only one.
- Market their nuclear expertise.
- Seek international and regional links.

These strategies will allow companies to share nuclear-specific expertise and facilities and to spread the fixed costs of some nuclear activities over a larger total output. New geographic links help to diversify market risks.

Many of these trends are already evident in the United States, where competition in wholesale electricity markets has been in place since 1996. By early 2001, about 27 GWe of US nuclear capacity, or over a quarter, had been affected by sales, asset exchanges or the formation of joint operating companies (Table 21). Because of the wide variation in operating costs and performance among US nuclear plants, it is likely that ownership changes will lead to operating efficiencies. Consolidation could extend quite far, according to some. Several major US nuclear utilities have suggested that the number of such firms in the United States could drop from around 50 today to ten or fewer. A prominent company among US nuclear plant sales is AmerGen, a joint venture between an American utility and British Energy, the main nuclear generating company in the United Kingdom. In Canada, Ontario Power Generation has agreed to sell a long-term lease of its Bruce A (2 544 MWe net) and B plants (3 470 MWe net) to a subsidiary of British Energy.

Existing nuclear plants are generally in a sound economic position. It is likely that the majority of existing nuclear plants in the OECD will be

Table 21

Consolidations of Ownership or Operation of US Nuclear Plants as of January 2001

Plant Name	New Owner or Operator	Net MWe	Type of Consolidation
Beaver Valley 1&2	FirstEnergy	1 630	asset exchange (498 MWe)
Clinton	AmerGen	930	sale
Duane Arnold	Nuclear Management Co.	520	inter-utility management company
Fitzpatrick	Entergy	816	sale
Hope Creek	PSEG Power	1 031	sale (52 MWe share)
Indian Point 2	undecided	994	sale
Indian Point 3	Entergy	965	sale
Kewaunee	Nuclear Management Co.	511	inter-utility management company
Monticello	Nuclear Management Co.	544	inter-utility management company
Millstone 2&3	Dominion Resources	2 024	sale
Nine Mile Point 1&2	Constellation Energy	1 670	sale
Oyster Creek	AmerGen	650	sale
Palo Verde	Pinnacle West (APS)	3 810	sale (610 MWe share)
Peach Bottom 2&3	PSEG Power, PECO	2 200	sale (328 MWe)
Perry 1	FirstEnergy	1 160	asset exchange (164 MWe)
Pilgrim 1	Entergy	670	sale
Point Beach 1&2	Nuclear Management Co.	970	inter-utility management company
Prairie Island 1&2	Nuclear Management Co.	1 025	inter-utility management company
Salem 1&2	PSEG Power	2 230	sale (328 MWe share)
Seabrook	Great Bay Power	1 150	sale (35 MWe share)
Three Mile Island 1	AmerGen	786	sale
Vermont Yankee	undecided	510	sale
Affected Capacity		26 796	

Note: Not all sales had been concluded as of January 2001.
Source: IEA; GPP, 2001.

able to compete with their fossil-fuelled rivals. There is some debate about how many might eventually be forced to close because of high operating costs. This number is difficult to assess because high-cost plants will be among the first to seek to cut operating expenses in newly competitive markets. Plants with lower operating costs will thrive in competitive markets, and those with high operating costs will either innovate to reduce them or cease operation. Small or old plants, and those requiring large capital additions, will face the biggest hurdles to continued operation. There will be strong incentives to reduce costs, and this will lead to improvements in the way existing plants are operated and managed.

Expected developments in a competitive market may be summarised as follows:

- A reinforced trend towards improved technical performance in all plant operational areas.
- Increased capacity and output.
- Industry consolidation.
- The closure of plants not able to generate at competitive costs.
- The continued operation of the majority of plants.

The Prospects for New Plants

The prospects for new plants are, even more than for existing plants, subject to a wide range of policy factors that will interact with commercial decisions.

The most important economic factor for new nuclear plants is investment costs. New plants must be able to repay their full investment costs. Finding debt and equity investors is possible only if the prospects are good for covering the full costs of operation, including capital investment. The economic requirements for new nuclear plants are therefore very different from those for existing plants.

As noted earlier, capital costs account for a large share of nuclear power's total generation cost. Development times, the cost of capital and the ability to reduce construction costs through economies of scale, are key factors affecting total capital cost. So are survey of scope (a series of plants) and design standardisation.

Over the past two decades, economic decisions on new power plants have largely favoured fossil-fuelled plants. Gas-fired combined-cycle plants have shown the strongest growth rate of any power plant type in the past decade because of falling gas prices and less expensive generation equipment. The capital cost of coal-fired plants has also decreased in many countries, despite more stringent regulations on their emissions. Nuclear therefore currently faces formidable economic competition from other power options.

The 1998 OECD study on electricity generating costs confirms the generally strong competitive position of fossil-fuelled plants compared to nuclear. But the study and past experience show that no single technology is the clear economic choice in all countries. The study results must be interpreted with caution. Many economic factors relevant to new power plant investments vary by country and by region. Examples are labour costs, regulation, industrial structure, domestic equipment supply and, not least, cost of capital. Specific circumstances within each region will determine the most economic choice for new plants.

A 1999 study by the nuclear power subcommittee of the Japanese Ministry of International Trade and Industry found that, at a 3% discount rate, nuclear power could be the least expensive alternative compared to fossil-fuelled or hydroelectric options. The committee found nuclear power to cost ¥5.9/kWh (5.5 US cents/kWh) compared to ¥6.4/kWh (5.9 US cents/kWh) for coal-fired power. A 1997 economic study by the French Ministry of Industry (the "Coûts de Référence Digec 1997") found that nuclear power remains a solid option for baseload generation. The competitiveness of nuclear power was found to depend on the ability to execute a construction programme with one unit coming on line each year over a ten-year period.

The estimated economic performance of nuclear plants reported in recent studies must also be interpreted with caution because, except in a few countries, cost estimates of new nuclear plants are made at an increasing remove from actual experience. Only France, Japan and Korea have had recent domestic experience with new plant construction. Though the plants built in these countries have bolstered technical confidence in recent designs, the conditions affecting construction cost are not necessarily the same as in other countries. Cost studies are, to a greater degree than at any time since the 1970s, dependent on paper designs that have been demonstrated in only a few countries.

The high capital costs of nuclear plants mean that their potential competitiveness depends heavily on their lower fuel costs. Nuclear fuel accounts for less than one-quarter of total generation cost in most estimates. By contrast, fuel can account for half of coal-fired generation cost and three-quarters of gas-fired generation cost. Changes in fossil fuel prices can therefore have a big influence on the competitiveness of nuclear power. Current low natural gas prices have contributed to the rapid development of gas power plants, but higher gas prices would affect the relative economics of gas compared to other power sources. The expectation of increases in fossil fuel price can have a major influence on the relative costs of new nuclear and fossil options.

A further issue is government financial support for nuclear power. This has been extensive, albeit not unique to nuclear power. For example, power generation using coal and lignite has been heavily supported in some OECD countries for reasons of energy security, employment and national strategy. Renewable energy technologies now receive much direct and indirect financial support from governments.

Among other means of support for nuclear power, governments have used the following mechanisms:

- Research and development, including demonstration plants.

- Provision of fuel supply services at subsidised prices.

- Provision of capital at low rates of return.
- Subsidising costs of waste disposal and/or fuel reprocessing.
- Limitation in liability arising from reactor accidents.
- Assistance in clean-up of nuclear wastes and accidents.

These supports, which were very substantial in many cases, have been declining in most countries since the early 1980s. Many past programmes were aimed at reducing the capital cost of dry-well technologies, and at providing the necessary infrastructure for supporting the industry's continued development. As nuclear technology has matured and the industry has developed, the financial role of governments has decreased. The transition to competitive electricity markets tends to reinforce pressure to remove government support for nuclear generators that is not warranted by clear public benefits.

CHAPTER 5

ENVIRONMENT, HEALTH AND SAFETY ISSUES

Introduction

This chapter considers the environmental issues of nuclear power. Like any other form of electricity generation, nuclear power generation can harm the environment or threaten human health. At the same time, it offers environmental advantages compared to the use of fossil fuels, especially in that it does not produce conventional airborne pollutants or carbon dioxide. The environmental implications of nuclear power are extremely contentious.

Plant safety has a unique importance in nuclear power because accidents have the potential to cause severe environmental consequences, much greater than those of other power plants. Any lapses in safety that might allow radioactive materials outside the plant raise both environmental and health issues. For this reason, nuclear safety has historically been given a high priority in nuclear power development.

Environmental and Health Hazards

The potential for harmful releases of radioactive materials is the predominant environmental and health hazard of nuclear power. Radioactive elements (radionuclides) emit particles or electromagnetic radiation that, if absorbed by human tissues in sufficient doses, can cause acute or long-term health problems. The nuclear industry therefore takes special and extensive precautions to minimise the risk of exposing the public or workers to radiation. Radioactive materials are present in all parts of the nuclear fuel cycle and power generation. Radioactive elements can be released into the environment either through normal operations or as a result of accidents. Potential releases of radioactive materials into the environment from nuclear waste disposal must also be considered.

Ongoing Releases of Radioactivity

Ongoing releases of radioactivity as a result of normal operations of nuclear plants and fuel cycle facilities are low and generally judged to be of minimal consequence to the environment and to people. Radiation protection standards have been developed over many years to ensure that ongoing releases result in only small doses to workers or to the public. Allowable doses to workers are similar to those that might be absorbed by individuals living in an area with high levels of natural background radiation. Allowable doses to the public are similar to doses from typical levels of background radiation. In general, estimated doses to workers and the public from civilian nuclear facilities have been well below allowable doses. Radiation protection authorities in OECD countries state that routine radiation releases and their risk to health are minimal.

The main sources of radiation to workers and the public from normal operations are:

- *Mining and milling:* release of radon gas; spread of dust; groundwater contamination.

- *Conversion, enrichment and fuel fabrication:* release of uranium in gaseous and liquid effluents.

- *Power generation:* release of gaseous fission products (noble gases) and contaminated water; low-level waste; decommissioning wastes.

- *Reprocessing:* release of gaseous fission products; liquid effluents; low-level waste.

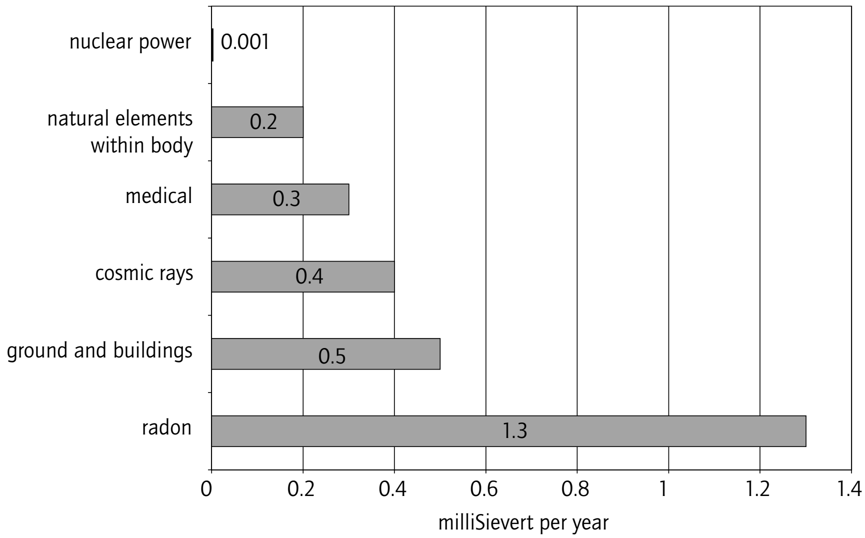
• *Transportation:* radiation from the transport package.

• *Waste disposal:* migration of radioactive elements from the disposal area into the environment, particularly over the course of decades or centuries.

Considering these potential sources of radiation, estimated doses from nuclear facilities account for less than 0.05% of the total dose from natural and medical sources (Figure 22), according to the United Nations Scientific Committee on the Effects of Atomic Radiation. Excluding accidents and local effects, nuclear power's contribution to radiation doses is insignificant. A French study (Dreicer *et al.*, 1995) for the European Commission's ExternE project estimated collective doses for all stages of the nuclear fuel cycle and integrated them over 100 000 years. Under the conditions present in France, including reprocessing of spent fuel, the estimated collective dose is 13 person-

Figure 22

World-Average Annual Individual Radiation Doses



Source: The United Nations Scientific Committee on the Effects of Atomic Radiation, as quoted in NEA (1997a; page 43).

Sievert per TWh. This is equivalent to an annual dose of well under 0.001 milliSievert per individual. Of the total collective dose, 79% was attributable to reprocessing, 17% to power generation, and the 4% remainder to fuel production (including mining), transportation and waste disposal. Radioactive isotopes of carbon, hydrogen, iodine and krypton are the main contributors to public radiation exposure.

Accidental Releases of Radioactivity

Accidental releases of radioactivity are potentially much larger than routine releases and a greater source of concern. Fission products within reactor cores are highly radioactive, and if released through meltdown or explosion of the reactor core, pose serious environmental problems. The need to avoid serious nuclear plant accidents is why nuclear power plants are among the most rigorously designed and controlled industrial facilities of any type. They are built with comprehensive, in-depth systems to prevent release of radioactive elements from the core and to contain them if there ever should be a problem. Where feasible, they have been sited far from densely-populated areas. As experience with nuclear power has accumulated, safety standards have become more stringent and regulatory oversight more complete.

There have been only minor releases of radioactive elements from OECD civilian nuclear installations, both power plants and fuel cycle installations, since the introduction of nuclear power. Even the highly visible accident at Three Mile Island released only minor amounts of radioactive elements, with no significant or even measurable impact on health. There can be no guarantee of absolute safety, but OECD safety authorities are satisfied that nuclear safety regulation makes the risk of damage to human health or the environment from nuclear accidents remote.

Despite the excellent safety record of OECD nuclear power plants and fuel cycle facilities, accidents can and do happen. Table 22 lists some of the most serious events over the past 30 years. Plant designers and safety authorities may overlook the possibility of certain technical failures or human behaviour whose effects could undermine the effectiveness of safety systems. Human error has been the source of many accidents at nuclear facilities, and it is especially difficult to predict.

The worst civilian nuclear plant accident in the world occurred in 1986 at the Chernobyl plant in the Soviet Union. While performing a test of plant systems, plant operators inadvertently brought the reactor to an unsafe state, causing it to explode. A high-temperature fire of the graphite core components ensued. Consequently, a large fraction of the radioactive fission products was dispersed into the atmosphere and around the plant.

Table 22

Selected Nuclear Facility Accidents, 1966 to 1999

Plant Name	Country	Year of Accident	INES* Level
Fermi-1	United States	1966	3
Sellafield reprocessing plant	United Kingdom	1973	4
Three Mile Island	United States	1979	5
Saint Laurent A1	France	1980	4
La Hague reprocessing plant	France	1981	3
Chernobyl 4 (non-OECD)	Ukraine	1986	7
Vandellós 1	Spain	1989	3
Sellafield reprocessing plant	United Kingdom	1992	3
Tokaimura reprocessing plant	Japan	1997	3
Tokaimura nuclear fuel conversion plant	Japan	1999	4

** International Nuclear Event Scale (see Table 28). Events above level 3 are accidents. Level 7 is the most severe.*
Source: International Atomic Energy Agency and Nuclear Installation Safety Directorate (France).

Safety regulators in the OECD believe that the Chernobyl accident resulted from a combination of human error, inadequate design and poor regulatory oversight. Most OECD nuclear plants have a structure to contain radioactive materials within the plant in case of accidents. The Chernobyl plant did not have such a containment structure. The combination of factors resulted in part from a political system that placed too much emphasis on production and not enough on safety. The Chernobyl accident is considered to be one that could not happen in an OECD country.

Reprocessing facilities present special environmental concerns because they handle huge amounts of highly radioactive elements. Spent fuel and fission products, some of which are gaseous, must pass through a complex series of chemical processes. The residues and by-products of these processes are often radioactive and must be carefully contained within the plant. Direct human operation of some equipment is impossible because of elevated radiation levels. Nuclear materials must be handled and stored so as to prevent inadvertent nuclear criticality. Plant operators face many challenges to make sure that there are no inadvertent releases of radioactive elements. Fuel fabrication plants face similar challenges. Five of the ten accidents listed in Table 22 were at reprocessing and fuel fabrication plants. In addition, a further 22 major incidents, including four each at the Sellafield and La Hague facilities have occurred since 1953 (NEA, 1993a).

Disposal of Radioactive Waste

All the steps in the nuclear fuel cycle generate radioactive waste. Radioactive waste disposal presents a potential environmental danger that is difficult to assess, particularly for long-lived and high-level wastes. Even if strict disposal standards and the high quality engineering of disposal facilities render the immediate risks of waste disposal small, it is difficult to demonstrate that future risks are equally small. Estimating radiation exposure over time is not a simple task.

Non-Radiation Hazards

Nuclear power has other potential harmful environmental effects but these are little different from those arising at non-nuclear power plants or industrial facilities. Such "conventional" environmental hazards include:

- Effects of mining.
- Environmental disturbances caused by large industrial sites.
- Thermal pollution from power plant cooling water.
- Leaks of toxic chemicals from fuel cycle and power plant facilities.

Uranium mining generates significant environmental damage. As with much of the production of mineral resources, considerably more waste material is produced than final product. In the case of uranium, open-pit and underground mining yield only approximately one tonne of uranium per 400 tonnes of ore.

The technique of *in situ* leaching extracts uranium ore by percolating a solvent through the uranium bearing rock. Ammonium carbonate and sulphuric acid are common leaching agents. This technique reduces the radiation exposure of workers and avoids the creation of mine tailing heaps, but it increases the risk of groundwater contamination. Heavy metals such as cadmium, arsenic and nickel can be mobilised by the process and enter water supplies. Waste slurries and waste water from the leaching operation must be carefully handled and treated.

Uranium milling produces waste products. For example, barium chloride is used in the treatment of uranium ore to produce yellowcake. Chemical disposal problems and possible groundwater contamination are sometimes associated with milling and ore concentration. As with much of the uranium fuel cycle, there is the possible release (albeit, at this stage in low quantities) of radon and various uranium isotopes.

Conversion and fuel fabrication require the use of toxic chemicals, and can result in possible environmental exposures. Nitric acid, ammonium and fluorine are all used in conversion processes. Small quantities of such chemicals are released during normal operations. Uranium itself has a chemical toxicity comparable to other heavy metals, such as lead. As with most aspects of chemical manufacture, accidents are responsible for a larger share of total releases than normal operations.

The operation of any nuclear power plant creates its own environmental impact. Occasionally toxic chemicals used in normal operations, such as hydrazine or oxalic acid, can be released. Power plant operations can result in local thermal pollution caused by the discharge of large quantities of condenser cooling water. Thermal emissions are a larger problem for nuclear plants than for conventional plants because nuclear plant efficiency is lower and average plant size is greater. Cooling towers may be required to ensure that heat releases do not reach unacceptable levels.

The non-radiological environmental consequences of nuclear energy production can be controlled to the same degree as in other industrial undertakings. Environmental protection authorities, industrial safety authorities and local government all contribute to ensuring that nuclear facilities meet the same standards as other facilities.

Environmental Benefits

Nuclear power has significant environmental benefits compared to some other methods of electricity generation. The most important environmental benefit of nuclear power today is that it does not produce the airborne pollutants that fossil fuels do (Table 23). If strong policies to reduce emissions of greenhouse gases are implemented, the fact that nuclear power production does not produce carbon dioxide will be an important additional benefit.

Table 23

Regulated Airborne Pollutants from Nuclear and Other Energy Sources

	Nuclear (1)	Coal	Gas	Non-Combustion Renewables
Sulphur dioxide	none	X	negligible	none
Nitrogen oxides	none	X	X	none
Particulates	none	X	none	none
Trace metals, VOCs (2)	none	X	none	none
Radioactive gases, dust	X	none (3)	none	none

(1) Emergency diesel generators are tested periodically and release small amounts of sulphur dioxide, nitrogen oxides, particulates, trace metals and volatile organic compounds.
(2) Volatile organic compounds.
(3) Depending on coal characteristics, coal combustion can release negligible amounts of radioactive materials. Radioactive emissions from coal plants are not regulated in any country.
Source: IEA.

Airborne Pollutants

Environmental restrictions on fossil pollutants have become more stringent over time. In most cases, new large coal-fired power plants in the OECD must have special systems to control emissions of sulphur dioxide, nitrogen oxides and particulate matter. Oil- and gas-fired plants often need equipment for control of nitrogen oxides. Although such systems reduce the amount of airborne pollutants from fossil-fuelled plants, new plants will still release residual amounts of pollutants. Nuclear power entirely avoids the environmental effects of residual fossil-fuel pollutants. To the extent that nuclear power displaces generation from older fossil-fuelled power plants without emission control systems, it avoids the release of their pollutant emissions as well.

In terms of resource extraction and transportation, nuclear power has less impact on the environment than other energy sources. Fossil energy sources require the excavation of larger quantities of ore per unit of electrical generation. Generating one TWh of electricity requires only 12 000 tonnes of 0.25% uranium ore, but would require 330 000 tonnes of anthracite coal, not including any associated coal mining wastes or 120 000 tonnes of natural gas. These figures depend on the concentration of energy mineral (uranium or coal) and the amount of mining waste at the particular mines, but in any case the scale of uranium mining is generally smaller than coal mining. The quantities of fuel that must be transported are correspondingly smaller for nuclear power.

Nuclear plants do not produce ash or solid residues from sulphur removal systems, as do solid-fuelled plants. Nuclear plants thus avoid the environmental effects of ash disposal.

Carbon Dioxide

The issue of climate change gives nuclear power an important new potential environmental benefit: because nuclear plants do not produce carbon dioxide, they make an important contribution to limiting greenhouse gas emissions from electricity production. Energy use accounts for about 80% of greenhouse gas production, and electricity production alone accounts for about one-third of worldwide emissions of carbon dioxide. Using electricity generation technologies that do not produce carbon dioxide, such as nuclear power and renewables, can reduce greenhouse gas emissions from power generation. Nuclear power's potential role in climate change policies is discussed in detail in two OECD publications (IEA, 1998; NEA, 1998c).

To curb greenhouse gas emissions, the international community agreed upon the United Nations Framework Convention on Climate Change in 1992. That agreement set non-binding limits on emissions from developed countries. By 1995, however, it was clear that the aim set in the Convention would not be met and that more vigorous actions were needed. These were agreed to in 1997 as the Kyoto Protocol to the

Convention. The Protocol set emissions limits to be achieved by developed countries between 2008 and 2012. To date, only 18 countries have ratified the Protocol. A total of 55 countries producing at least 55% of emissions from developed countries must ratify the Protocol before it enters into force.

Countries have identified various policies that could help to mitigate the production of greenhouse gases. They include:

- Developing or promoting energy sources that produce little or no greenhouse gases.

- Reducing emissions from existing sources through improvements in energy efficiency.

- Setting limits on emissions.

- Increasing taxation of fuels that produce carbon dioxide.

- Providing subsidies to energy sources that produce little or no greenhouse gases and reducing subsidies to energy sources that produce large amounts of greenhouse gases, such as coal.

- Establishing markets for the right to emit greenhouse gases.

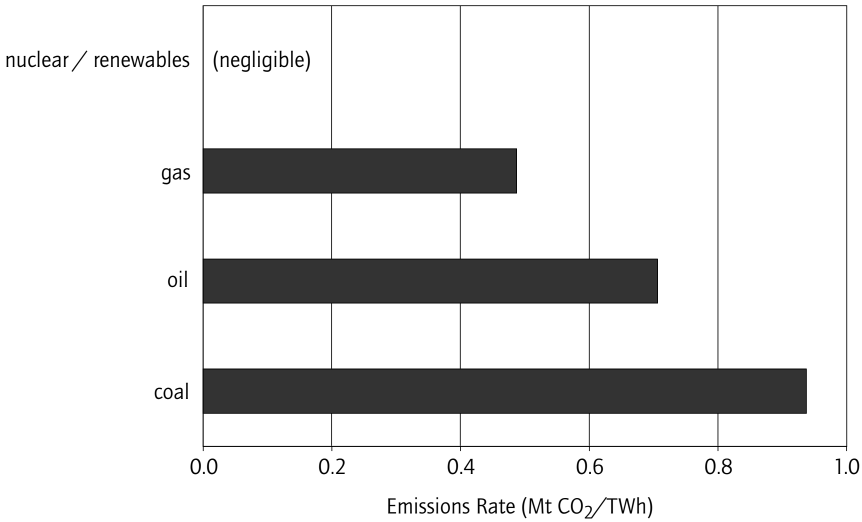
Strong policies to reduce emissions of carbon dioxide and other greenhouse gases effectively place a value on *not* producing them. This has been recognised since the early stages of the climate change debate. Emissions limits at the level of individual producers, such as power plants or automobiles, would implicitly place values on carbon dioxide emissions. Market-based policies such as taxation or the creation of emissions trading markets would make the value explicit. In the case of carbon dioxide emissions from fossil fuel use, the term "carbon value" is appropriate. This is the cost to energy users to emit carbon dioxide or, equivalently, the value of not emitting carbon dioxide.

Nuclear power production would not bear any cost related to reducing the output of carbon dioxide, while fossil-fuelled power plants would. Restrictions on CO_2 production could place coal-fired power generation at a significant cost disadvantage, while favouring first gas-fired power, then nuclear and renewables. The magnitude of nuclear power's potential economic benefit for greenhouse gas reduction depends on the severity of the limits imposed on greenhouse gas production.

Nuclear power has already made an important contribution to minimising CO_2 production. Figure 23 shows average OECD emissions of carbon dioxide per unit of generation from fossil-fuelled power plants. Nuclear power and renewables produce negligible quantities of carbon dioxide, while coal-fired generation produces an average of over 0.9 Mt/TWh, or over 6 Mt per year from a 1 000 MWe plant. With nuclear power, OECD emissions of carbon dioxide have decreased to an average of about 0.45 Mt/TWh, as shown in Figure 24. In the absence of nuclear power, coal-fired and gas-fired power plants generally would

Figure 23

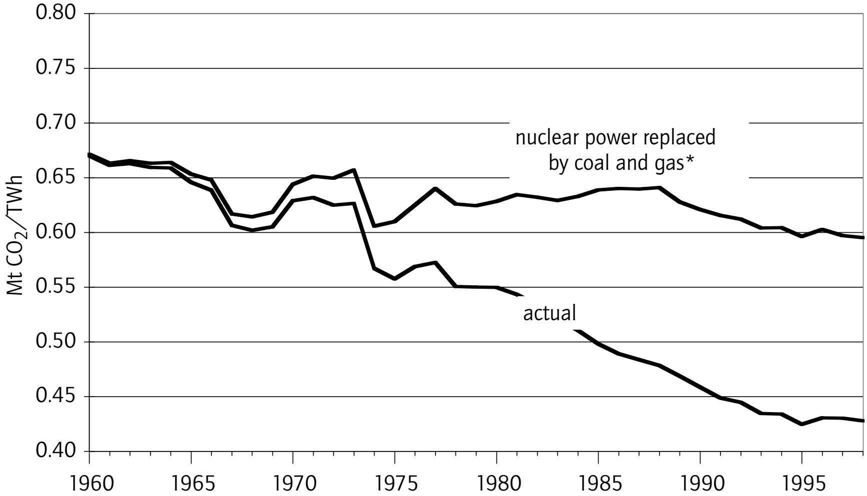
CO_2 Emissions by Electricity Generation Source in the OECD, 1998



Note: A 1 000 MWe power plant operating at 80% capacity factor produces about 7 TWh per year. An estimate of annual CO_2 emissions from an "average" OECD power plant can be obtained by multiplying the source-specific numerical value in the figure by 7.
Source: IEA.

Figure 24

Effect of Nuclear Power on CO_2 Emissions per TWh in OECD Countries, 1960 to 1998



** Three-quarters of nuclear power is assumed to be replaced by coal-fired generation of 43% gross efficiency; one-quarter is replaced by gas-fired generation of 51% gross efficiency. Values prior to 1971 are based on IEA countries.*
Source: IEA, CO_2 Emissions from Fuel Combustion, 1999 Edition*; Secretariat calculations.*

usually have been the preferred options. If these had substituted for nuclear power over the past 30 years, carbon dioxide emissions from power production would be about one-third higher than they now are with nuclear plants in service.

Key Issues

Radioactive Waste Disposal

The objective of any approach to radioactive waste disposal is to minimise the risk that radioactive elements could escape into the environment and expose humans to radioactivity.

For purposes of disposal, one of the most relevant waste characteristics is the length of time needed for the radioactivity to decay, as measured by the "half-life" of its constituent elements. The half-life of a radioactive element is the time needed for the radioactivity to decrease to one-half its initial value. The decrease of radioactivity is exponential, so it decreases significantly as the number of elapsed half-lives increases. Waste can be considered to be "short-lived", meaning that negligible radioactivity remains after several hundred years, or "long-lived", meaning that substantial radioactivity remains after several hundred years. Short-lived waste can be disposed in waste disposal facilities whose protective features to isolate radioactive materials from the environment can be adequately predicted over the course of several centuries. On the other hand, long-lived wastes require disposal facilities with much more elaborate features because the engineering, geological and even human behaviour surrounding the waste is difficult to project over millennia. Similarly, the concentration of radioactivity can be high-, medium- or low-level.

More than 95% of the total radioactivity in radioactive wastes is from high-level waste, but high-level waste accounts for less than 5% of the total *volume* of waste. Low-level and intermediate-level waste account for relatively little radioactivity, but most of the volume.

High-level Wastes

High-level wastes are generated mainly from the fission of uranium and plutonium and by the creation of elements heavier than uranium, the "transuranics"[6]. Fission products amount to 3 to 4% of spent fuel, and the transuranic elements constitute about 0.1% of spent fuel. Fission products are highly radioactive and release heat continuously, but do so for a relatively short period – tens or hundreds of years. They typically require cooling to keep waste temperatures from rising.

6. Discussions about high-level waste often refer to actinides. The actinides include all the transuranic elements (the elements heavier than uranium) as well as thorium, protoactinium and uranium.

Transuranic elements typically have less intense radiation and release little heat, but remain radioactive for thousands of years.

If spent fuel is not reprocessed, its entire volume is considered as high-level waste. If it is reprocessed to separate out the fission products and transuranics, only the smaller volume containing these elements is treated as high-level waste. A typical 1 000 MWe nuclear power plant produces 10 m^3 of spent fuel per year. If this spent fuel is reprocessed, about 2.5 m^3 of concentrated waste is produced. Today, spent fuel and high-level wastes are stored at power plants, in special-purpose interim storage facilities and at reprocessing facilities.

Table 24 provides some estimates of the amounts of spent fuel accumulated in OECD countries.

Deep geological disposal of high-level waste is the option in which scientists and engineers place the greatest confidence. This involves treating the waste, if necessary, to put it in a suitable chemical and physical form, packaging it in long-lived engineered barriers and placing these in deep, stable geological formations. High-level waste resulting from reprocessing is typically mixed with a glass substance or rock-like ceramic to immobilise the radioactive elements and reduce any potential for leaching. A recent NEA publication summarises progress towards geological disposal of radioactive waste (NEA, 1999e).

Various other options for high-level waste disposal have been explored in the past 40 years. Different projects assessed disposal in deep oceanic seabed sediments, very deep boreholes, polar ice caps, geological subduction zones and outer space. None of these methods was found to be satisfactory in terms of all the relevant factors, including cost, risk, political issues and legal constraints. There is now a technical consensus that geological disposal is the best method among the many studied over the years. Geological disposal is a passive system that does not rely on continuing human involvement for safety. It places wastes deep enough to minimise the possibility of later human contact, is applicable in a variety of geological formations and takes advantage of existing mining technology.

Table 24

Estimated Quantities of Spent Fuel in 1999 – Annual, Total in Storage and Storage Capacity

	Amount Arising in 1999 (tonnes heavy metal)	Total in Storage (tonnes heavy metal)	Storage Capacity (tonnes heavy metal)
Belgium	78	1 030	3 830
Canada	1 200	5 248	37 738
Czech Republic (1)	43	614	600
Finland	74	845	1 530
France (2)	1 205	8 217	22 230
Germany	430	2 933	14 100
Hungary	50	453	668
Italy	0	233	316
Japan	1 088	7 029	13 214
Korea	480	4 153	8 425
Mexico	22	80	984
Netherlands	12	27	73
Spain	194	2 250	4 890
Sweden	232	2 980	6 500
Switzerland	64	150	905
United Kingdom	788	4 729	13 568
United States	2 300	40 645	62 685
Total	10 259	81 616	192 256

(1) Czech storage capacity represents only the AFR storage facility and does not include on-site spent fuel storage.
(2) French spent fuel in storage represents unreprocessed spent fuel and spent fuel from French nuclear plants in storage pools at La Hague reprocessing plant.
Sources: NEA, Nuclear Energy Data 2000, *Table 9 (columns 1 and 3); International Atomic Energy Agency, Nuclear Fuel Cycle and Materials Section (column 2).*

A wide technical consensus exists among the scientific and technical community on key aspects of geological disposal (NEA, 1999e):

- There is a high level of confidence that geological disposal is technically safe.

- That the time needed to implement geological disposal was estimated too optimistically in the past.

- That the technology for constructing and operating disposal sites is mature enough for deployment.

- That significant progress has been made in the past decade regarding the scientific understanding and technology required for geological disposal, but further scientific and technical work will need to continue over decades to refine, test, demonstrate and implement it.

With the exception of only a few countries, generally with small nuclear capacity, countries with nuclear plants continue a variety of development programmes in high-level waste disposal (Table 25). These programmes have made substantial progress on a technical front. Seven "generic" underground rock laboratories for high-level waste disposal have been operated in the OECD and two laboratories (Gorleben in Germany and Yucca Mountain in the United States) are located at potential waste disposal sites. Many site characterisation studies have been carried out, including some where boreholes and tunnels have been dug in representative geological formations. The design of engineered barriers such as metal canisters has advanced, and mathematical techniques for assessing safety have been developed and improved. In parallel, the technical basis for regulation of long-term disposal sites has been developed. Programmes for the disposal of spent fuel appear to be most advanced in the United States, Finland and Sweden.

In the United States, the Yucca Mountain site has been studied since 1987. Up to September 1999, about $3.2 billion had been spent on studies at the site, including drilling of tunnels for access and experimentation. A recommendation to use the site for disposal of

Table 25

National Programmes for Disposal of High-Level Radioactive Wastes

	Earliest Date for Waste Facility Operation	Reprocessing?*	Status/Comments
Belgium	2035	Yes	Research programme since 1974, in co-operation with France. Underground research laboratory at Mol in 1984. Siting studies and demonstration operations for a geological disposal facility to continue until 2015.
Canada	2025	No	Underground research laboratory in Manitoba opened in 1990. Search for sites under the "granite shield" programme halted in 1998 following an independent environmental assessment. Currently developing a new disposal facility concept.
Czech Republic	2035	open **	Disposal facility concept to be developed.
Finland	2020	No	Four sites undergoing detailed site investigations. Municipality of Eurakoji voted to support disposal facility.
France	2020	Yes	Original site selection programme abandoned in 1990. The site of a disposal laboratory facility in clay was chosen in 1998 and is to be developed by 2003. A second facility in granite is to be sited and developed.
Germany	2008	Yes	Geological studies began in the 1960s. Asse salt mine used as underground laboratory since 1965-1995. Developing a disposal site in salt formation at Gorleben since 1979; progress currently stopped due to intense opposition.
Hungary	2050	open **	Investigating suitability of clay site in the Mecsek Mountains.
Italy	no target	No	Several studies in the 1970s and 1980s on disposal in clay. Little activity in recent years.
Japan	2030 to mid-2040s	Yes	Horonobe underground research facility proposed in 1984 but not developed; Mizunami underground research facility proposed in 1995 and is under preliminary development. The "Specified Radioactive Waste Final Disposal Act" was legislated in June 2000. Under the Act, the Nuclear Waste Management Organization of Japan (NUMO) was established in October 2000 as an implementing organisation for geological disposal.

Table 25

(continued)

	Earliest Date for Waste Facility Operation	Reprocessing?*	Status/Comments
Korea	no target	No	Centralised storage until a disposal site is developed.
Mexico	no target	No	On-site storage until a disposal site is developed.
Netherlands	no target	Yes	Research programme on disposal options since 1984. Since 1994 the programme focus has been on retrievable storage. No sites identified.
Spain	no target	No	Research programme since 1987. Decision on disposal facility to be made in 2010. Current focus is on a centralised, interim storage facility
Sweden	2020	No	Siting investigations since 1977; parallel research programme. Stripa underground research lab operated from 1976 to 1992. Äspö underground laboratory opened in 1994. A disposal canister test facility was opened in 1998.
Switzerland	2050	Yes	Deep geological concept developed in the 1980s. Underground laboratory work at Grimsel since 1984 and Mont Terri since 1998; siting investigations continue.
United Kingdom	2040	Yes	Plans for an underground disposal laboratory abandoned in 1997. Programme to build a geological disposal facility is under review.
United States	2010	No	Various research programmes since the 1960s. Investigation of Yucca Mountain since 1987. Positive viability assessment of Yucca Mountain published in 1998.

** "yes" in the reprocessing column means that reprocessing is currently carried out or planned for at least a portion of spent fuel from civilian power plants. ** The government of the Soviet Union agreed to accept spent fuel from Czechoslovak and Hungarian nuclear power plants. It intended to reprocess the spent fuel and dispose of high-level wastes. Russia may still accept spent fuel for reprocessing, but would in this case return high-level waste to each country.*
Sources: NEA (1998d); Richardson (1999); IEA.

high-level wastes could be made by 2001 and some believe that wastes could be placed there by 2010, although the US Government Accounting Office has identified a number of impediments to meeting this schedule (GAO, 1997).

In Finland, the company responsible for spent fuel disposal, Posiva, has performed environmental impact assessments for four sites, including detailed geological studies. In June 1999, Posiva applied to the government for a decision in principle on the plans for the spent fuel disposal facility to be situated at the Olkiluoto site in Eurakoji. In January 2000, the community of Eurakoji agreed to host this facility. The preliminary safety assessment performed by the Radiation Protection and Nuclear Safety Authority did not show any deficiency that might hinder the decision.

The Swedish Nuclear Fuel and Waste Management Company, SKB, has a well-developed technical concept for spent fuel disposal. It involves the use of copper and steel canisters placed in granite bedrock. SKB has testing and development facilities for the canisters (in Oskarshamn) and for the disposal facility (in Äspö). The company has eight site feasibility studies in progress or completed and expects to carry out detailed studies at two sites beginning in 2001. The Swedish approach is notable in the prominence it places on involving potentially affected municipalities and developing public understanding as early as possible.

The wide *technical* consensus on the adequacy of geological disposal of high-level waste is not reflected in views of the broad public or of some political bodies. Grave doubts have been expressed about the long-term risks of radioactive contamination of the human biosphere from high-level waste sites, and about loss of control over the fate of the wastes. The greatest environmental risk from high-level waste sites is that radioactive elements would eventually come in contact with water over time, leach and be carried out of the waste site. It is not easy to demonstrate that radioactive wastes will remain isolated from human contact for tens of thousands of years. Physical characteristics of engineered barriers and the geological behaviour of disposal sites cannot be predicted with absolute certainty over such long periods. Human institutions cannot be expected to afford continuous protection against intrusion into waste sites or even to remember where they are. Much of the public is not yet convinced that performance standards, licensing procedures and waste sites as finally developed can offer a satisfactory level of long-term safety.

In recent years several existing programmes for geological disposal of high-level or long-lived wastes have been re-evaluated or rejected. For example (NEA, 1999e; Seaborn, 1998):

- In 1997, the UK environment minister rejected the planning application for construction of a "rock characterisation facility" at Sellafield. This left the United Kingdom without a practical plan for the disposal of long-lived radioactive waste.

- In 1998, a Canadian environmental panel convened by the federal government, after eight years of study, concluded that "from a technical perspective, the safety of the [geological disposal] concept has been on balance adequately demonstrated for a conceptual stage of development, but from a social perspective it has not." The concept "has not been demonstrated to have broad public support [or ...] the required level of acceptability to be adopted". The panel recommended developing a framework for an ethical and social assessment and creating an agency specifically charged with handling spent nuclear fuel.

No country today has an operating disposal site for high-level wastes, nor is any realistically expected to have one before 2020 except in the United States. In some countries, waste disposal programmes are in political or administrative deadlocks. The US waste site is nominally scheduled to open by about 2010. There is one deep geological disposal facility for intermediate-level *military* wastes in the United States, the Waste Isolation Pilot Plant. Though interesting, this facility is not necessarily a model for civilian high-level waste disposal because it excludes heat generating, high-level waste or spent fuel of the type resulting from civilian power production. It was granted an operating permit under site-specific procedures for the disposal of military wastes.

A consensus-building process for implementing waste disposal programmes has been hard to find. The public as well as a wide technical community must have confidence in their ethical, economic and societal aspects, and that the organisational structure, legal framework and regulation provide an acceptable path to decision-making. As early as 1985, the US Office of Technology Assessment (OTA, 1985) noted that "distrust may indeed be the single most complicating factor in the effort to develop a waste disposal system that is acceptable technically, politically and socially." Experts in radioactive waste management cannot alone decide on disposal strategies. In recognition of this, Canada, France, Germany, Japan, the Netherlands, the United Kingdom and the United States have all modified their waste disposal programmes to incorporate wider political and consultative processes. Some countries have also established or reorganised waste disposal entities, often detaching them from organisations responsible for other aspects of nuclear power development and promotion. This was done or is planned in Canada (2000), the Czech Republic (1997), France (1991), Japan (2000), Spain (1984) and the United States (1983).

Other factors have also contributed to the delay. Early schedules for developing geological waste disposal sites were often over-optimistic. An example is the 1971 guidelines issued by the US Atomic Energy Commission. This document directed that all high-level wastes were to be solidified within five years of production and buried within ten years (Davis, 1971). Unrealistic implementation schedules cause a disposal programme to focus on inappropriate milestones and deadlines for work that is fundamental for later progress. Work that is rushed may have to be redone, thus increasing the total time needed for the programme.

The long time needed for radioactive wastes to decay raises ethical issues. In recent years, a greater emphasis on sustainability has focused attention on minimising the potential burden of long-lived radioactive wastes for future generations. The interests of those living near waste disposal sites should be taken into consideration, and the disposal method should not place a burden on future generations, foreclose their options or hinder their ability to make decisions. No individuals should unfairly bear a greater burden for waste disposal than others, at least without some compensating benefit. Applying these principles practically has proven challenging.

Finally, the potential use of plutonium recovered from waste sites is a factor. If spent fuel or separated plutonium are placed in waste disposal facilities, there is a potential danger that the waste storage facility could become an illicit plutonium mine in the future (Oi, 1998; NEA, 1977: p. 37). Spent fuel is difficult to handle for at least 100 to 200 years because of its high radioactivity. Reprocessing spent fuel poses considerable technical challenges that make spent fuel a relatively unattractive source of plutonium. After an initial period of cooling, however, spent fuel could be manipulated with greater ease. Plans for geological disposal must take into account the probability that plutonium might be extracted in the future for nuclear weapons. If separated plutonium were not processed, it would pose a greater potential threat of proliferation. Special measures would have to be taken to reduce its utility in weapons or accessibility. However, it is also argued that it would be inappropriate to place spent fuel in a disposal site from which later recovery was impossible or prohibitively expensive, because governments or utilities might wish to recover plutonium for its energy value in the future.

The absence of permanent disposal sites has not, so far, created a bottleneck for power generation, because temporary or provisional storage facilities have been built to safely hold high-level wastes. From a long-term technical perspective, there is no urgency about developing high-level waste sites. The longer spent fuel and high-level wastes are stored before final disposal, the cooler and the less radioactive they become. Spent fuel remains conveniently accessible for reprocessing, if needed.

Keeping high-level wastes in temporary storage facilities can pose some *immediate* problems, however. In countries without central storage facilities or with transportation bottlenecks, nuclear power plant operators can face problems in finding sufficient storage space for spent fuel. This has been an acute problem in the United States, where the US government failed to take possession of utility spent fuel stocks in 1998, as required by law. Utilities have responded by storing their spent fuel in dry casks and by using denser arrangements of spent fuel in on-site cooling pools ("re-racking"). In Germany, the 1998 ban on waste shipments led six nuclear plants to plan for increased on-site storage of spent fuel. Belgium, Germany, Japan, Switzerland and the Netherlands have reduced the quantities of waste that must be handled domestically in the near term by taking advantage of processing time and waste storage capacity in foreign reprocessing plants. As of 1999, the French reprocessing plant had returned only 250 (less than 2%) out of 16 000 containers of reprocessed fuel to their foreign owners.

Governments and utilities have come under increasing pressure in recent years to "do something" about spent fuel and high-level waste. French and British reprocessing companies have been criticised for holding stocks of wastes belonging to utilities in other countries. There is pressure to demonstrate reduced risks to security and nuclear proliferation by implementing final waste disposal plans as early as possible. Several legislatures have debated laws forbidding nuclear plant development until there is a clear solution to the problem of high-level nuclear waste.

The search for politically acceptable solutions continues. It has led to discussions of new concepts for disposal facilities and the exploration of technical alternatives apart from geological disposal. These include "retrievability", waste "transmutation" and international waste disposal sites (see Box 2).

Box 2

Retrievability, Transmutation and International Waste Disposal Sites

Retrievability *has become a common concept in high-level waste management. It means that high-level wastes, particularly spent fuel, should be retrievable in the future. The reasons for this retrieval could be either to remove the waste if the waste facility is failing to adequately isolate radioactivity, to apply new waste disposal concepts, or to recover valuable nuclear materials. The potential application of new disposal solutions is perhaps the strongest argument. It is argued that we should not presume to know with absolute certainty today what will be considered an indefinitely acceptable solution. Our current high-level waste disposal programmes may be considered as no more than the first step by people in the future.*

There has been considerable debate about "monitored retrievable storage". In this concept, high-level wastes are kept indefinitely in monitored storage facilities. This approach has the reassuring characteristic that protective barriers can be constantly monitored to prevent the escape of radioactivity, but it places a substantial burden on future institutions to manage responsibly. It seems unlikely that long-term monitored storage could provide an acceptable solution.

Transmutation *is the process of changing, by nuclear reactions, long-lived radioactive elements into short-lived elements. It could theoretically minimise the need for long-term geological disposal sites. Use of transmutation would considerably decrease the cost of building disposal sites and demonstrating their safety. Before transmutation can be used, long-lived radioactive elements must be separated from waste. This "partitioning" would extract the long-lived radioactive isotopes that contribute the most to long-term health danger, notably neptunium, americium, curium (transuranics), technetium, iodine and caesium (fission products). Chemical processes similar to those used in nuclear fuel-reprocessing plants would be required to effect the separations. Once separated, the elements could be placed in special purpose reactors or in existing thermal reactors.*

Though technically interesting, transmutation does not offer any near-term hope for a quick or inexpensive solution to the disposal of high-level wastes (NEA, 1999d; NRC, 1996). The volume and toxicity of waste can be reduced, but the length of time over which high-level wastes remain hazardous would not be significantly shortened. Many decades or, more likely, centuries would be needed before the total radioactive toxicity of wastes and material within the fuel cycle would begin to be reduced. The costs for an advanced fuel cycle to transmute and reduce the volume of long-lived isotopes would be (optimistically) 30-50% higher than that for "simple" reprocessing. A fleet of special-

purpose fast reactors would be needed. A 1999 US study estimated that transmutation of the total projected amount of US spent fuel, using accelerator transmutation, would cost $280 billion over 117 years and would not eliminate the need for a geological disposal site.

International waste disposal sites *are a third possibility. The idea is to accept high-level wastes from countries other than the one in which the site is located. The site could be in a country with no nuclear power facilities. This is feasible since the absolute quantities of high-level wastes produced are such that a single disposal site could hold the wastes from several or many countries. International sites would help to reduce the proliferation of disposal sites, would be a welcome solution for countries with only a few nuclear plants. Given the expense of developing any site, the economic arguments for international sites are strong. An NEA expert group recommended the use of international disposal sites two decades ago (NEA, 1977) and the concept resurfaces frequently in international forums on waste disposal (McCombie, 1997). Mounting frustration among utilities and governments with the slow pace of developing waste disposal facilities may indeed favour renewed examination of the concept of international waste sites. But for all its advantages, the idea is politically very sensitive. There is an acute sensitivity about appearing to "dump" nuclear waste in foreign countries, especially in non-OECD countries.*

Pangea Resources, a company supported by British Nuclear Fuels Ltd. (70% ownership) and the Swiss radioactive waste disposal co-operative, is developing a concept for an international waste disposal site. This company has identified four countries having desert regions with suitable climatic and geological conditions: Australia, Argentina, China and South Africa. It envisions a dedicated fleet of 70 ships and transport infrastructure to bring waste from around the world to the disposal site. The Australian Federal Government is resolutely opposed to the application of the Pangea concept within Australia. The Western Australian Senate have unanimously passed a motion opposing the concept.

In 1999, a group of US and German companies created the Non-Proliferation Trust to pursue, with the Russian ministry of atomic energy (MINATOM), the development of an international waste storage site in Russia. After a period of storage in Russia, spent nuclear fuel from OECD countries could be returned to the country of origin, reprocessed, or disposed of in a Russian disposal site. The United States is opposed to any option involving spent fuel reprocessing. The lower house of the Russian Parliament passed a law in late 1999 that, among other things, allows for the creation of regional (i.e. international) storage facilities and disposal sites for high-level radioactive waste, but the Russian upper house voted down a similar bill in early 2000.

Low- and Intermediate-level Wastes

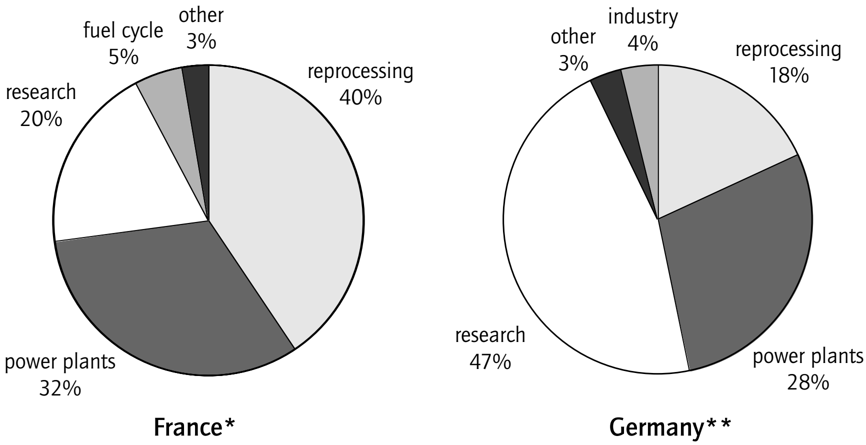
Low-level waste consists of uranium mine tailings, enrichment plant effluents, liquid and solid wastes from fuel manufacture and reprocessing, lightly contaminated equipment, clothing and supplies, and waste from plant decommissioning. Intermediate-level wastes are produced in power plants and reprocessing plants. Filters, chemical-processing resins, fuel rod casings and metal from spent fuel assemblies are examples of this type of waste.

In most countries with nuclear power, nuclear power production accounts for the majority of low-level and intermediate-level wastes. Medicine, industry and research also produce such wastes.

Figure 25 shows sources of low- and intermediate-level waste in France and Germany. A 1 000 MWe nuclear plant typically produces between 100 and 200 m^3 of low-level wastes each year.

Figure 25

Sources of Low-Level and Intermediate-Level Radioactive Wastes



**Disposed at the Aube Disposal Centre in 1996.*
***Stock at end 1995. Data refer to conditioned waste with negligible heat generation.*
Source: NEA, 1998d.

Low-level solid wastes are typically packaged in steel drums, buried in shallow trenches or engineered facilities just below ground level, and compacted to reduce volume and increase stability but otherwise untreated. Some countries use engineered facilities such as concrete-lined trenches or vaults. Deep disposal of low-level wastes has also been carried out or is planned. The facilities can be excavated specifically for the purpose, or can be disused mines or tunnels where the cost of excavation is minimal or nil. Low-level liquid wastes are solidified or bound to solid adsorbents to facilitate disposal in solid-waste disposal sites.

The Czech Republic, France, Hungary, Japan, Spain, the United Kingdom and the United States operate surface disposal facilities for low-level waste. Finland, Norway and Sweden operate geological disposal facilities for low- and intermediate-level waste. In Germany, low- and intermediate-level wastes were disposed of in the Asse salt mine between 1967 and 1978, and in the Morsleben salt dome between 1981 and 1998.

Sea dumping of packaged low-level wastes was used until the early 1980s, but this is now prohibited by international agreement. Low-level liquid effluents from the French and British reprocessing plants are sent into ocean waters through pipes. This practice came under scrutiny in 1998 during negotiations on the Ospar Treaty concerning marine environmental protection. The treaty now requires radioactive liquid effluent discharges to be reduced to near zero by 2020. Although the Cogema reprocessing plant at La Hague has reduced its sea discharges of liquid effluents by a factor of 150 in the last ten years, the treaty result indicates that almost any level of sea disposal has become unacceptable. British Nuclear Fuels believes that the treaty requirements will be technically difficult to attain, but feasible.

Intermediate-level waste disposal requires more elaborate safety precautions. Intermediate wastes may be incorporated into concrete, bitumen or plastics, then packaged in concrete or steel casks. These waste packages may be placed in deep trenches or in geological facilities. Most intermediate-level wastes are currently placed in interim storage buildings since only a few final waste sites have been developed. The disposal methods envisioned for high-level wastes, namely geological disposal, are being considered for intermediate wastes as well. The few operating waste sites for intermediate-level wastes use geological disposal.

Uranium mining and milling wastes are low-level wastes present in large quantities in OECD countries, though they are small compared to other mining wastes such as those from coal or mineral ores. They are 50 to 100 times more voluminous than all other radioactive wastes combined. Although their radioactivity is similar to that of natural uranium, they are, unlike natural uranium, on the earth's surface, closer to human activities, and in a pulverised form. They generate radon gas, dust and contaminated rainwater streams. Tailings may contain other chemical toxins such as arsenic or lead. The OECD countries most concerned with mining and milling wastes are Australia, Canada, the Czech Republic, France, Germany, the United States, and, to a smaller extent, Belgium, Hungary, Portugal and Spain. An OECD Nuclear Energy Agency report discusses environmental activities at uranium mining and milling sites (NEA, 1999f).

Currently operating uranium mines and mills are required to manage wastes during and after their operational lives in a way which minimises risks to public health. Current and planned environmental protection measures are expected to ensure that health risks are negligible. On the other hand, wastes from operation of mines and mills in the past have been under increasing scrutiny. Generally, they have not yet been disposed of in a permanent way and may constitute a long-term problem. The health risk from past mining and milling wastes can be reduced by restoration projects. These schemes aim to minimise potential exposure to radiation by stabilising, protecting or relocating the wastes.

The fate of "depleted uranium" has come under greater scrutiny in recent years (UI, 1996). At the end of 1995, there were 667 000 tonnes of depleted uranium in OECD countries, most of which is stored as uranium hexafluoride in steel cylinders. This is a convenient form for storage periods of several decades, but not for final disposal. Enrichment plant operators have stored the depleted uranium because it can be used for the manufacture of mixed oxide (MOX) fuel. It will also represent an energy source if breeder reactors come into operation. However, breeder reactors are not likely to appear any time soon, so enrichment plant operators must decide whether depleted uranium hexafluoride should be converted back to a more stable uranium oxide or uranium metal form suitable for indefinite storage or disposal. About two-thirds of French depleted uranium is already in the form of uranium oxide. The United States Department of Energy programme for the management and conversion of depleted uranium hexafluoride, published in July 1999, is estimated to cost between $3 and 4 billion. The depleted uranium was produced from enrichment for both civilian and military purposes.

Existing sites for low-level wastes are becoming increasingly more expensive to operate and new sites are more difficult to find. No new US low-level waste disposal facility has been developed since 1971 despite public expenditure of some $600 million on ten candidate sites (GAO, 1999). Industry has implemented improved waste management procedures, scrap metal recycling, waste compaction and other methods that have steadily decreased the volume of low-level waste produced. Volumes of low-level waste generated in OECD nuclear plants have typically been halved in the last 15 years. At present, the lack of availability of low-level waste sites does not pose a bottleneck to civilian nuclear power generation.

In the future, large plant decommissioning programmes will produce relatively large quantities of low-level waste. The current capacity of operating low-level waste facilities is insufficient to accommodate the decommissioning waste from nuclear power plants and other nuclear facilities (NEA, 1996c: p. 13). Plant decommissioning programmes will require increases in the capacity of existing disposal sites and the opening of new facilities.

Increasingly stringent limits on radioactive emissions and political constraints on waste disposal will continue to raise the cost of disposal options. The same is true of other forms of power generation and industry in general.

Transportation of Nuclear Material

The volume of radioactive materials transported is small compared to fossil fuels. As with fossil fuels, special precautions must be taken to ensure that transportation does not result in harm to health, safety or the environment and that the risk of accidents is minimised. Ensuring safe transportation of radioactive materials is an issue at nearly every stage of the nuclear fuel cycle. Particularly with high-level waste, the consequences of accidental releases could be very serious.

All radioactive materials are transported in sealed packages to prevent losses and protect the material in case of accidents. Packages are adapted to the radiation level of the material being transported. Some low-level wastes, yellowcake, uranium hexafluoride and materials with only surface contamination can be transported in industrial-grade containers without elaborate shielding or precautions, most commonly in steel drums or cylinders. Stronger, shielded containers are used for transporting fresh fuel and wastes with higher levels of radioactivity. These containers incorporate shielding so that radiation levels at the surface of the package is within acceptable limits. They are designed to withstand accidents and fires. Transportation packages for the most highly radioactive materials, spent fuel and high-level wastes, are massive containers designed to remain intact and sealed even in extreme circumstances. Special "casks" are adapted to rail, road and marine transport. The quality of the packages is such that expected radiation exposure of the public and transport workers is within acceptable limits. Casks containing spent fuel and high-level wastes have been used safely for over 30 years. To date, no transportation accident involving nuclear materials from nuclear power activities has released significant amounts of radioactive materials.

The health and environmental risks of transporting civilian nuclear fuel and wastes are limited compared to the risks of transporting some other fuels. Natural gas transportation infrastructure (pipelines, terminals and ships for liquefied natural gas) may leak and lead to fires or explosions. For a given power plant output, the quantities of coal that need to be transported are huge compared to nuclear fuel. The risk of rail or shipping accidents is higher because the quantities are larger. Coal dust is generated from loading terminals and open freight cars or barges. Oil can leak from tankers, causing serious damage to ecosystems.

Notwithstanding the excellent record of nuclear materials transport, transportation of high-level waste, spent fuel, MOX fuel and large decommissioning loads has attracted increasing public scrutiny in OECD countries. Opposition to transportation of nuclear materials has been growing. This is owed in part to an increased focus on transportation by antinuclear activists, but also to greater public concern about transportation safety in general. Non-compliance with rules for radioactive waste shipments has also caused problems. Local authorities have increasingly challenged the transportation of nuclear materials.

- In 1979, the governors of Nevada and Washington (United States) temporarily closed the low-level waste disposal facilities in their states after it was discovered that shipments of wastes to the facilities had leaking containers.

- Shipments of spent fuel and waste to and from European reprocessing plants were suspended in Europe in April 1998 because of public pressure when it was made public that the rail transport containers did not respect established norms for surface contamination.

- The State of Nevada has expressed concern about the adequacy of shipping containers for nuclear waste. In a 22 June 1999 letter to the chairman of the US Nuclear Regulatory Commission, the Nevada attorney general stated that "the current regulations expose the public across the country to unacceptable levels of risk from the transportation of highly radioactive materials." The state has also drawn attention to rail and road transport implications of the Yucca Mountain waste disposal project.

• In December 1999 the Dutch Council of State rejected a transport licence for spent fuel from the Dodewaard reactor because it did not contain enough information about transport routes. The case arose from a legal challenge by antinuclear groups.

The use of centralised storage and disposal facilities increases public risk along the main transport routes. The number of transports required would increase dramatically once high-level waste disposal facilities are put into operation. Studies in the United States estimate that the amount of waste shipped to a disposal facility in the first full year of operations will exceed the total amount shipped in the United States for the past 30 years (SON, 1999). Between 35 000 and 100 000 shipments will be required over the 25-year emplacement phase of the Yucca Mountain disposal facility, leading to an expected 50 to 260 transportation accidents. While the likelihood of accidents severe enough to cause a failure of a transport cask and a resulting release of radioactive material is very low, both technical and public acceptance challenges are likely for such a large number of shipments.

Transports of MOX fuel and plutonium impose special precautions related to non-proliferation concerns. Shippers must guard against potential terrorist acts. Armed ships were used for the September 1999 transport of MOX fuel to Japan.

Plant Decommissioning

The objective of plant decommissioning is to reduce residual radioactivity at the site to a safe level for subsequent re-use or isolation. Spent fuel and the internal parts of the nuclear reactor account for over 95% of total radioactivity present in the plant. Many other metal parts of the nuclear steam generating system, such as piping, pumps and steam generators, also become radioactive and must either be disposed of as low-level waste or decontaminated and recycled. Concrete and other structural elements also become contaminated, and the methods used to clean surfaces generate waste streams. All these sources of radioactivity must be removed or permanently contained within the plant. Apart from spent fuel and internal parts of the reactor, most radioactive waste from decommissioning a nuclear power plant is considered low-level waste.

The technical methods for plant decommissioning are well developed. Utilities and government agencies have gained extensive knowledge based on many projects to decommission experimental reactors, fuel cycle facilities and a few early commercial nuclear plants (NEA, 1996b). Dismantling the ruined unit 2 of the Three Mile Island plant also provided much useful experience. The European Union and the United States have sponsored extensive research and development programmes in decommissioning technology. For example, the European Union sponsored pilot dismantling projects at light water reactor power plants in Mol, Belgium and Gundremmingen, Germany, at a British gas-cooled reactor at Sellafield, and at a French reprocessing pilot plant at La Hague.

The NEA co-operative programme on decommissioning has provided a vehicle to share the techniques and results of these and many other projects. The programme has highlighted the progress made in technology and methods for nuclear plant closure (NEA, 1996b). Since the programme was founded in 1985, its emphasis has shifted from the decommissioning of experimental or prototype nuclear facilities to the decommissioning of early commercial facilities. This experience has provided the basis for a better understanding of the unit costs of the operations involved such as cutting techniques, remote disassembly and surface cleaning.

The main issues for nuclear plant decommissioning are:

- Timing and sequence of steps for decommissioning and waste management.

- Regulatory requirements, including timing and acceptable levels of residual radioactivity.

- Decommissioning of larger, commercial power plants and of fuel cycle facilities.

- Cost.
- Ensuring adequate funding.

Decommissioning proceeds in steps that vary in time according to company strategy and national regulatory requirements. The plant may be dismantled after a brief cooling period of several years, allowed to sit undisturbed for several or many decades, or permanently entombed. In all cases, the spent fuel will be removed as soon as possible since this removes the largest source of radioactivity within the plant and most of the threat to public health. The period before dismantling begins is a key variable in determining the cost of decommissioning. Other factors being equal, the longer this period, the less the cost of final dismantling and disposal of radioactive waste. This must be balanced against the cost of ongoing operations and maintenance at the facility before actual dismantling begins.

Changes in regulations, waste disposal costs or other factors could increase or decrease the cost of decommissioning. More stringent requirements or shorter schedules for dismantling would tend to increase the cost. In some countries, such as Germany or Japan, the site must ultimately be returned to a "greenfield" state, in which all structures are removed and the site is allowed to be used for any activity. In other countries, plant structures may be left as they are if, after a given period of time, residual radioactivity decays to levels meeting regulatory requirements for the intended future use of the site.

Although decommissioning technology has been successfully used at a number of facilities, there has been little experience at large, commercial power plants or at fuel cycle facilities. The large commercial facilities are likely to pose unforeseen problems that may require further technological development. Regulatory requirements could also strongly influence the technology and cost of decommissioning. The relevant requirements cannot be projected today with certainty since, as experience is gained in the decommissioning of large commercial plants, the requirements are likely to change. This is similar to the early situation in plant construction. As the industry and regulators acquired practical experience, safety regulation changed.

Some decommissioning strategies involve isolating a facility for long periods, perhaps more than 100 years, before final demolition. Companies may find it hard to employ strategies stretching over such long periods, particularly if stringent demonstration that adequate funding is available is required. Political or public acceptance of such closure plans may prove difficult to gain.

Governments must consider how to ensure that adequate funding will be available from plant owners. While the nuclear industry generally believes funding schedules to be adequate, some specific plants have been identified where decommissioning funding or financial guarantees appear to be inadequate.

There are a number of demonstration plants, built by government organisations, for which the costs of decommissioning were not set aside. Governments may find that funding the decommissioning of some of these plants will be difficult. For example, the European Union struggled to fund the decommissioning of nuclear research facilities operated by its Joint Research Centre at Ispra (Italy), Petten (the Netherlands), Geel (Belgium) and Karlsruhe (Germany). The European Commission ultimately found a funding solution for decommissioning, estimated in 1999 to cost 450 million over 25 years.

Radiation Standards

Ionising radiation can affect the human body by damaging or destroying cells. High doses of radiation can destroy many cells, leading to skin burns, damage to internal organs, and even death, depending on the dose. Such directly observable health effects are seen at doses above about 500 milliSievert. At lower doses, health effects may not be directly observable, but may appear after a period of time. The main effect of exposure to lower doses of radiation is to induce cancer. Acute doses of over 200 milliSievert have been firmly linked to increased cancer risk in humans. Doses below 200 milliSievert may also induce cancer, but there is no firm evidence of this (NEA, 1998b). In all cases, the risk of cancer depends on many human factors such as age, gender and genetic characteristics (see NEA, 1997a for a thorough discussion). As shown in Figure 22, the total average annual radiation dose from natural sources, plus medical sources and nuclear power is typically around 3 milliSievert.

Radiation standards have been developed to protect the public, workers and medical patients from the harmful effects of radiation. They have been designed to reduce to a minimum the risk that exposure to radiation will result in latent cancer. However, a practical problem is defining the dose at which increased health risk is negligible. It has been assumed that any dose, no matter how small, increases the risks of contracting cancer. This key regulatory assumption for assuring that an individual's risk of contracting cancer is as low as reasonably achievable is known as the "linear non-threshold" hypothesis.

Radiation protection authorities are satisfied that the current regulatory basis provides a high level of protection of human health. Very stringent requirements are in place for all activities involving exposure to radiation. However, the linear non-threshold hypothesis has been questioned because it can require that tiny amounts of radiation be avoided, sometimes at great cost, and the decontamination of materials whose radiation level is lower than background radiation. This model of radiation effects is said to needlessly increase the cost of operations and, especially, waste disposal (Rockwell, 1997). The use of some other model could dramatically decrease the cost of power generation and waste disposal, while still providing a conservative level of health protection. For example, decontaminating the site of a decommissioned nuclear facility would be much less expensive if the residual level of radioactivity left on the site were allowed to be just slightly higher. The safety of high-level waste disposal might be easier to demonstrate, and the cost lower, if there were a threshold of residual radiation below which the wastes could be considered harmless. Because it is not possible to statistically demonstrate that low doses actually lead to an increased incidence of cancer, some suggest that this is a "practical threshold" below which regulations are not needed. The outcome of this debate could have an important effect on the economics of nuclear power. Meanwhile, it is considered that the current assumption should remain in use (NEA, 1998b).

The choice of radiation or waste disposal standards does not always follow simply from radiation protection principles. Two recent examples illustrate this. The first is the effective ban on ocean dumping of radioactive materials agreed under the Ospar Treaty (Convention for the Protection of the Marine Environment of the North-East Atlantic) in 1998. A ministerial statement following the 1998 meeting said that the aim is to attain "concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances." Reprocessing plant operators argued that this was unnecessary and costly. The second example is the development of radiation standards to apply to the Yucca Mountain high-level waste disposal facility. The US Nuclear Regulatory Commission favours a "total effective dose equivalent" of 25 millirem per year, while the US Environmental Protection Agency set a limit of 15 millirem per year, as well as a separate limit on drinking water contamination of 4 millirem per year. Different engineering approaches and implementation costs would result from the different limits.

Nuclear Safety Regulation

The responsibility for ensuring the safe operation of nuclear facilities rests primarily with the owners and operators of those facilities. Nuclear safety regulations provide guidance on the standards and procedures to use to make sure that public health and the environment are protected, but the application of those regulations is undertaken as an integral part of normal facility operation and planning. This process follows the same philosophy of primary responsibility as in other areas of public safety regulation, such as the operation of industrial facilities or conventional power plants.

Safety regulation and regulators nevertheless have a key role. Safety regulation has a fundamental influence on the design and operation of all nuclear facilities. Many items of equipment, entire systems, operating practices and operating constraints are in place solely for the purpose of ensuring plant safety. The cost of electricity from nuclear plants depends heavily on the details of safety regulation, as described in "Safety Costs" (Chapter 4). Safety regulators have to make sure that companies and individuals are in fact adhering to the relevant safety regulations. Regulators provide an independent check that compliance is full. Regulations, especially in the nuclear field, can be complex with uncertainties on how to apply them. Several options may ensure safety, but at different costs. Regulators therefore have an important role in working with operators to interpret regulations and agree upon the best course of action when uncertainties arise.

A major challenge to nuclear regulators, and to the nuclear industry as a whole, is to ensure that standards and regulations are implemented fully in practice. High standards of nuclear safety do not automatically guarantee that acceptable safety levels are achieved, as the incidents and accidents noted in Table 22 illustrate. As in any industry, regulations must be carefully implemented to ensure that public health and the environment are protected. Independent, effective monitoring of facilities is essential. High standards of implementation are important in building and maintaining public trust in nuclear facilities.

The series of plant incidents and accidents in Japan in the 1990s is widely considered to have weakened the ability of the government and utilities to develop their plans for new nuclear plants and to have strengthened Japanese anti-nuclear feeling.

Facility Design and Operation

As noted, safety regulation has a fundamental influence on the design and operation of nuclear facilities. Improving the effectiveness of regulation in all industries has become a government priority in many countries, and the liberalisation of electricity markets has reinforced the pressure in nuclear safety regulations to consider cost-effectiveness. The notion of "risk-informed regulation" has focused attention in recent years on ways to assess more carefully the safety benefits of specific regulatory requirements. Regulators themselves are seeking ways to improve the effectiveness of their regulations and actions.

In some countries, the issue of nuclear regulatory effectiveness has been less acute because fewer difficulties had been encountered in practice. Less detailed regulatory requirements have been specified, and greater emphasis placed on the responsibility of plant operators to meet safety objectives. Consistently applying a streamlined set of licence conditions can avoid costly difficulties during both plant construction and operation. Finland, France and Sweden are often cited as having notably consistent regulatory processes.

The lack of predictability and consistency of nuclear regulation has been criticised in some countries. Utilities consider that the absence of a stable regulatory framework, both nationally and internationally, is a barrier to the development of nuclear technology (Alonso and Zurita, 1999). Changes in nuclear safety regulation can, overnight, affect the usefulness and economic value of individual nuclear facilities. This is a criticism that has been frequently made by the US nuclear industry (e.g. O'Connor, 1989). Until 1989, nuclear plants in the United States could only be licensed under a two-step system of construction and operating permits that left a final decision on operation until the full plant investment had been made. In Germany, the application of licensing procedures has been subject to legal attack so that some facility owners saw their plants shut down after receiving, in principle, final operating approval. In most countries, changes in regulation have required new investments in existing plants.

In the United States in 1989, the Nuclear Regulatory Commission responded to criticism by providing an alternate licensing process that certifies the safety of a new plant before construction begins. Under this process, a single permit/operating licence can be issued. If the plant, as built, passes the acceptance criteria as defined at the time of the licence issuance, it will automatically be given approval to operate. Reactor designs can also be certified under the new regulations. The Nuclear Regulatory Commission cannot require a plant built in accordance with an approved design to be modified, except under restrictive conditions. The new regulations are designed to improve the predictability of the licensing process, while still allowing public participation. Three plant designs have been certified using this process, though no orders for any of these plant types has been placed. In 1998, an amendment to the German Nuclear Act introduced a similar generic licensing process in Germany.

In 1999, the US Nuclear Regulatory Commission introduced a new system of evaluating the safety performance of nuclear plants. The new programme takes into account improvements in the performance of the nuclear industry over the past twenty years. The Commission intends to apply more objective, timely and safety-significant criteria in assessing performance. These new projects also respond to the agency's need to effectively regulate the industry with a smaller staff and budget.

Other safety issues are taking on greater importance, particularly as a result of electricity market competition. They include (NEA, 1998a):

- Changing the plant technical operation of plants in response to the desire for improved economic performance (greater operational flexibility, higher utilisation of nuclear fuel, longer periods between refuelling, etc.).

- Ensuring that commercial interests and strategies do not compromise safety.

- Developing ways to monitor the adequacy for safety of new working arrangements.

- Maintaining access to research results while guarding regulatory independence.

- Monitoring the safety effects of the increased use of contractors, managerial changes, and ownership changes.

- Co-operation between national safety authorities.

In any industry, a careful balance must be struck between economic competitiveness and safety. Too great a focus on economic performance can perturb safe facility operation. This can be a concern in times of rapid commercial change. Nuclear regulators recognise this concern and, as electricity markets evolve, regulatory bodies are paying particular attention to ensure that safety performance is not compromised. The British Nuclear Installations Inspectorate has expressed a concern that staff reductions, increased use of contractors, reliance on overtime, and the management of commercial change in British Energy could threaten safety in the medium to long term if not addressed, though they do not question the immediate safety of operating nuclear plants (HSE, 2000). The Canadian regulator is concerned that "the drive to remain fiscally competitive in a deregulated market will overshadow some of the fundamental needs for safety in nuclear installations." (Harvie, 2000). The International Nuclear Regulators Association, composed of nuclear regulatory authorities from seven OECD countries, has noted the importance of this issue (Jackson, 1998).

Lifetime Extension

Competition in electricity markets and heightened environmental concerns increase the value of extending the lifetime of existing nuclear plants. A growing issue for nuclear safety regulation is how to ensure the safety of ageing plants. Many factors change as plants get older, not just their physical condition. Analytical techniques, documentation, rules and standards, and available technology (such as for spare parts) change over time. Changes in these factors require safety authorities to adapt their methods while still ensuring safety.

Safety authorities must judge whether the physical ageing of plant components and structures has any effect on their safety characteristics. A simple example is that rust or corrosion might block the operation of a critical valve. Embrittlement of reactor vessels and steam generator corrosion are large-scale ageing problems that have been encountered, and for which safety authorities have already accepted technical solutions. Safety authorities and plant operators must take adequate measures to assess the physical state of important plant components. New measuring techniques and sensors can help to do this, and they may also reveal problems not previously detected. Safety authorities must take advantage of new sensor technologies and inspection techniques, and determine what to do about newly discovered defects.

Instrumentation and many other technologies have advanced since the plants of the 1980s were built. Safety regulators must decide how, or if, current standards should be applied to plants designed and operated to older standards. Regulators must develop methods to address changes in technology.

Waste Disposal

A difficult task facing safety regulators is to determine the adequacy of proposed final disposal sites. The requirements that regulators may set, the methods to assess the safety of long-term disposal, and the process by which the standards and methods are accepted require a major effort in each country. Safety regulators also face the challenge of how to deal with the accumulation of spent fuel and wastes in interim storage.

Safety criteria for disposal of long-lived radioactive waste can be based on dose limits (such as milliSievert per year) or on risk criteria, typically expressed as a probability of inducing cancers. This very basic choice of criteria results in different methods of site evaluation and dictates differences in how regulatory actions are explained to the public. Single, high-level standards or indicators are easily understood by the public, but may not be adequate to take into account the many factors involved in ensuring the safety of a waste disposal facility (NEA, 1997b: p. 239). Furthermore, environmental protection, not just protection of human health, must be considered.

The time scale involved in high-level waste disposal makes scientific predictions of geological behaviour of specific sites all but impossible. However, politicians and the public often demand to know the specific time periods to which safety assessments must refer. Safety regulation must find a way to take into account a qualitative view of what could happen in 10 000 or 100 000 years. These and other issues must be dealt with in technical and non-technical reviews to arrive at broadly accepted, workable processes for establishing waste disposal sites. The approaches developed in coming years and their cost implications are crucial to nuclear power's future.

Regulatory Independence

It is very important that the regulator be independent of commercial and short-term political pressures, and of the influence of promotional and development organisations and anti-nuclear groups. The importance of an independent regulatory body is recognised in the Convention on Nuclear Safety, which came into force in 1996. Article 8 of the treaty specifies that governments should "ensure an effective separation between the functions of the regulatory body and those of any other body or organization concerned with the promotion or utilization of nuclear energy." Decisions concerning individual facilities must be made on the basis of uniformly applied regulatory principles and not on the associated effects on individuals, companies or the industry. This rule of independence has been applied only progressively in nuclear regulation. The credibility and acceptability of nuclear regulation, including safety results, depend on whether this rule is being maintained and applied to the fullest reasonable extent. In some countries the independence of nuclear safety regulation remains to be strengthened.

Table 26

Reinforcement of Nuclear Regulators' Independence in Selected OECD Countries

	Year	Change Effected
Belgium	1995	Federal Nuclear Inspection Agency (AFCN) created
Canada	2000	Atomic Energy Control Board replaced by the Canadian Nuclear Safety Commission
Czech Republic	1997	Atomic Act reinforced the independence of the safety authority (SUJB)
France	1990 2001	reinforced financial and operational autonomy of the safety authority (DSIN) with respect to the Atomic Energy Commission; placed under the oversight of the Ministry of Industry and the Ministry of the Environment * measures to increase the independence of the safety authority
Hungary	1997	Hungarian Atomic Energy Authority given expanded autonomy and powers
Japan	1978 2000	Nuclear Safety Commission separated from the Atomic Energy Commission Commission moved out of Ministry of International Trade and Industry to Prime Minister's Office
Korea	1990	establishment of the Korea Institute of Nuclear Safety, a technical body reporting to the Ministry of Science and Technology
Spain	1980	Nuclear Safety Board (CSN) separated from the Nuclear Energy Board
Switzerland	1998	upon request by the Federal Nuclear Safety Inspectorate, an international regulatory review team provided advice on strengthening the Inspectorate's effectiveness and independence
United Kingdom	1975	the Nuclear Installations Inspectorate was placed under the authority of the Health and Safety Executive
United States	1975	Nuclear Regulatory Commission separated from the Atomic Energy Commission

** Expected actions.*
Source: IEA.

At the beginning of many nuclear development programmes, an important concern was that inappropriate safety regulation might stifle technological development. Nuclear regulatory authority was commonly given to the same organisation that was responsible for the promotion and development of nuclear power. Safety concerns were therefore tempered by the wish to move ahead quickly with new plant development. In order to properly regulate a technology, one needs to know it and have some experience with it. In the early stages of nuclear power programmes, that knowledge and experience did not yet exist, and so developers naturally played a key role in regulation. This initial perspective on nuclear power regulation has changed over time. Table 26 lists regulatory changes that have tended to reinforce the independence of nuclear safety authorities in selected countries.

CHAPTER 6

PUBLIC OPINION AND POLITICAL RESTRICTIONS

Public opinion and current political restrictions on nuclear power are key factors in its future. However, the issues are complex. This chapter considers the main reasons for negative public opinion and some of the actions governments and industry have taken to address that opposition. It then considers the present situation on political restrictions.

Public Opinion

A majority of the public was generally benign to nuclear power in its early days. In many countries, this has now changed. An important minority of the public is now hostile to nuclear power, although the “true” state of public opinion is difficult to determine. Groups for or against nuclear power regularly produce opinion polls with opposite results.

Opposition to nuclear power, where it exists, is part of a much wider public resistance to the implementation of large projects of any type, such as airports. Opposition is often founded on safety concerns, such as crashing planes, and is usually strongest among those who live near the proposed facilities.

It has become especially difficult to find acceptable sites for new nuclear facilities. Opposition to these is common in all OECD countries, including those with active nuclear programmes.

Public opinion also has an international dimension. Some governments and the public are concerned about the safety of nuclear facilities in neighbouring countries, and about the possibility that civilian nuclear programmes may be used to develop nuclear weapons. Table 27 summarises nuclear facilities about which some countries within the OECD have publicly expressed concerns.

Table 27

Nuclear Facilities Subject to International Contentions

Facility Name	Located in	Concerned Country or Body	Comment
OECD Facilities			
Akkuyu	Turkey	Greece	Planned nuclear power plant.
Aldeavila waste laboratory	Spain	Portugal	Planned waste facility; Association of Portuguese Municipalities has expressed concern.
Barsebäck	Sweden	Denmark	First unit (of two) closed as part of Swedish phase-out plans.
Sellafield	UK	Norway, Ireland	Concern about discharges into the Irish Sea; concern about accidents.
Temelin	Czech Rep.	Austria	Agreement negotiated on terms of start-up.
Non-OECD Facilities			
Bushehr	Iran	United States Czech Republic	Russia providing assistance to complete it.
Chernobyl	Ukraine	G7, EU	Final operating unit closed in 2000 following lengthy negotiations.
Juragua	Cuba	United States	VVER plant begun in 1980s with Soviet help; halted in 1992.
Kozloduy	Bulgaria	EU, Greece	
Medzamor	Armenia	EU	
Mohovce	Slovakia	EU, Austria	1998 European Parliamentary resolution.

Source: IEA.

Negative public opinion, where it exists, can be traced to a number of factors.

One issue is military connections. Nuclear power is perceived by some to facilitate the development of nuclear weapons, to increase the risk of nuclear war, and to create possibilities for nuclear terrorism. In a historical sense the connection is understandable, since civilian nuclear power programmes grew from military programmes to produce nuclear weapons and nuclear-powered naval vessels. Uranium mines, enrichment plants, reprocessing plants, test reactors and other facilities were developed for military purposes and then used to support civilian nuclear power development. Some investments made initially for military purposes continue to be used today for commercial purposes.

Civilian nuclear power plants may be used to produce material for nuclear weapons. Early French and British nuclear programmes used gas-cooled reactors for both electricity production and production of plutonium for nuclear weapons. In December 1998, the United States government awarded a contract for the production of tritium, a hydrogen isotope used in nuclear bombs, to a civilian nuclear power plant. It is also possible for plutonium produced in civilian nuclear power plants to be diverted illegally for use in nuclear bombs. Enrichment plants, specialised reactors supporting civilian nuclear programmes and other facilities can be used to produce materials of use for military purposes. Support for nuclear disarmament has increased over time, and to the extent that nuclear weapons and nuclear power are linked in debate, this has not been helpful to the cause of nuclear power.

Another issue is secrecy. A culture of secrecy was needed for military programmes, and this carried over to the associated civilian nuclear programmes. In France, the United Kingdom and the United States, early civilian nuclear programmes were managed by the same organisations that were responsible for certain military programmes. Many problems or accidents have been accompanied by secretive behaviour that was later discovered through information leaks or the work of investigative reporters (NEA, 1991c: p. 16).

The criticism of nuclear power has itself tended to mute full and open exchanges of information between those in the nuclear industry and the general public. The nuclear industry could feel that information freely given might be misused or turned against it, particularly when dealing with accidents, problems or environmental questions.

A further key issue is safety, the environment and accidents. Accidents at nuclear facilities have the potential to release significant amounts of radioactivity with serious health effects and damage to the environment. Governments and the nuclear industry have always taken great care to minimise the possibility that serious accidents could occur. Given the large number of nuclear facilities in operation, relatively few serious accidents have occurred. According to nuclear safety authorities, no accident in the OECD has presented a significant danger to public health or the environment.

Despite this, the safety and environmental impact of nuclear plants and other nuclear facilities remains a focal point of public concern about nuclear power. Concern about exposure to natural sources of radiation such as from rocks, fertiliser, radon gas or air travel is minimal. In contrast, man-made radiation is feared. Even though the potential health impact of radiation does not depend on whether it is from a natural or man-made source, man-made radiation is often claimed to be connected with cancer and birth defects. The connection with military nuclear explosions plays a role as well.

It is difficult to convey the idea that public health and the environment can be safeguarded, through multiple layers of protection, even if accidents occur. Those who communicate the safety characteristics of nuclear plants will of course stress the low probability of accidents, but this can be misperceived as a zero level of accident occurrence. Thus, several accidents that "could not happen" severely shook public confidence in nuclear power. The 1979 core meltdown at the Three Mile Island plant in the United States received a tremendous amount of publicity and had a very negative impact. Nuclear programmes and the political debates on nuclear power were affected in many countries by the accident. The 1986 explosion of the Chernobyl reactor in the

Ukraine had equally negative repercussions within the OECD, notwithstanding the fact that the plant did not follow the same design philosophy or operate under the same regulatory system as in OECD countries.

As a result of both accidents, and others, nuclear plants are now scrutinised to a degree found in no other industry. Any incident involving the need to stop plant operations is reported widely in the non-specialist media. Critical reports of nuclear plant operations by nuclear regulatory authorities are widely disseminated. Radiological incidents in all phases of the industry, including transport or reprocessing, are similarly reported, as are issues related to radioactive wastes.

Potential problems related to radioactive wastes provide a focal point for critics. Radioactive releases from nuclear facilities such as reprocessing plants or even laundries handling lightly contaminated clothing are viewed with concern and portrayed as a danger to health. The lack of operational solutions for safely disposing of high-level wastes is portrayed as a major deficiency. Many contaminated sites associated with civilian nuclear power also give the impression that wastes are not properly handled and pose a threat to health. Access to beaches around the French and UK reprocessing plants has been temporarily restricted at times, and fishing near the Dounreay reprocessing plant has also been restricted. In some cases, real threats to public health have been found.

The effectiveness and independence of nuclear regulators is a related issue. Their effectiveness is probably similar to that of safety regulators in other industries but the public is especially sensitive to releases of radioactivity from industrial facilities and lapses in nuclear safety have the potential to release radioactivity. Nuclear safety regulation has therefore been highly scrutinised and criticised. As in the safety regulation of other industries, incidents in civilian nuclear power have been cited to argue that nuclear power regulation and enforcement are inadequate. Actions taken by safety regulators can have serious financial implications for owners of businesses involved in nuclear power. There is always a risk that the commercial and political pressure to minimise financial consequences could impair safety. The allegation of an insufficient level of regulatory independence is often a source of negative publicity for nuclear power.

Finally, economics can be added to the sources of negative public opinion. Cost overruns and poor economic performance, whether the criticisms are justified or not, have been used as an argument against nuclear power in some countries. In particular, critics have pointed to the capital costs of nuclear facilities (which increased dramatically from the 1960s to the 1980s), to the problems related to cancelled projects with large debts, and to the payments for stranded costs in the wake of electricity market reform.

Negative public opinion can be very costly for nuclear power. Opposition to the construction or operation of power generation facilities increases the cost of power production, through delaying operation, increasing the cost of licensing, and providing extra physical security to facility operations. Political and regulatory authorities must move slowly, or sometimes change direction, in granting permission to build and operate power facilities.

In the case of nuclear power, public opposition affects the cost of uranium mines, nuclear fuel preparation plants, nuclear power plants and waste disposal sites. In some cases, large investments have been lost. In recent years, nuclear power opponents have focused on waste disposal sites. Nearly all national programmes to establish high-level waste disposal facilities have been caught up in lengthy, expensive development programmes driven as much by the need to answer public concerns as to demonstrate technical adequacy. The cost of transportation of high-level waste or spent fuel can increase owing to public opposition. Although governments assume the cost of enforcing laws protecting the free movement of goods, utilities must also spend additional money to ensure the safe transport of nuclear materials in the face of public opposition.

Public opposition increases the cost of finding sites for new facilities. Much longer periods of evaluation, analysis and dialogue are needed. Money and other inducements are sometimes offered to surrounding communities to help the process move along.

Government and Industry Response to Negative Public Opinion

Governments and industry have both taken steps to improve communication with the public about nuclear issues. All countries with nuclear generating capacity, towards the end of the 1970s and the start of the 1980s, launched efforts to win or maintain public confidence (NEA, 1984).

Information programmes have included the organisation of meetings at local and national levels, visits to nuclear power plants, direct contacts with local populations, exhibitions and information stands, advertisements, educational material for schools, and audio-visual documents. Some campaigns have offered more specialised information on certain aspects of nuclear energy, such as the management of radioactive waste, and the organisation of information and distribution services to the press. At the institutional level, arrangements include public inquiries, official debates, local hearings and information missions and prior consultations on a formal basis with all the elected assemblies concerned (NEA, 1991b). The moderate success of many earlier information campaigns has led to further efforts to improve communication.

Clearly, the issues of environmental protection and economics, cited above as sources of negative public opinion, can also be sources of positive public opinion. Nuclear power has certain environmental advantages and benefits in comparison with fossil energy, notably the absence of airborne pollutants. Well-managed construction programmes and well-run plants can and do contribute to competitive nuclear generation costs.

Governments have placed growing emphasis on public participation in the regulatory processes of siting, construction and operation of nuclear facilities. Involving local communities was already a well established trend by the early 1980s. Since then, some governments have developed new initiatives for expanding public participation in decision-making (NEA, 1991c: p. 101).

A long-standing trend among nuclear safety authorities is to provide more information on their activities and on the safety performance of nuclear facilities. Annual reports typically note the major actions of the safety regulator, current issues in plant operations, plant incidents and concerns that arose during the year, as well as programmes for improvement of regulatory processes.

Nuclear trade organisations in many countries have made improved communication a high-priority programme. Many organisations and utilities have Internet websites and brochures to explain the benefits of nuclear power, its environmental characteristics, safety performance, and other characteristics. A good example is the Internet website of Électricité de France, where explanations can be found on nuclear plant operation, the nuclear fuel cycle, environmental impacts, radioactive waste management, nuclear safety, radioactivity, plant decommissioning, and many other nuclear issues. In Japan, the “Atom Net” website provides information about operating nuclear power plants and radioactive waste management, and a complete list and description of incidents at nuclear power plants. A third example is the Spanish website “Nuclearlink” sponsored by Union Fenosa, a Spanish nuclear utility, and the Spanish Nuclear Society. This site carries a full catalogue of sources of information on nuclear power, in the interest of openness, and it also provides many links to antinuclear organisations. These examples are typical of the considerable efforts made by industry to strengthen public communication and provide a basis for informed discussion.

Many nuclear power plants and other nuclear facilities associated visitor centres where the public can learn more about the operation of the facility and speak directly to knowledgeable personnel. These centres make the facilities known, but also provide wide-ranging information on nuclear power and energy in general. Since they are located close to nuclear facilities, they demonstrate in a tangible way that nuclear facilities are “normal” industrial facilities whose operation need not be feared. Most visitor centres receive between 10 000 and 20 000 visitors a year, and some large ones can expect over 100 000 a year. About half of the visitors are schoolchildren (NEA, 1993b: p. 39). The nuclear industry considers visitor centres to provide excellent opportunities for communication with the public.

The OECD Nuclear Energy Agency and the International Atomic Energy Agency introduced the International Nuclear Event Scale in 1990 to facilitate communication between the nuclear community and the public in the event of incidents at nuclear facilities. Since incidents and accidents are so widely reported, it was felt that the scale would help to place the vast majority of them into proper perspective as having no public safety significance. The scale ranges from 0 to 7. Events classified from 1 to 3 are “incidents” and those from 4 to 7 are “accidents”. Table 28 shows the scale and its criteria. Use of INES has generally been considered successful in improving public communication about problems at nuclear facilities.

International nuclear organisations have shared information on public communication and provided information on nuclear power. For example, the OECD Nuclear Energy Agency hosted a series of workshops on “Public Understanding of Radiation Protection Concepts”, “Public Information During Nuclear Emergencies”, “Communicating with the Public on Nuclear Power Plant Operating Experience”, and “Public Information on Radioactive Waste Management”. It has published a series of books on public opinion and communication, as well as analyses of numerous technical issues of relevance for a general audience. The International Atomic Energy Agency carries out activities specifically devoted to improving public understanding of nuclear energy (El Baradei, 1999).

A number of other developments in the nuclear industry and nuclear policy have tended to contribute a more positive opinion of nuclear

Table 28

Summary Description of the International Nuclear Event Scale

Level	Descriptor	Criteria
7	major accident	Major release of radioactivity, widespread health and environmental effects.
6	serious accident	Significant release of radioactivity, likely to result in full implementation of local emergency plans to limit serious health effects.
5	accident with off-site risk	Severe damage to reactor core and/or radiological barriers. Limited release of radioactivity, likely to require partial implementation of planned countermeasures.
4	accident without off-site risk	Minor external release of radioactivity. Significant damage to reactor core and/or radiological barriers, or fatal exposure of a worker.
3	serious incident	Only very small release of radioactivity to environment. Severe spread of contamination within facility and/or acute health effects to a worker.
2	incident	Significant spread of contamination inside the facility and/or overexposure of a worker.
1	anomaly	Anomaly beyond the authorised operating regime.
0	deviation	No safety significance.

Note: Criteria descriptions have been simplified for summary purposes. Please refer to the source fact sheet or other INES documents for more complete information. See Table 22 for examples of plant accidents and their INES ratings.
Sources: International Atomic Energy Agency, Radiation, Health and Society, *and INES Fact Sheet.*

power, even though such developments were not necessarily aimed at affecting public opinion.

- The links between military and civilian programmes have decreased naturally over time as the civilian nuclear industry has grown and developed. Institutions, regulation, and industrial facilities have increasingly become separate and specifically devoted to military and civilian activities. (See "Nuclear Non-Proliferation" in Chapter 2 for a discussion of non-proliferation issues.)

- As the nuclear industry has matured, it has assumed an increasing share of total expenses previously borne by governments.

- Many governments have strengthened the independence of nuclear safety authorities, primarily for reasons of effectiveness rather than public opinion.

- The nuclear industry has acted to improve the economic performance of nuclear plants, both through design changes and changes in operation. Technological maturity reduces the risk of unexpected increases in construction or operating costs.

- The safety record of OECD nuclear plants has remained exemplary. The long-standing and continuing absence of substantial releases of radioactive elements from nuclear facilities, as verified by radiation protection authorities, has provided a strong counter-argument to those claiming that nuclear facilities are unsafe.

Political Restrictions

Since 1978, some 14 GWe of nuclear power plants and a nuclear fuel production plant have been closed or halted in advanced stages of construction in six OECD countries for non-economic reasons (Table 29). The power plants in Table 29 represent about 40% of all OECD nuclear power plants that have been closed for any reason, or about 5% of currently operating generation capacity. The average operating lifetime of plants closed for non-economic reasons was less than six years, compared to about 20 years for all closed OECD nuclear power plants. The reasons for closing the 16 facilities in Table 29 can be grouped into four categories:

- Concerns about plant safety that could not be resolved by engineering modifications.

Table 29

OECD Nuclear Facilities Closed for Non-Economic Reasons

	Plant Name	Type (if not power)	Gross MWe	Stop	Years in Service	Reason for Closure
Austria	Tullnerfeld		722	1978	0	Referendum did not allow it to open after completion.
Germany	Greifswald 1-5		2 200	1990	11-17	Closed after German reunification because of safety concerns.
Germany	Rheinsberg		80	1990	25	Closed after German reunification because safety concerns.
Germany	Mülheim Kärlich		1 302	1988	2	Construction licence declared void by Federal Administrative Court.
Germany	Hanau	MOX plant	120 t/yr (heavy metal)	1995	0	Partial licences declared unlawful; opposition of the State Government of Hesse.
Germany	SNR-300 Kalkar	fast breeder	327	1991	0	Opposition of the State Government of North Rhine-Westphalia.
Italy	Caorso		862	1988	10	Referendum of Nov. 1987.
Italy	Trino Vercellese 1		270	1988	24	Referendum of Nov. 1987.
Italy	Latina		210	1987	25	Referendum of Nov. 1987.
Italy	Montalto di Castro		2 018	1988	0	Referendum of Nov. 1987 (70% complete).
Spain	Lemóniz 1&2		1 860	1984	0	1983 National Energy Plan (92% complete).
Spain	Valdecabal-leros 1&2		1 950	1984	0	1983 National Energy Plan (50% complete).
Sweden	Barsebäck 1		615	1999	25	Political decision.
United States	Rancho Seco		966	1989	15	Referendum of June 1989.
United States	Shoreham		849	1989	3	Local authorities refusal to provide emergency plan.
United States	Zimmer		840	1984	0	NRC safety concerns; utility judged cost too high to complete properly.
OECD Total			**14 231**			

Note: Spanish nuclear plant completion levels are averages of the two units in each plant.
Source: IEA.

- Public referendums calling for closure of plants.
- Legal challenges to the operating or construction licences.
- Opposition of political authorities.

Apart from nuclear facilities, it is rare for large industrial facilities to be closed down for these types of reasons, especially before they have begun operating. Normally, public and commercial interests are protected by licensing procedures that assure plant developers that their plants will be able to recover investment through normal operation, and which assure that risks to the public are acceptable. Public concerns were especially influenced in the late 1980s by the 1986 Chernobyl plant explosion in the Ukraine. All the facilities in Table 29 except the Austrian power plant and incomplete Spanish plants were definitively abandoned after 1986.

One consideration that made it possible to abandon these facilities was that their investments were repaid anyway. However, responsibility for the repayment of investments in the Mülheim Kärlich plant is still under legal dispute. In all cases but this one, electricity consumers have borne the cost of abandoned facilities.

Almost half of OECD countries have placed restrictions on the operation or construction of nuclear power plants (Table 30), either through legal prohibitions or political decisions. In several European countries, national referendums resulted in prohibitions on nuclear plants. In some countries, local referendums have stopped the development of nuclear power plants at specific sites. Formal "phase-out" policies or laws have been adopted in three countries with operating nuclear power plants: Germany, the Netherlands and Sweden. These phase-outs require that existing nuclear power plants be closed when they reach the end of their lifetime and do not allow new plants to be built.

Table 30

Restrictions on Nuclear Power Plants in OECD Countries

	Year In Force or Voted	Duration	Type	Comments
Australia	1983/86	indefinite	legal	Victoria (1983), New South Wales (1986).
Austria	1978	indefinite	legal	Prohibits construction or operation of nuclear power plants.
Belgium	1999	indefinite	policy	Phase-out of nuclear power.
Denmark	1985	indefinite	parliamentary decision	Nuclear power should not be considered in energy planning.
Germany	1998	n.a.	policy	Phase-out of nuclear power.
Greece	1975	indefinite	policy	Concern about seismic safety.
Ireland	1999	indefinite	legal	Section 18 of Electricity Regulation Act.
Italy	1987	5 years	referendum	No new plants, existing plants shut down.
	1990		legal	Permanently closed nuclear plants.
Netherlands	1994	n.a.	parliamentary motion	Phase-out; Borssele plant to close at the end of 2003.*
Norway	1984	indefinite	parliamentary discussion	Clear signal given from Parliament in its discussion of Storting Report No. 71.
Poland	1990	20 years	parliamentary resolution	Discontinued construction of a VVER power plant.
Sweden	1980	indefinite	legal	No new plants, phase-out of existing plants.
Switzerland	1990	10 years	legal	Allows no new nuclear power plants to be constructed.

n.a.: not applicable.
** The Dutch High Administrative Court ruled in February 2000 that the modification of Borssele's licence, limiting its operation to 31 December 2003, was not legal.*
Source: IEA.

CHAPTER 7

NUCLEAR TECHNOLOGY DEVELOPMENT

Research and Development Spending Patterns

Spending by Country

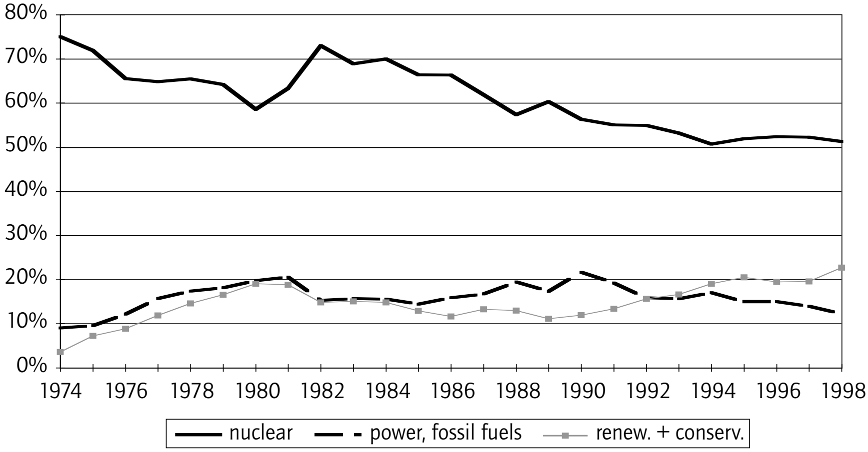
Nuclear power technology has received much larger sums of money from OECD governments for research and development than have other energy technologies. Over the period 1974 to 1998, government spending for nuclear technology research and development totalled about $160 billion, in 1999 money. Nuclear energy's share of reported OECD government funding for energy technology research and development has varied between one-half and three-quarters since 1974 (Figure 26). That share of government-sponsored energy research and development has however generally been decreasing since 1982. In 1998 nuclear power's share was about half. Other areas of energy technology research have received 10 to 20% shares of government funding.

Reported government spending on nuclear research and development in 1998 stood at $2.9 billion for non-breeder fission technology and $1.0 billion for breeder and fusion technology (Table 31). Non-breeder fission technology includes light water reactors, other converter reactors such as gas-cooled reactors and heavy water reactors, nuclear fuel cycle technology, and other supporting nuclear technologies such as safety, environmental protection, and nuclear materials control. This category of research is most relevant to today's operating reactors since there are no commercially operating breeder or fusion reactors.

Seven countries account for over 95% of total OECD government spending on nuclear research and development, both in 1998 and

Figure 26

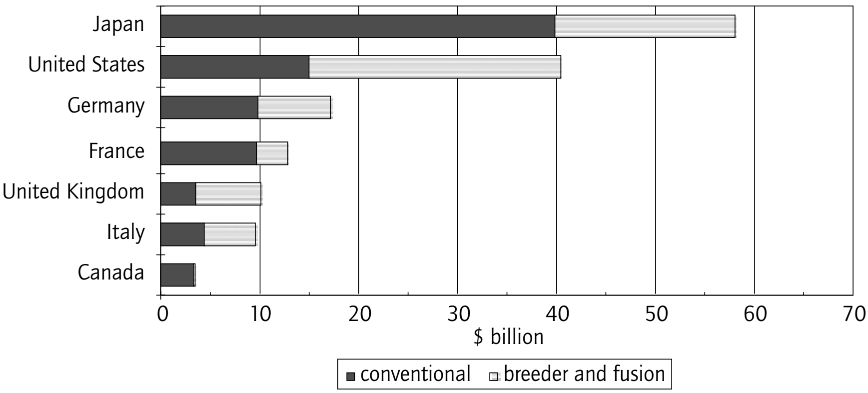
Nuclear Power's Share of Reported OECD Government Energy R&D Spending, 1974 to 1998



Notes: Finnish data not included prior to 1990. French data not included before 1978. Data on Hungary are not included.
Source: IEA.

Figure 27

Reported OECD Government Nuclear Energy R&D Spending, Cumulative from 1974 to 1998



Notes: Only those countries with reported cumulative spending of $1 billion or more on non-breeder fission research and development are shown in this figure. French data not included before 1978.
Source: IEA.

Table 31

Reported Government Research and Development Spending on Nuclear Technology, 1998 and Cumulative from 1974 to 1998

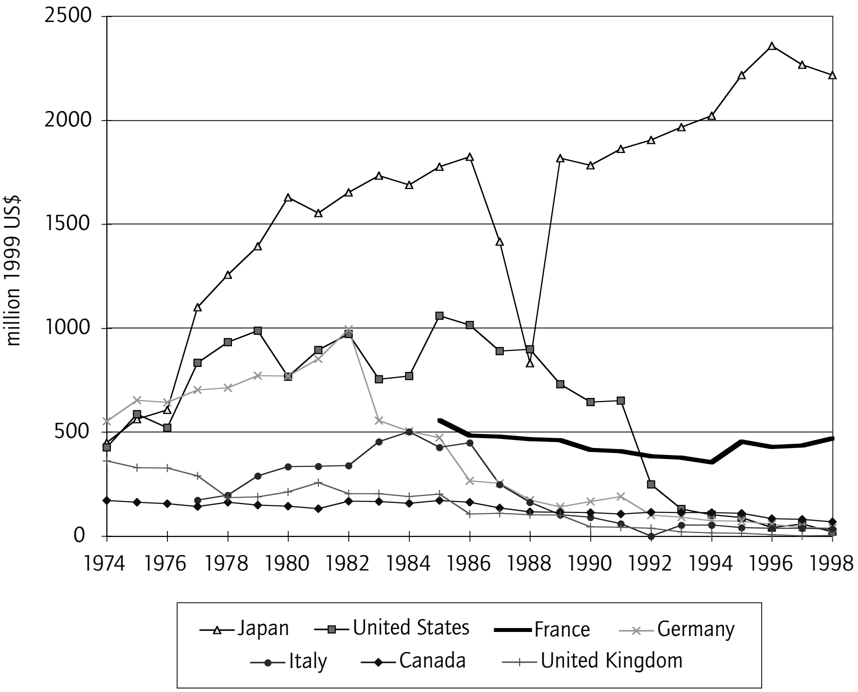
	Non-breeder Fission, 1998	Breeder and Fusion, 1998	Nuclear Power's Share of Energy R&D	Total, All Nuclear Technologies 1974 to 1998	Share of Cumulative OECD Total
	Million 1999 $	Million 1999 $	%	Million 1999 $	%
Japan	2 217	510	71	58 080	37
United States	20	220	12	40 488	26
Germany	39	132	56	17 188	11
France	470	54	93	12 877*	8
United Kingdom	3	21	34	10 162	6
Italy	34	72	44	9 569	6
Canada	68	3	41	3 499	2
Belgium	48	5	71	1 873	1
Netherlands	13	7	15	1 629	1
Switzerland	0	0	0	1 110	< 1
Spain	8	14	43	1 027	< 1
Sweden	1	5	10	500	< 1
Denmark	3	2	10	141	< 1
Austria	0	3	9	116	< 1
Norway	8	0	21	116	< 1
Finland	7	1	10	75*	< 1
Australia	0	0	0	71	< 1
Portugal	0	0	0	46	< 1
Greece	0	0	0	32	< 1
Turkey	1	0	16	13	< 1
Mexico	0	0	0	10	< 1
Ireland	0	0	0	4	< 1
New Zealand	0	0	0	1	< 1
Hungary	0	0	31	0	< 1
Iceland	0	0	0	0	< 1
Luxembourg	0	0	0	0	< 1
OECD Total	**2 939**	**1 049**	**51**	**158 625**	**100**

** Finnish data not included before 1990. French data not included before 1978.*
Source: IEA.

cumulatively over the last 25 years (Figure 27). These countries are Japan, the United States, Germany, France, the United Kingdom, Italy and Canada. Historical government spending on nuclear energy research and development by these countries is shown in Figure 28 (non-breeder fission technology) and Figure 29 (breeder and fusion technology). All countries but Japan and France have decreased their spending on non-breeder fission research and development since the mid-1980s. Japan and France are now devoting considerably more

Figure 28

Reported OECD Government Nuclear Energy R&D Spending, Non-Breeder Fission Technology, 1974 to 1998

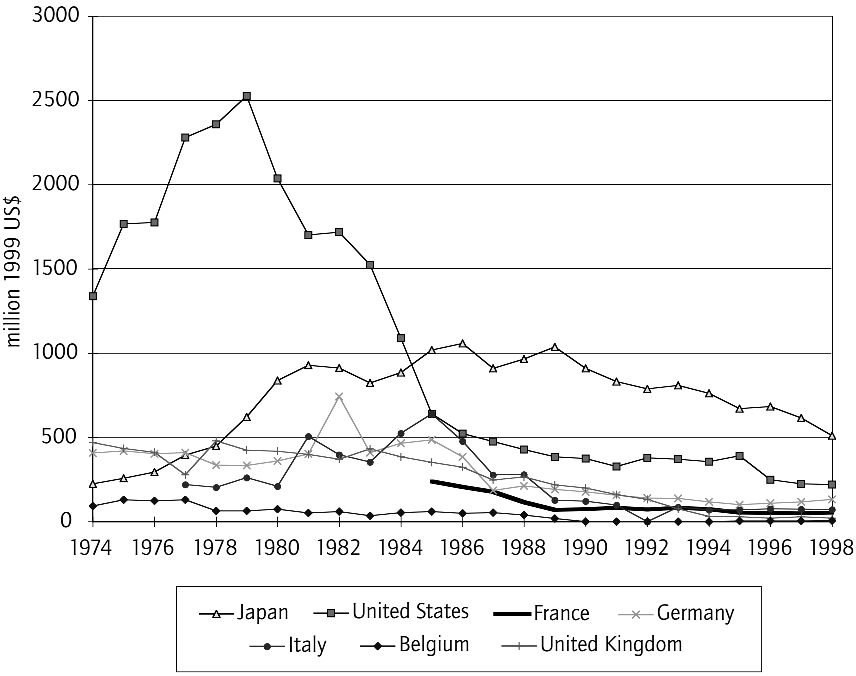


Note: Only those countries with reported cumulative spending of $1 billion or more are shown in this figure.
Source: IEA.

resources to research and development on conventional nuclear technology than all other OECD countries combined. They account for 90% of OECD spending in this area. In breeder reactor development, only Japan, France, Sweden and Canada reported any spending in 1998. In fusion research, 14 countries reported spending in 1998. Japan, Germany and the United States provided about three-quarters of total OECD funding of fusion research. These three countries have historically dominated government research spending on fusion, accounting for 75% or more of total OECD funding in this area.

Figure 29

Reported OECD Government Nuclear Energy R&D Spending, Breeder and Fusion Technology, 1974 to 1998



Note: Only those countries with reported spending of $1 billion or more are shown in this figure.
Source: IEA.

Spending by Technological Area

Figure 30 shows the shares of major technology areas in total OECD spending on nuclear research and development. Spending on technologies which are now in operation (light water reactors, Candu heavy water reactors, and British gas-cooled reactors) accounted for 9% of total spending from 1974 to 1998. Research on nuclear fuel cycles accounted for 23% and nuclear support technologies 16%. The remaining half of reported OECD government spending on nuclear research and development has been on reactor technologies which are not yet in commercial operation, namely, other converter reactors (7%) such as high-temperature gas-cooled reactors, breeder reactors (26%), and fusion reactors (18%).

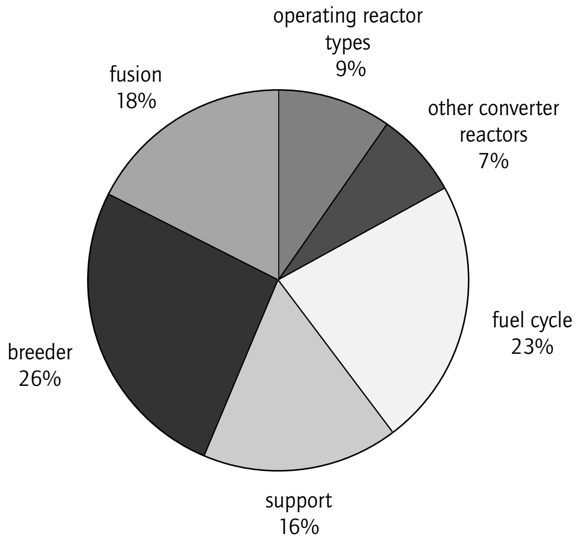
Research related to light water reactors has historically been the highest priority. Of this, research on safety has been predominant, while research on operations, fuel and economics has decreased in importance (NEA, 1996e: p. 18). This reflects the maturation of the fleet of nuclear plants and growing industrial experience.

As utilities have gained experience with existing reactor types, research on new types of reactors has diminished in most countries, except for fusion reactor research and for breeder reactor research in France and Japan. Radioactive waste management and nuclear plant decommissioning have taken a higher priority, in line with the current industrial and political importance of these areas. France has programmes in geological disposal, long-term waste storage and transmutation, the aim of which is to inform the ultimate decisions on long-term disposal options for high-level wastes. Japan has a significant programme in transmutation. Other areas of increasing emphasis are safety, fuel cycle improvements, life extension of nuclear plants and nuclear plant component repair (such as steam generators). Basic nuclear research has, in general, fallen to low priority.

Spending on different technological areas and on different reactor systems has differed greatly by country. Countries with smaller total nuclear research budgets generally focused their research money on light water reactors, the nuclear fuel cycle, and supporting technologies. Canada and the United Kingdom, since they have no light water reactors except Sizewell B in England, have devoted most of their reactor research funding to their domestic designs, Candu and gas-cooled reactor technologies, respectively. Germany and the United States had major programmes on high-temperature gas-cooled reactors in the 1970s and early 1980s. The United States had a very large breeder reactor programme in the 1970s, peaking at an annual expenditure of $1.5 billion in 1979. Italy, Japan, Germany and the United Kingdom also had large breeder reactor research programmes. Italy had a substantial research programme on reactors cooled with organic fluids.

Figure 30

Technology Shares in Government Nuclear Energy R&D Spending, Cumulative from 1974 to 1998



Notes: Finnish data not included before 1990. French data not included before 1978. Data on Hungary are not included.
Source: IEA.

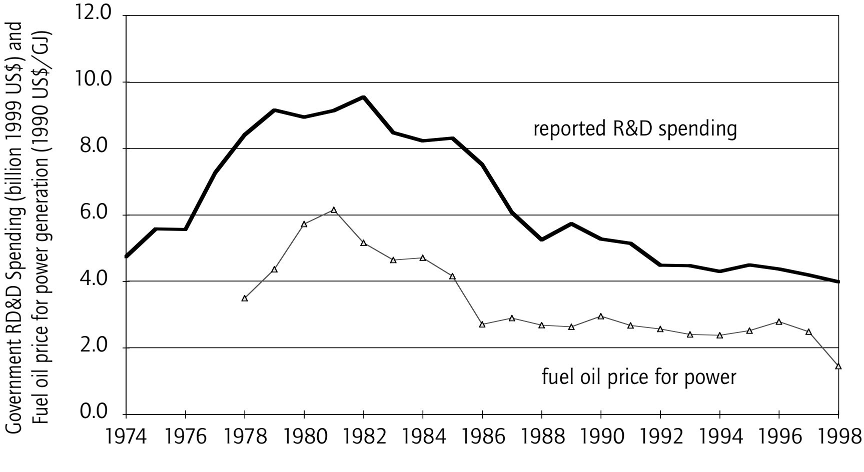
Correlation with Oil Prices

There is an interesting correlation between oil prices and total OECD government spending on nuclear research and development (Figure 31). Using the fuel oil price for power plants as a convenient indicator of oil prices relevant to power production, there has been a correlation factor of 90% between the two.

Many country-specific policy factors intervene in the allocation of research monies, such as concern about energy security, industrial policy, technological independence, and nuclear moratoriums. Accidents at nuclear facilities have affected spending on research projects. Declining government energy research budgets in general affect the total allocated to nuclear research. Furthermore, IEA data on

Figure 31

Total OECD Government Spending on Nuclear R&D Compared to Fuel Oil Price for Power Generation, 1974 to 1998



Notes: Finnish data not included before 1990. French data not included before 1978. Data on Hungary are not included.
Source: IEA

nuclear research and development are not complete. Notwithstanding these points, the relationship between research and the oil market is notable for the OECD as a whole. It suggests that governments adjusted their allocations to nuclear research with some attention to energy market conditions and the potential economic attractiveness of nuclear power. Energy security may be another important factor.

Technology Developments

In recent years the pace and funding of nuclear technology development has slowed substantially. Many nuclear research organisations have diversified into non-nuclear research areas and have increased the share of their income from non-governmental sources. There is at present very little funding for work on advanced systems of nuclear power utilisation. This reflects the current prospect of limited nuclear power growth in the near future. However, a number of advanced conventional reactor designs have been developed on paper and will be put into service as commercial opportunities allow. There are also numerous design concepts which address various design objectives not met by current or advanced reactors

Advanced Conventional Reactors

Advanced nuclear power plant designs and concepts have focused on improved reliability, better economics and enhanced safety. Design improvements have been introduced mainly in an evolutionary fashion through small modifications taking advantage of successful, proven design features and new technological developments, including in non-nuclear areas such as control and instrumentation (see IAEA, 1997).

Several nuclear power plants commissioned recently incorporate a number of key features of advanced reactor designs. Examples are: the first two 1 315 MWe advanced boiling water reactors, Kashiwasaki Kariwa 6 and 7, commissioned in 1996 and 1997 in Japan, and the 1 400 MWe N4 units in the Chooz and Civaux plants, in France.

Advanced light water reactors under development include large size units (1 200 to 1 300 MWe), and mid-size plants (~ 600 MWe). Important programmes in advanced light water reactor development were initiated in the mid-1980s in the United States. Three large evolutionary plants, the System 80+, the Advanced Boiling Water Reactor and the AP600, received design certification from the US Nuclear Regulatory Commission (NRC) between 1997 and 1999. In Europe, France and Germany have developed a 1 500 MWe advanced PWR, the European pressurised water reactor known as the "EPR", with enhanced safety features likely to meet the requirements of French and German safety authorities. Finnish and Swedish utilities have worked with the supplier of the BWR 90+ plant to develop its design. Efforts to develop advanced light water reactors are being pursued in other OECD and non-OECD countries such as Japan, Korea, China and Russia.

Advanced evolutionary heavy water reactors are under development in Canada. These new designs are based upon Candu 6 and Candu 9 plants. Recent experience with plants under construction or recently built in China, Korea and Romania provide useful feedback in improving the technology and economics of Candu designs.

All advanced reactors aim to enhance the competitiveness of nuclear power as compared to fossil-fuelled power plants, especially gas-fired plants, while also maintaining high safety standards. Owing to the cost structure of nuclear-generated electricity, designers have focused their efforts on reducing capital costs (NEA, 2000a). Shortening construction times reduces interest paid during construction, which is a significant component of nuclear investment costs. Progress has been made already in this regard; nuclear units commissioned recently in Japan and Korea were built in 4 to 5 years. At the same time, advanced reactors are designed to last longer – up to 50 to 60 years. Extending operating lifetime decreases levelised electricity generation costs. Simplification is a key goal in the design of advanced reactors since reducing the complexity of nuclear steam supply system components reduces costs, makes operation and maintenance easier, and improves safety. Advanced reactor designs aim at more compact, simplified plant layout, smaller buildings and structures, fewer safety-related valves, pumps and piping and simplified steam turbines.

Another area of cost reduction is in fuel utilisation. Advanced reactor designs aim to improve fuel energy utilisation ("fuel burnup") and lower the total cost of fuel fabrication and other cost components related to the amount of fuel handled. Improving nuclear plant thermal efficiency also reduces the cost of fuel. This was a particular objective of the development programme for the Advanced Boiling Water Reactor.

New Reactors

Some have argued that improving existing thermal reactors will not be sufficient to improve nuclear power's economic performance or safety significantly (e.g. Stadie, 1999). There is lively debate as to whether entirely new reactor designs are called for, but in any case a number of research activities in OECD countries have aimed to depart substantially from the currently dominant designs. Over the years, many designs have been studied, some followed by test or prototype reactors. In the 1980s and early 1990s, there was an emphasis on plant designs with some form of "inherent" or passive safety. This was in reaction to increasingly stringent safety requirements which, when met with engineered systems, resulted in increased plant capital cost (Forsberg and Reich, 1991). More recently, there has been an emphasis on designs with the potential to drastically reduce generation cost.

The United States Department of Energy has undertaken a Nuclear Energy Research Initiative to "develop advanced reactor and fuel cycle concepts and scientific breakthroughs in nuclear technology to overcome the principal technical and scientific obstacles to the expanded use of nuclear energy." The Initiative funds projects in proliferation-resistant reactor and fuel technology, new reactor designs with higher efficiency, small reactors, waste disposal, and advanced nuclear fuels. In January 2000, a group of countries began discussions on a multi-lateral effort to explore so-called "Generation IV" nuclear plant designs. Canada, France, Japan, Korea, the United Kingdom and the United States joined in the discussions.

Atomic Energy of Canada, Limited (AECL) has been developing concepts for a "Candu-X" reactor that departs more widely from the evolutionary improvements in other Candu plant designs. Among other innovations, the Candu-X would use supercritical steam generators to improve thermal efficiency. In parallel, AECL is developing advanced fuel cycles that could use slightly enriched uranium (as opposed to the natural uranium used in current Candu reactors), uranium recovered from reprocessing of spent light water reactor fuel, MOX or thorium.

The high-temperature gas-cooled reactor is currently attracting much interest. In this design, an inert gas such as helium cools the reactor core. The gas can be heated to temperatures high enough to drive a gas turbine or to provide process heat. Proponents of the reactor cite a combination of positive characteristics:

- Excellent safety performance, even in the absence of reactor core cooling.
- Ability to take advantage of improved gas turbine technology.
- Favourable characteristics for plutonium consumption.
- Strong economic potential at a relatively small size.

The Dragon test reactor was the first high-temperature gas-cooled reactor to operate, from 1964 to 1976, in the United Kingdom. This was a co-operative project of the OECD Nuclear Energy Agency. Four larger, electricity-producing reactors were operated in Germany and the United States from the 1960s to the end of the 1980s. These early plants were not very successful commercially, with an average utilisation rate of less than 25% and an average operating lifetime of 11 years. The Japan Atomic Energy Research Institute has been pursuing the concept for many years and placed a 30 MWth reactor into service in 1998. The South African utility Eskom has been developing a prototype reactor of this type since 1993. The British nuclear supplier BNFL joined the project in 2000. Russia and private companies in the United States, France and Japan have a joint programme to develop a high-temperature gas-cooled reactor to dispose of military plutonium.

Various teams have developed nuclear reactor concepts that rely on factory-manufacture of most components. Modular reactors and supporting nuclear systems could be produced in controlled factory conditions, then shipped to the plant site and assembled with relatively little on-site labour. This approach would reduce fabrication and construction costs, improve the quality of the systems, and reduce construction time. The electrical generation capacity of individual modules would be limited by the physical size of components that can be easily shipped and would also depend on the type of reactor. Therefore, economies of scale for individual reactor units might be limited. A programmed series of units using modular construction techniques could provide a balance between manufacturing costs and economies of scale, both in operation and decommissioning. Russian teams are exploring the use of shipbuilding techniques for nuclear plant construction. Complete designs for barge-mounted systems have been developed in the past and a ship-mounted 10 MWe plant built for the US Army supplied power to the Panama Canal Zone from 1968 to 1975.

Although many countries once supported fast breeder reactor programmes, all OECD countries but Japan have ended them. Various prototype reactors have been built, but none demonstrated a commercially viable concept. The co-operative European project to build the 1 200 MWe Superphénix plant, placed into service in France in 1986, ended formally in 1998 after technical-economic failure. The only other large, recent prototype breeder project, the 280 MWe Monju plant in Japan, suffered a sodium leak in 1995 and has not operated since. The need to use liquid sodium or other liquid metals has proven to be a particularly difficult technical challenge for breeder reactors. Russian designers have proposed using lead as a coolant.

Molten salt reactors and reactors providing heat for non-electricity applications have been studied. The interest in waste transmutation has spurred studies of reactors capable of incinerating transuranics and long-lived fission products. Fast reactors and accelerator-driven reactors are candidate systems.

Availability of Technology and Expertise

The current outlook for nuclear power raises concern within the industry and some governments that the availability of nuclear technology and expertise could be threatened. With few new plants expected in OECD countries and the eventual retirement or closure of many plants due in the coming decades, the infrastructure built up since the beginning of commercial nuclear power will shrink. This process has already begun in nuclear research establishments, educational programmes and equipment suppliers.

Among organisations specifically providing equipment and services for new nuclear plants, particularly nuclear reactor vendors, over-capacity has already led to consolidation and re-orientation towards support of existing plants. Equipment suppliers need few engineers able to design new plants and systems. A similar situation exists among suppliers of other equipment and services for existing nuclear plants. All companies involved in the supply of nuclear fuel (mining, conversion, enrichment, fuel fabrication) have been under pressure from over-capacity and the availability of military surplus uranium and plutonium. Electricity market competition will tend to intensify the pressure and spur changes among these companies.

A leading example is British Nuclear Fuels Limited, a UK-government owned company. In 1998 the company purchased, along with a US partner, the civilian nuclear power activities of the US company Westinghouse, the company with the largest share of installed nuclear plant reactors. In 2000, BNFL purchased ABB Nuclear.

It becomes more difficult for regulators to maintain the relevant technical knowledge when, for example, applications for new plants diminish in number or disappear. The decreased availability of nuclear research facilities may make it more difficult to develop solutions to new problems. Nonetheless, the absolute priority given to safety and to safety regulation should ensure that regulators have access to research facilities for which they have a real need.

Educational programmes in nuclear sciences have decreased steadily in the past 20 years. In the United States, for example, the number of annual graduates in nuclear engineering dropped from 800 to 300 during that period and the number of university reactors dropped from 70 to 30. On the other hand, in OECD countries as a whole, university graduates in nuclear technical programmes have remained nearly constant in the last decade. Over the period 1990 to 1998, about 3 000 degrees have been awarded annually (NEA, 2000b).

The first wave of nuclear engineers and managers who began their careers in the 1970s will be retiring in coming years. The nuclear workforce in most countries is old compared to other industries. In the United States, the two trends of decreasing university graduates and ageing workforce have pushed salaries of nuclear engineers to the second highest rank among all engineering specialities, after petroleum engineers.

The centre of nuclear expertise and experience with the latest power plants could shift to those countries where there is growth in nuclear power. This would most likely be in Asia, particularly China.

ANNEX I

NATIONAL DEVELOPMENTS AND CURRENT ISSUES

This annex briefly summarises nuclear power issues in OECD countries. It is selective and addresses broad or topical issues. In most OECD countries, nuclear plants and fuel cycle facilities are operating without particular incident or ongoing controversy. The descriptions below do not attempt to describe the prosaic, but important, contribution of nuclear power to each country's energy supply. More complete overviews of national nuclear power programmes are available in IEA in-depth country reviews. Detailed descriptions of nuclear power programmes are available from the OECD Nuclear Energy Agency[7]. Table 32 categorises OECD countries according to the status of nuclear power in each country. Of the countries that do not currently use nuclear power, only Austria, Italy and Turkey are covered in this annex.

Austria

A single nuclear power plant was constructed at Tullnerfeld, but it never went into service following the results of a referendum held in November 1978. Austria maintains a strong anti-nuclear stance, promoting a general nuclear phase-out. It has placed great emphasis on the safety of nuclear power in countries wishing to accede to the European Union.

7. NEA, 1995, *Nuclear Energy Programmes in OECD/NEA Countries,* Information Brochures, Organisation for Economic Co-operation and Development (Paris, France).

Table 32

Nuclear Power Status in OECD Countries

Currently Use Nuclear Power			Do Not Currently Use Nuclear Power
Plans for Growth	No Restrictions on Future Use	Policy or Legal Restrictions on Future Use	
Japan Korea	Canada Czech Republic Finland France Hungary Mexico Spain United Kingdom United States	Belgium Germany Netherlands Sweden Switzerland	Australia Austria Denmark Greece Iceland Ireland Italy Luxembourg New Zealand Norway Poland Portugal Turkey
Share of OECD Electricity Generation (1998)			
14%	64%	10%	12%

Belgium

Nuclear electricity from two plants supplies just over half of Belgium's electricity. The Belgian utility Électrabel owns these plants, while Électricité de France has a 50% share of the Tihange 1 unit and SPE (a Belgian utility) has 4% shares in four other units. Électrabel also has a 25% share in two units of the Chooz nuclear plant in France.

From 1966 to 1974, the Eurochemic company operated a reprocessing plant at Mol. Subsequently, spent fuel from Belgian plants has been reprocessed by Cogema in France under contracts dating from 1978. Following a parliamentary resolution of December 1993, the government decided that both reprocessing and direct disposal should be considered as equal options for spent fuel in Belgium, but that no new reprocessing contracts should be concluded for a 5-year period. Reprocessing contracts concluded after the late 1970s were put on hold. At the time it was decided to allow the use of MOX fuel in two Belgian units, Doel 3 and Tihange 2. MOX fuel is produced at the Belgonucléaire plant in Dessel.

Historically nuclear power has enjoyed strong and sustained support. However, in 1999 the coalition government decided on a policy of gradual phasing-out of nuclear power. Nuclear plants are to be decommissioned once they have completed 40 years service. The government also approved the cancellation of a 1991 reprocessing contract with Cogema and imposed a moratorium on reprocessing of spent fuel.

Canada

Canada pursued an independent path towards commercial nuclear energy, ultimately leading to the development of the heavy water Candu reactor by the government corporation Atomic Energy of Canada, Ltd. Canada is the largest producer of uranium in the OECD. Until 1999, Ontario Hydro operated about 90% of Canada's 15 000 MWe nuclear capacity at three large multi-unit plants. In April 1999, Ontario Hydro was split into five separate companies. Ontario Power Generation Inc. became the owner of Ontario Hydro's nuclear plants, representing 90% of Canada's nuclear capacity. By 2010 the company will be required to reduce its provincial market share from 85% to 35%.

Canadian nuclear power plants enjoyed a long period of successful technical performance beginning in 1967. In 1997, after a deterioration in the operating conditions of the nuclear stations was identified, Ontario Hydro established a nuclear performance and assessment group which concluded that operation of all 19 units would "continue to degrade long-term safety and performance" [8]. At the time, the reactors were, in the opinion of Canada's nuclear regulator "operating safely under the conditions of the licence and for the length of time the licences were issued". In order to bring the other 12 units back to "a high level of safety and efficiency", the Ontario Hydro Board of Directors adopted the group's recovery plan, which included temporary lay-up of seven units, four at Pickering A and three at Bruce A. In 2000, the Board of Ontario Power Generation (one of the successor companies of Ontario Hydro) gave its approval to bring the units of the Pickering A plant back into service. A screening environmental assessment review of the plan to restart the Pickering A plant has been completed. In July 2000, Ontario Power Generation announced an agreement to lease all units of the Bruce plant, including the three laid-up units of Bruce A, to British Energy.

The Atomic Energy Control Board was re-organised in 1999 to strengthen safety regulation. The board, now known as the Canadian Nuclear Safety Commission, has new compliance and enforcement powers.

In March 1998, a government commission appointed by the federal Minister of the Environment completed a comprehensive review of plans for high-level waste disposal. The commission report concluded that "From a technical perspective, safety of the [deep geological] concept has been on balance adequately demonstrated for a conceptual stage of development, but from a social perspective, it has not." The concept of geological disposal had not been demonstrated to have broad public support. The commission called for greater involvement of nuclear utilities and greater public involvement to arrive at an acceptable solution. A revised process for developing long-term solutions to nuclear waste management and disposal is under development.

8. Testimony of William Farlinger, Chairman of Ontario Hydro.

Czech Republic

The Czech Republic has one nuclear power plant that supplies about 20% of the country's electricity. The Dukovany plant has four Soviet-designed VVER units that entered service between 1985 and 1988. A modernisation programme is under way to enable the plant to continue operating for 40 years. Two units with a total capacity of 1 800 MWe have been under construction since 1982 at the Temelin plant. The plant has been much delayed by successive projects to improve and modernise its safety systems. The first unit could go on line in 2001. The government re-affirmed its support for completion of the project in May 1999.

The "Law Concerning Peaceful Utilisation of Nuclear Energy and Ionising Radiation" was approved by the Czech Parliament and went into effect on 1 July 1997. Following the provisions of this law, a new Radioactive Waste Repository Authority was established.

Finland

Finland has an unusual mix of nuclear plants: one Soviet-design VVER and one western PWR. The plants have excellent operating records, account for about one-third of Finland's electricity generation and compete within the Nordic electricity market. There are geological waste disposal facilities at each plant for low-level waste. The utilities Fortum and TVO have been considering the construction of one new nuclear unit each and submitted environmental impact assessments to the Ministry of Trade and Industry in 1999. The assessment process for both units concluded successfully in January 2000. The two companies announced at the end of 1999 that TVO would be responsible for any new nuclear project. In November 2000, TVO has applied for a government decision in principle to build the fifth reactor. The Council of State must decide in principle, in accordance with the Nuclear

Energy Act, whether the project is "in line with the overall good of society". The Council's decision must be ratified by the Parliament.

France

French energy policy has shown an uncommonly strong commitment to nuclear power. The fraction of electricity supplied by France's nuclear plants (about three-quarters) is the highest in any country in the world. In nuclear plant capacity, France is second only to the United States. France developed an early and sustained nuclear programme immediately following the Second World War through its Commissariat à l'Énergie Atomique (Atomic Energy Commission) and state-owned utility Électricité de France. France attributes its successful nuclear programme to standardisation of plant design, sustained industrial development and a supportive government attitude. The latest French plant was placed into service in 1999. France has numerous fuel cycle facilities, including enrichment, conversion and fuel fabrication facilities. The reprocessing plant at La Hague is one of only two large reprocessing plants in the OECD.

Current issues in France have been:

- Transportation of spent fuel in rail wagons that did not meet regulatory limits on radioactive contamination.
- Continued development of underground research laboratories for high-level waste disposal.
- Reorganisation of the nuclear safety authority to give it greater autonomy from government ministries.
- Closure of the Superphénix breeder reactor power plant.
- Political support for a decision to build a new nuclear plant based on the European Pressurised Water Reactor design.

French industry and Électricité de France have argued that a prototype plant based on the new design must be ordered within a few years or they may lose a minimum level of industrial capability. Framatome, the state-owned nuclear supplier, and the German company Siemens created a joint venture in late 1999 to pool their commercial activities in nuclear equipment supply.

The arrival of an environment minister belonging to the Green Party in 1997 has livened political discussions of nuclear power. The government believes greater openness and democratic debate are needed in nuclear policy. A draft law to reinforce the independence of the safety regulator is under development.

Germany

Nuclear power provides about one-third of German electricity. Since the early 1980s, the German environmental movement has put increasing pressure on supportive government policy towards nuclear power. Three separate nuclear facilities were built but unable to operate because of public and political opposition: the 1 219 MWe Mulheim Karlich nuclear power plant, the prototype fast breeder at Kalkar, and the Hanau MOX fuel fabrication plant. Political opposition culminated in the 1998 election of a coalition government whose aim was to phase out the use of nuclear power.

The government negotiated with nuclear utilities throughout 1998, 1999 and 2000 to seek an agreement on how to implement its phase-out policy. Issues of reactor lifetime, taxation, trade, environment, electricity prices, and overall energy policy were raised in the negotiations. A memorandum of understanding was signed in June 2000 that fixes a total quantity of electricity that may be produced by German nuclear plants. The agreement provides plant operators with the flexibility to allocate a total generation of 2 623 TWh among nuclear plants as they wish, on the basis of an assumed standard lifetime of 32 years. The federal government and the electricity suppliers assume that the understanding and its implementation will not give rise to any damage claims among the parties.

In 1998 the government decided to stop foreign reprocessing of spent nuclear fuels as of January 2000. Owing to a lack of consensus within the government, opposition from the nuclear industry and diplomatic issues with France and the United Kingdom (where the reprocessing plants are located), the government postponed the deadline. The June 2000 agreement allows transports of spent fuel to reprocessing facilities, after which direct disposal of spent fuel will be the only permitted option up to July 2005. Utilities are to establish interim spent fuel storage facilities at their plants to hold fuel before a permanent centralised disposal site is in service.

The Atomic Act is to be amended according to the memorandum of understanding reached between the government and utilities.

The revelation of contaminated rail transport wagons caused a political scandal in 1998. The government gave permission to resume waste transports in 2000.

Hungary

Hungary has one 1 840 MWe nuclear plant at Paks supplying about 40% of Hungary's electricity. The plant consists of four Soviet-designed VVER reactors. The technical and economic experience with the plant has been very satisfactory.

The 1997 Nuclear Energy Act updated the regulatory framework for nuclear power in Hungary. Among other effects, it declared safety to be the highest priority, it created an independent regulatory agency, the Nuclear Safety Directorate of the Hungarian Atomic Energy Authority, it assigned financial responsibility for accidents to nuclear plant operators, and it established a central fund for financing waste disposal and decommissioning. This fund became operational at the beginning of 1998.

A new entity called Puram (Public Agency for Radioactive Waste Management) was created in 1998. This entity is responsible for running the disposal facility for low- and intermediate-level wastes at Püspökszilágy and to pursue development of a new disposal facility for the same wastes. Spent fuel from the Paks plant is stored on site in a dry vault storage system. Siting studies for a final disposal facility of spent fuel are under way.

Italy

Italy had an active nuclear power programme in the 1960s to the 1970s. Four plants with a total capacity of 1 450 MWe were built, as well as a number of test reactors. In 1987 a referendum led to the closure of all four plants. A law confirmed the closure in 1990.

In December 1999, the government announced plans to establish a national radioactive waste disposal facility and dismantle the disused reactors. A new company called SOGIN (Società gestione impianti nucleari per azioni) will be responsible for implementing the government plan. Wastes currently in on-site storage are to be treated and conditioned within 10 years. A national repository for low- and intermediate-level waste is to be developed within 10 years. The nuclear plants will be decommissioned within 20 years. The cost of the programme was estimated at €3.1 billion.

Japan

Nuclear power is an important and fundamental element of Japanese energy policy. Since Japan has no substantial indigenous energy sources, the Japanese government has consistently promoted the development of nuclear energy to help ensure a stable supply of energy, and continues to view this as fundamental in the context of a forecast sharp increase of energy demand in Asia. Nuclear power is also seen as a key to sustainable development and to meeting the objectives of climate change policy, which for Japan involves a 6%

reduction in CO_2 emissions from the 1990 baseline. (In the energy sector, the government's target is to achieve no increase from 1990 levels.) It is for these reasons that Japan has promoted the establishment of an indigenous nuclear industry based on the whole fuel cycle, including reprocessing of spent fuel, and significant R&D facilities.

Nuclear power supplies about one-third of Japanese electricity and represents the country's single largest source of non-fossil energy. Its nuclear capacity is third after the United States and France. The technical performance of Japanese nuclear plants, such as measured by utilisation rate, steadily increased in the 1990s. There is a substantial programme for the ongoing development of the nuclear industry. The government's aim is for the installation of additional generating capacity of over 20 GWe, though this target is under review and will likely decrease. Japan has a small enrichment plant and reprocessing plant, along with various test and development reactors. Government spending on nuclear research and development is the highest in the OECD.

Under the government policy to reprocess spent fuel, the latter is stored as an energy stockpile until it can be reprocessed. The government therefore intends to open an interim spent fuel storage facility by 2010. To date, all reprocessing has been done in the European reprocessing plants, but a reprocessing plant in Rokkasho is expected to enter into operation in 2005. In the short term, policy is to use recovered plutonium in light water reactors as MOX. As of March 2000, four nuclear plants are licensed to use MOX fuel, though none had begun using it. The Atomic Energy Commission expects to publish in 2000 a "New Long-Term Programme for Research Development and Utilisation of Nuclear Energy".

However, the government is also involved in the ongoing process of addressing effectively the issues, including management problems and public confidence, arising from plant accidents that occurred in the 1990s, the most recent of which was a criticality accident at the Tokaimura fuel fabrication facility in October 1999 (the second incident in Tokaimura). These incidents have concerned R&D and waste disposal facilities, and have not therefore directly called into question the safety of commercial power plants. Nevertheless, the incidents have increased public concern over nuclear energy.

In August 1996, the town of Maki voted down the construction of a nuclear power plant, the first such instance in Japan. There have been other instances of public opposition (for example, to planning for a permanent waste disposal site). In some cases, opposition to new facilities from local and other interest groups is strong. Once facilities are established, local residents are mostly positive, where local development measures are made available. The problem of public opinion for major facilities is not related to nuclear energy alone. Some communities have also begun to raise objections to the location of industrial waste disposal sites.

The government and the electricity companies have responded by improving information disclosure and dissemination, and improving the transparency of procedures in the nuclear programme. Official inquiries into the problems have also highlighted the need for better management and improved nuclear safety regulations. As a result, a number of actions have been taken to restore public confidence. A report by the Nuclear Energy Sub-Committee in January 1997 emphasised the need for policies directed towards the communities where nuclear plants are located, aimed at building up regional economies, closing the awareness gap between residents of areas with nuclear power sites and urban energy consumers (who take a stable energy supply for granted) and improving transparency in nuclear policy-making, including opportunities for public comment.

A law on the final disposal of certain radioactive wastes was enacted in May 1999, and a law regulating interim off-site spent fuel storage facilities and their operators was passed by the Diet in June 1999. In line with these laws, the government is currently considering the allocation of public sector and private sector responsibilities in nuclear waste disposal, the establishment of a waste management fund from levies on nuclear power generation, and creation of an independent body for nuclear waste management.

Institutional arrangements have been strengthened. The Power Reactor and Nuclear Fuel Development Corporation was reorganised as the Japan Nuclear Cycle Development Institute in 1998. Most recently, the government passed a set of laws in December 1999, immediately following the Tokaimura accident. These were a revision of the Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (for the enforcement of safety surveillance) and a "Special Law for Nuclear Disaster Measures".

The Japanese government remains strongly committed to nuclear power and to pursuing improved transparency and dialogue with the public on nuclear policy.

Korea

Korea's nuclear plants provide over 40% of the country's electricity. Because South Korea has very limited domestic energy resources, nuclear power was perceived as a potential resource for electrical power as early as the 1960s. The government has a long-standing and consistent policy to support nuclear power development. This has been implemented by, most importantly, the state-controlled (57%) Korean Electric Power Company, KEPCO. Nuclear plants have been added regularly to the Korean system since 1977. The country has an unusual mix of light water reactors from two vendors (ABB/Combustion Engineering and Westinghouse) and Candu heavy water reactors. Two units are under construction. Korean power plants have shown very satisfactory economic and technical performance.

As part of a programme to restructure the electricity supply industry, the government intends to divide KEPCO's generation plants into six subsidiaries, including a wholly nuclear subsidiary that will remain in public hands. The basic electricity reform plan recognises the continued importance of security of supply and of nuclear power in the overall energy mix. KEPCO is continuing with plans to construct ten additional nuclear units by 2010.

As in other countries, plans for disposal of radioactive waste have met with increasing public opposition, which has slowed their timetable. Site studies on the east coast of Korea were halted in 1989 by local opposition. Potential work at a new site on Anmyon Island, off the west coast of Chungnam Province was cancelled in 1990, and a waste disposal project at Kurop Island was cancelled in 1995, both because of public opposition. For the time being, wastes and spent fuel are stored on site at nuclear plants.

Mexico

Mexico became the latest OECD country to introduce nuclear power in its energy supply in 1990, when the first unit of the country's single 1 308 MWe plant at Laguna Verde began commercial operation. The plant provides about 5% of the country's electricity.

Netherlands

The Netherlands has a single operating nuclear plant at Borssele providing about 5% of national electricity production. The plant was extensively refurbished and upgraded in a project that ended in 1997. A small plant at Dodewaard was closed in 1997 for economic reasons. The Urenco Company has an enrichment plant at Almelo. The Dutch Parliament voted in 1994 to close the Borssele plant by the end of 2003. The government adopted this decision and limited the validity of the plant's operating licence to the end of 2003. However, the Dutch High Administrative Court ruled in February 2000 that the modification of Borssele's licence was not legal. Therefore, there remains uncertainty on the implementation of the parliamentary decision.

Spain

There are seven nuclear plants in Spain, the last plant coming on line in 1988. They provide about one-third of national electricity production. Spanish nuclear policy was marked by a 1984 moratorium on five units under construction. The 1994 Electricity Law confirmed this decision, without legally ruling out nuclear power as a future option. Repayment of the debt on the partially completed plants (about $6 billion) has proven to be a highly visible issue, particularly as Spain made the transition to a competitive electricity market beginning in 1997.

Sweden

Four nuclear plants supply over half of Sweden's electricity. These plants operate within the NordPool competitive electricity market and have shown good technical and economic performance. Sweden has two underground laboratories for geological disposal of spent fuel.

The main issue in Swedish nuclear policy has been the policy of phasing out nuclear power. A 1980 referendum resulted in a parliamentary decision that foresaw the closure of all nuclear units by 2010. There has been an ongoing debate on how to implement the parliamentary decision and successive governments have opted for different solutions. In 1997, Parliament decided on guidelines for Swedish energy policy, including a modified policy on nuclear power.

In its decision on guidelines for energy policy, Parliament stated that 2010 should no longer be considered as the year for final closure of all nuclear reactors. The decision stated that the two reactors at the Barsebäck plant should be closed, one by mid-1998 and the other by mid-2001. The closure of the second reactor should only take place provided that the corresponding loss in generation can be compensated for by a reduction in electricity demand and by new generation. The energy policy decision also stated that the government should decide on a policy of phasing out the remaining nuclear power plants before 2002 elections. Closure of the Swedish nuclear plants poses a challenge for Swedish commitments to the Kyoto Protocol, and a climate policy strategy is therefore an important part of Swedish energy policy. According to the "Act on Phasing Out Nuclear Power", the owner of a nuclear plant is entitled to compensation when the plant is to be closed. An agreement has been reached between the Swedish State and the owner of the Barsebäck plant on compensation for closure of the unit 1 reactor. The agreement was approved by Parliament in May 2000.

Switzerland

Switzerland's four nuclear plants provide about 40% of the country's electricity. The Beznau and Gösgen plants also provide process and district heat. The performance and safety records of the plants are excellent; capacity of existing nuclear plants has increased by 5% since 1990 after plant upgrades. Switzerland has no domestic fuel cycle industry. A central interim storage facility for spent fuel and high-level wastes began operation in 2000.

The Swiss population was asked to vote five times on constitutional amendments regarding nuclear power. In September 1990, a referendum resulted in a 10-year moratorium on the construction of any new nuclear power plants. Two further popular initiatives gathered enough signatures to require a vote possibly by the end of 2001. The first initiative, "Power without Nuclear", seeks closure and decommissioning of the five Swiss nuclear power plants after 30 years of operation. The second one, "Moratorium Plus", aims to extend the current moratorium on construction of new nuclear reactors for another ten years.

A conflict-solving group including members of the federal administration, the nuclear industry and environmental organisations was set up to find a common solution for reprocessing and/or direct disposal of spent fuel. However, in 1998, this conflict-solving group ended its work without any common solution. Reprocessing contracts with French and British reprocessing companies cover about one-third of total spent fuel expected to be generated. In February 1999, the Swiss federal government announced plans to end the reprocessing of spent nuclear fuel. This change would not affect existing reprocessing contracts.

The Atomic Energy Law expired in 2000, about the same time as the moratorium on new plant licences. A new draft law is being prepared.

Turkey

Although there are no nuclear power plants in Turkey, the Turkish government has long held the goal of introducing nuclear power to the country. In 1977, a licence was issued to the Turkish Electricity Company for the construction of a nuclear power plant at Akkuyu on the Mediterranean coast. The project was suspended in 1980 after failure to reach agreement with plant suppliers. Two other projects to build nuclear plants at Sinop on the Black Sea and at Akkuyu were abandoned in the early 1980s, also because of the inability to reach agreement with bidders. Another attempt to develop a nuclear plant at Akkuyu began in 1995. Bids were solicited in late 1996, but no award was made. The government suspended the project indefinitely in July 2000.

United Kingdom

The United Kingdom independently developed the Magnox and AGR series of gas-cooled reactors and was the first country to introduce commercial nuclear power in 1956. The latest plant is the country's single pressurised water reactor, Sizewell B, which was put into operation in 1995. There is an extensive group of nuclear facilities, including a Urenco enrichment plant, fuel fabrication plants and numerous test and development reactors. Nuclear power supplies about one-quarter of British electricity. British Nuclear Fuels Ltd. (BNFL) commissioned the second large OECD reprocessing plant for oxide fuels (i.e. from all commercial reactors except Magnox) at Sellafield in 1997.

In 1990, the United Kingdom became the first OECD country to introduce a competitive electricity market. At that time the nuclear plants were placed in a government corporation called Nuclear Electric in England and Wales, and in Scottish Nuclear Ltd. in Scotland. Subsequently, the modern AGR gas-cooled reactors and the Sizewell B plant (about three-quarters of total nuclear capacity) were placed into a new company, British Energy. This company was privatised in 1996. British Energy is the UK's largest single supplier to the electricity market. The older Magnox plants remained in state hands and were transferred to BNFL in 1998. In June 2000, the company announced a phased programme for the closure of the stations which reflects their licensed lifetime. Under this programme, the latest station would close in 2021. BNFL stated that market conditions and technical issues could result in earlier closures.

High-level waste generated from spent fuel reprocessing at Sellafield is being progressively vitrified and stored at the site for at least 50 years. UK Nirex Ltd (Nirex) is responsible for providing and managing facilities for the safe disposal of intermediate and certain low-level radioactive waste. In March 1997, the Environment Minister dismissed Nirex's appeal for planning permission to develop the Rock Characterisation Facility (RCF) near Sellafield. The government decision letter restated that national policy was that a suitable site for a deep disposal facility should be found, and that the disposal facility should be built as soon as reasonably practicable. In March 1999, a committee within the House of Lords published the report of its enquiry into "The Management of Nuclear Waste". The report confirmed the principle of deep geological disposal of wastes, proposed a new non-governmental commission to oversee the implementation of radioactive waste disposal, and recommended the creation of a waste disposal company. The government continues consultations on future policy.

United States

The United States has the largest fleet of nuclear power plants in the world. US nuclear plants account for about one-fifth of total US power generation and one-third of total OECD nuclear power generation. The United States spearheaded development of OECD light water reactor technology beginning in the 1950s. The country has a wide variety of nuclear facilities in all phases of the fuel cycle and research and development. After a period of rapid growth in installed capacity and orders in the 1960s and 1970s, the 1979 accident at the Three Mile Island nuclear plant marked the beginning of a new period of consolidation of technological development and, later, plant optimisation. No new lasting plant orders were placed from 1974 onwards, and the last new plant came on line in 1996.

Electricity market liberalisation is currently a major issue affecting nuclear power. Several plants applied for extensions of their operating licences and the Nuclear Regulatory Commission expects many more. Many existing plants appear to be well placed to compete in electricity markets and changes in ownership continued in 2000. Companies are seeking to improve commercial performance of nuclear units by pooling expertise and consolidating operations. The government-owned enrichment company was fully privatised in July 1998.

The US Department of Energy, as its predecessors, has been responsible for nuclear technology development. In the 1990s, it has largely focused on cleaning up old nuclear facilities, including those related to military purposes, and on developing a disposal site for spent fuel and high-level wastes. The Yucca Mountain high-level waste project is probably the most advanced of OECD projects to develop a deep geological disposal site. It was originally planned to open in 1998, but current plans call for its operation in 2010. This delay has placed the government under strong pressure from nuclear utilities to accept spent fuel, which is currently stored in pools and dry storage systems at each power plant. Some plants face difficulties in storing additional spent fuel at their site that could lead to closure of the plants if not resolved.

Both houses of the legislature have debated measures to establish a federal interim central storage facility for spent fuel near the Yucca Mountain site, but no law has been enacted to do this.

The Nuclear Regulatory Commission has undertaken a programme to improve the quality, consistency and cost-effectiveness of its regulatory actions. The nuclear industry has been supportive of this reform and expects it could help to improve the economic foundation for existing and, eventually, new nuclear plants.

The government has pursued plans to dispose of surplus weapons plutonium in either MOX fuel or mixed with high-level waste. Spent fuel reprocessing was terminated in 1972 and government policy not to reprocess dates from 1978.

ANNEX II

IEA POLICY STATEMENTS ON NUCLEAR POWER

Statements by the IEA Governing Board

Nuclear power is mentioned in the IEA's 1974 founding treaty, the "Agreement on an International Energy Program". Article 41 states that the IEA's Standing Group on Long Term Co-operation should consider, among other areas for co-operative action, the development of energy resources such as nuclear energy. Information exchange, concrete projects and environmental protection issues were foreseen. Radioactive waste management and nuclear safety were identified as priority areas for co-operative research and development programmes. Uranium enrichment, then thought to pose a potential bottleneck in long-term nuclear energy supply, was to be considered at the same level of importance as energy conservation, the development of alternative energy sources, and research and development. In their first communiqué, IEA Energy Ministers called for expanded co-operation in the field of nuclear energy to ensure its development with due regard to safety and environmental conditions.

The second meeting of the Governing Board at ministerial level took place in 1977. At that meeting, ministers agreed upon a set of "Principles for Energy Policy", of which principle No. 8 was:

> *"Steady expansion of nuclear generating capacity as a main and indispensable element in attaining the group objectives, consistent with safety, environmental and security standards satisfactory to the countries concerned and with the need to prevent the proliferation of nuclear weapons. In order to provide*

for this expansion it will be necessary through co-operation to assure reliable availability of:

• adequate supplies of nuclear fuel (uranium and enrichment capacity) at equitable prices;

• adequate facilities and techniques for development of nuclear electricity generation, for dealing with spent fuel, for waste management, and for overall handling of the back end of the nuclear fuel cycle(1).

Note (1) The following Delegations expressed individual positions regarding Principle 8, as set forth in the Conclusions of the Meeting of the Governing Board which adopted this Decision: Denmark, Norway, The Netherlands, Spain, New Zealand, Sweden."

The individual positions referred to in Note 1 essentially reserve the right of each country to make its own decisions regarding nuclear energy, subject to national circumstances. The Spanish delegate made a formal remark about the meaning of "prevent proliferation." Annex B to the Principles states that several of the main R&D areas requiring emphasis are "improved performance of nuclear converter reactors", "nuclear fuel cycle issues, including safety and waste disposal", and "breeder reactors and alternative fuel cycles which are economically, politically and environmentally acceptable."

At the same meeting, IEA ministers called for

"6. ... Co-operative efforts to increase coal consumption, production and trade and to maintain steady expansion of nuclear power, consistent with non-proliferation and environmental concerns, as a main and indispensable element in attaining IEA group objectives. Some Ministers, however, expressed different views as to the nuclear principle and reserved their position with regard to that principle.

7. Ministers generally recognised that nuclear power will be required in order to attain IEA group objectives. Ministers of many Member countries expressed the determination of their

> *governments to expand their nuclear generating capacity. Ministers recognised that some of the constraints on development of nuclear energy can only be reduced by international co-operation. They agreed that given the importance of nuclear power as an alternative source of energy, the IEA should play an active role in the development of nuclear energy policies, taking full account of work being done elsewhere."*

At the outset of the IEA's work, Member countries clearly wished to support the co-operative development of nuclear power in those countries that sought it, while recognising that some countries did not consider nuclear power to be necessary or attractive.

In 1979, the Governing Board noted that nuclear projections had been lowered repeatedly and that the accident at Three Mile Island (three months before their meeting) had renewed public concern about safety. Ministers agreed on the "urgent need for effective national and international efforts to ensure that safety systems are sufficient to minimise the possibility of nuclear plant accidents and their consequences." They also agreed on the need for effective action on long-term waste disposal and non-proliferation. To help meet energy demand, timely additions to nuclear capacity were needed.

The accident at Three Mile Island prompted a critical review of nuclear power programmes in many countries. France and Japan were the only IEA countries in which there were lasting orders for nuclear power plants after 1980. Accordingly, joint statements by IEA Energy Ministers in 1980 and later emphasised the need to complete nuclear plants in progress. A 1980 analysis by the IEA Secretariat and adopted by the Governing Board suggested areas where energy policies could be strengthened in individual countries. It noted that Germany, Italy, Japan and the United States should make greater efforts to accomplish projected nuclear programmes and to create a "suitable environment" for discussing nuclear issues. Efforts by the countries should take into account economics, energy considerations, safety and non-proliferation. In 1981 and 1982, the Governing Board made short statements on nuclear power emphasising the need for timely completion of nuclear

Table 33

Statements on Nuclear Policy by the IEA Governing Board at Ministerial Level, 1975 to 1999

Year	Reference IEA/Press	Context of Meeting or of Excerpt	Main Nuclear Issues Mentioned
1975	A(75)20	first meeting	Co-operative programmes in nuclear energy. Co-ordinated nuclear R&D.
1977	(77)10	IEA Principles for Energy Policy	Steady expansion of nuclear capacity. Co-operation on nuclear fuel, spent fuel, and waste management. Exception of some countries with respect to the need for nuclear.
1979	(79)14	3 months after Three Mile Island accident	Safety. Undesirable economic and social consequences if more nuclear is not available.
1979	(79)28	after second oil shock	None.
1980	(80)8	Secretariat analysis	Need to accomplish projected nuclear programmes in Germany, Italy, Japan and the United States. Creating proper environment for discussion of nuclear issues.
1980	(80)20	special meeting to discuss oil market	None.
1981	(81)10	actions for structural change	Major and increasing role of nuclear power. Conditions for the timely growth of nuclear power: • Public understanding. • Waste management and disposal. • Licensing and regulation. • International trade in nuclear fuel and technology.
1982	(82)8	structural change	Major and increasing role of nuclear power. Slowdown in nuclear development programmes. Same issues as in 1981. IEA/NEA assessment of nuclear prospects to 2000.

Table 33

(continued)

Year	Reference IEA/Press	Context of Meeting or of Excerpt	Main Nuclear Issues Mentioned
1983	(83)6	annex to communiqué	Relevant issues for nuclear to fulfil its contribution to energy security: • Stable nuclear trade. • Nuclear safety standards and approval of facilities. • Spent fuel storage and waste disposal. • IEA/NEA identification of possible R&D programmes.
1985	(85)6		Progress and slowdown in nuclear programmes. Streamlined licensing, standardised designs, waste management.
1987	(87)4	one year after Chernobyl accident	Safety. Status of nuclear power programmes. Independent decisions on best national fuel mix.
1989	(89)4	diversity of energy supplies	Independent decisions on best national fuel mix. Safety.
1991	(91)7	after Gulf Crisis	Nuclear power's contribution to energy supply. Relevance to climate change. Independent decisions on best national fuel mix.
1993	(93)8	IEA Shared Goals and Ministerial Statement	Nuclear power's contribution to energy supply. Safety, waste management, decommissioning and role of OECD Nuclear Energy Agency in these areas. Independent decisions on best national fuel mix. Relevance to climate change.
1995	(95)14		None.
1997	(97)9	energy dimension of climate change	Nuclear power's role in reducing carbon dioxide emissions.
1999	(99)7		Assessment of full range of energy issues and choices, including renewables and nuclear power.

Source: IEA.

programmes. Ministerial communiqués mentioned the need to improve nuclear safety regulation and to maintain reliable and predictable international trade in nuclear materials and fuel cycle services.

A 1983 annex to the Ministerial Statement spoke about the issues relevant for nuclear power "to fulfil its important potential for contributing to overall long-term energy security." These again included stable trade in nuclear equipment, fuel and fuel cycle services, safety, international co-operation on spent fuel storage and waste disposal, and energy research and development. The IEA and NEA were requested to work together to periodically assess the progress of Member governments in waste disposal and R&D in advanced technologies.

The 1987 ministerial meeting took place one year after the explosion of the Chernobyl nuclear plant in the Soviet Union. Consequently, the Ministerial Statement at that meeting focused on nuclear safety and the status of nuclear power programmes in IEA Member countries. The different national choices with respect to nuclear power were emphasised. Each IEA country would have to decide on the mix of fuels best suited to its particular circumstances. Ministers gave their "full political and technological support to arrangements for international co-operation on nuclear safety which exist, or are being developed, particularly within the Nuclear Energy Agency of the OECD and the International Atomic Energy Agency. The 1989 ministerial meeting again noted the different positions of IEA Member countries regarding nuclear power. All IEA countries agreed "upon the necessity for continuing to apply the highest available standards of nuclear safety in all its aspects, particularly operation and waste management."

The 1991 statement by the Governing Board was the first to mention the environmental aspects of nuclear power. Ministers noted that

> *"A number of countries are also of the view that the use of nuclear energy, because it emits no sulphur dioxide, nitrogen oxides or greenhouse gases, provides an important response to the challenge of stabilising greenhouse gas emissions."*

The 1991 statement reflected the fact that some countries did not favour the nuclear option because of the health and safety issues associated with nuclear power plant operation and waste disposal. These issues were seen as regional, with cross-border implications. In 1993, ministers repeated the preceding quotation, appending to it the explicit point that

> *"A number of other IEA countries are of the opinion that those advantages do not offset the environmental concerns over the use of nuclear energy and have decided not to utilise nuclear power."*

IEA ministers adopted the "Shared Goals" at their 1993 meeting. These mention nuclear as follows:

> *"**1. Diversity, efficiency and flexibility within the energy sector** ... Non-fossil fuels, particularly nuclear and hydro power, make a substantial contribution to the energy supply diversity of IEA countries as a group.*
>
> ***4. More environmentally acceptable energy sources** ... The development of economic non-fossil sources is also a priority. A number of IEA members wish to retain and improve the nuclear option for the future, at the highest available safety standards, because nuclear energy does not emit carbon dioxide."*

No Governing Board statement since 1993 has addressed nuclear policy issues. The 1997 communiqué referred in technical terms to the role of nuclear power in decreasing the carbon content of IEA countries' energy requirements. The previous rate of "de-carbonisation" would be unlikely to be sustained, at least in part "because nuclear programmes have now been slowed or halted in most countries." In 1999, ministers asked the IEA Secretariat to "continue assessing the full range of energy issues and choices, including renewable energy and nuclear power."

Other IEA Policy Documents Concerning Nuclear Power

Since the IEA was established in 1974, it has continuously assessed the role of nuclear power programmes in national and international contexts. In 1975, the Standing Group on Long-Term Co-operation established a Sub-Group on Enriched Uranium Supply and an Ad-Hoc Group on Emergency Sharing of Enriched Uranium, Services and Natural Uranium. In 1976, these groups were reconstituted as the Nuclear Sub-Group, whose objective was to "review national nuclear policies and activities and to identify any constraints or limitations affecting the development of the nuclear sector" [IEA/SLT/M(76)8]. The group produced annual unpublished reports on the situation of nuclear power in Member countries. The group's work was discontinued following a 1986 decision.

All IEA in-depth energy policy reviews of countries with nuclear power programmes have assessed the role of nuclear power in those countries. In-depth reviews often provide recommendations on nuclear power programmes that are discussed by the Standing Group on Long-Term Co-operation. The policy recommendations are generally oriented to improving or maintaining the quality of national programmes on nuclear energy and encouraging governments to meet their own national goals with respect to nuclear power. Examples follow.

> *[Seek a] rapid decision on the future of the first nuclear power plant which has already been built. (Austria 1977)*
>
> *Proposals to facilitate the licensing procedure of light water reactors should be enacted and implemented promptly to shorten the lead time of approved facilities. (Unites States 1977)*
>
> *Avoid delays in the nuclear expansion programme. (Spain 1981)*
>
> *Seek solutions to overcome the lack of consensus on nuclear energy policy in order to continue to pursue efforts with respect to all elements of the fuel cycle. (Germany 1987)*

Support cost-effective development of nuclear power, placing top priority on safety factors while continuing to strengthen the ability of private industry to acquire sites for nuclear facilities. (Japan 1987)

Maintain the current high level of nuclear expertise and continue to safely operate existing nuclear power plants as an essential contribution to energy security; and keep all options open for the future. (Belgium 1992)

Continue to pursue long-term activities to develop technology in the fields of low- and high-level radioactive waste disposal and dismantling of nuclear facilities. (Belgium 1992)

Continue to develop interim and/or final storage facilities for spent nuclear fuel and decide on permanent storage. (Finland 1994)

Continue to redefine policy with respect to nuclear power; if nuclear is to be retained as a long-term option, formulate a strategy for research, development and demonstration of advanced reactor designs. (Italy 1994)

Maintain high nuclear safety standards and secure their visibility while encouraging utilities to use nuclear power plants as efficiently as possible. (Japan 1994)

Seek consensus and public acceptance at national and local levels needed to meet nuclear expansion targets. (Japan 1994)

Strive to reach a decision on the nuclear supply option in order to establish a reliable framework for investment decisions, and explore complementary or alternative options, based both on their economic and environmental performance. (Switzerland 1994)

Further encourage active public and parliamentary participation and promote transparency in nuclear energy decision-making. (France 1996)

Ensure early progress toward an Interim Retrievable Storage for Spent Nuclear Fuel using funds already collected from ratepayers. (United States 1998)

Expedite progress on the characterisation of the Yucca Mountain site so that a decision may be taken on its suitability for final spent fuel disposal. (United States 1998)

Actively continue to provide support for all activities connected with management and final disposal of spent fuel and vitrified high-level waste. (Germany 1998)

Maintain a sufficient level of technological competence to keep nuclear energy as a viable option. (Switzerland 1999)

Nuclear energy has been considered in various IEA market analyses of electricity and energy supply, although these have not included new policy statements. All editions of the *World Energy Outlook* consider the growth of nuclear power and its prospects for the future. Also, in 1982 the IEA and OECD Nuclear Energy Agency jointly published an assessment of *Nuclear Energy Prospects to 2000*. Nuclear power is analysed in books entitled *Electricity Supply Industry* (1978), *Electricity in IEA Countries* (1985), and *Electricity Supply in the OECD* (1992).

The first published IEA analysis specifically devoted to nuclear policy issues appeared in 1998 as *Nuclear Power: Sustainability, Climate Change and Competition*. The report did not make policy recommendations.

Verbatim Excerpts of IEA Ministerial Communiqués Concerning Nuclear Power

Ministerial Communiqué, 27 May 1975 [IEA/PRESS/A(75)20]

7. The Ministers agreed on the need to elaborate a co-ordinated programme of co-operation for the accelerated development of alternative energy sources as provided in the decision already taken by the Governing Board, including in particular a commitment to increase, encourage and safeguard investment by general and specific measures.

The Ministers agreed that the Agency should initiate promptly an examination of the potential for expanded co-operation in the area of nuclear energy. This co-operation in all fields will be directed toward ensuring the development of this important alternative source of energy with due regard to safety and environmental conditions. Amongst other questions shall be discussed the availability of nuclear fuel and technology to meet the problems of safety and waste management.

On the basis of the above mentioned decision Ministers insisted on the importance of the establishment of co-operative projects in the research and development fields specified in the IEP Agreement, particularly coal and nuclear questions. In this connection, they agreed to build further upon the progress already achieved by the Agency in the area of energy research and development. They resolved that productive results in this area will require a sustained effort to develop concrete international co-operation. In support of this objective, they agreed that a special session of the Governing Board, with attendance by senior research and development officials, should be held in the autumn of 1975 to complete the formulation of a research and development programme.

Ministerial Communiqué, 6 October 1977 [IEA/PRESS(77)10]

6. Ministers expressed their firm political determination to reinforce their national policies in order to achieve these group objectives. For this purpose, the decision establishes twelve principles of energy policy which will serve as guidelines for the implementation of national measures, taking into account domestic energy circumstances and social and economic requirements. The principles call for constant and careful attention to important environmental, safety and security concerns to which the production, transportation and use of energy give rise. They provide for stronger energy conservation, switching to use of more plentiful fuels, and rapid expansion of indigenous energy supplies. They emphasise the need for a favourable investment climate, adequate energy prices and reduced uncertainty about energy policies. They call for co-operative efforts to increase coal consumption, production and trade and to maintain steady expansion of nuclear power, consistent with non-proliferation and environmental concerns, as a main and indispensable element in attaining IEA group objectives. Some Ministers, however, expressed different views as to the nuclear principle and reserved their position with regard to that principle.

7. Ministers generally recognised that nuclear power will be required in order to attain IEA group objectives. Ministers of many Member countries expressed the determination of their governments to expand their nuclear generating capacity. Ministers recognised that some of the constraints on development of nuclear energy can only be reduced by international co-operation. They agreed that given the importance of nuclear power as an alternative source of energy, the IEA should play an active role in the development of nuclear energy policies, taking full account of work being done elsewhere.

Annex I.

Decision on Group Objectives and Principles for Energy Policy Adopted by the Governing Board of the IEA Meeting at Ministerial Level on 5th October 1977

Principle #8. Steady expansion of nuclear generating capacity as a main and indispensable element in attaining the group objectives, consistent with safety, environmental and security standards satisfactory to the countries concerned and with the need to prevent the proliferation of nuclear weapons. In order to provide for this expansion it will be necessary through co-operation to assure reliable availability of:

- adequate supplies of nuclear fuel (uranium and enrichment capacity) at equitable prices;

• adequate facilities and techniques for development of nuclear electricity generation, for dealing with spent fuel, for waste management, and for overall handling of the back end of the nuclear fuel cycle (1).

Note (1) The following Delegations expressed individual positions regarding Principle 8, as set forth in the Conclusions of the Meeting of the Governing Board which adopted this Decision: Denmark, Norway, The Netherlands, Spain, New Zealand, Sweden.

Ministerial Communiqué, 22 May 1979 [IEA/PRESS(79)14]

10. Ministers noted that nuclear projections have been lowered repeatedly in recent years. They also noted that the recent accident at Harrisburg (Three Mile Island) has renewed public concern about safety. However, they also recognised that oil or other alternative energy sources would not be sufficient to meet growing energy demand in the short and medium term and that undesirable economic and social consequences would therefore result if more nuclear power is not available. They therefore agreed on the need for projected additions to nuclear power supply to be realised in timely fashion and exceeded wherever possible, having due regard to legal and constitutional provisions. They also agreed on the urgent need for effective national and international efforts to ensure that safety systems are sufficient to minimise the possibility of nuclear plant accidents and their consequences, and to adequately inform the public of the results. They also recognised the need to bring the International Nuclear Fuel Cycle Evaluation (INFCE) to a successful conclusion by early 1980, and to ensure that effective action is taken to resolve long-term waste disposal and non-proliferation questions.

Ministerial Communiqué, 22 May 1980, Annex I [IEA/PRESS(80)8]

Secretariat Analysis of Areas Where Energy Policies Could be Strengthened in Individual IEA Countries

(ix) Greater efforts must be made to accomplish projected nuclear programmes and to create an environment in which discussion of nuclear issues can take place in an objective and balanced way, taking account of economic and energy considerations as well as safety and proliferation aspects (Germany, Italy, Japan and the United States), and to streamline regulatory processes for the licensing of nuclear plants and for authorisations related to nuclear fuel cycle activities in other Member countries.

Ministerial Communiqué, 15 June 1981 [IEA/PRESS(81)10]

9. Nuclear power will have to play a major and increasing role in many countries in order to achieve the necessary structural change which all IEA countries have agreed upon. This will be facilitated by better conditions for the timely growth of nuclear power. IEA countries should therefore take prompt national and international action to increase public understanding of reactor safety; implement waste management and disposal programmes; streamline licensing procedures to shorten lead times with continued emphasis on safety; ensure that regulatory practices do not unnecessarily constrain investment; and reinforce the reliability and predictability of international trade in nuclear fuels and technology under appropriate safeguards, in order to enhance public acceptance of and confidence in nuclear power, including advanced reactor technology. Industrialized countries also can contribute to a better world energy balance by making better use of their technological capacity, including the use of nuclear and other technologically complicated energy sources.

Ministerial Communiqué, 24 May 1982 [IEA/PRESS(82)8]

9. Ministers agreed that to achieve necessary overall structural change away from oil which all IEA countries have agreed upon, nuclear power will have to play a major and increasing role in many countries. Ministers noted, however, that there has been some slowdown in nuclear development programmes. In order to maintain momentum for the development of nuclear power and to achieve current projections, further efforts are needed, internationally and by many IEA countries. Ministers therefore agreed to pursue policies for making licensing and regulatory processes in those countries less subject to frequent changes and delays; ensuring high safety standards in construction and operation of nuclear facilities; demonstrating the availability of technologies for the disposal of high-level radioactive wastes; and maintaining reliable international trade in nuclear materials and fuel cycle services, consistent with non-proliferation objectives. They welcomed the IEA/NEA assessment of nuclear prospects to the end of this century, and agreed that further study of prospects for electricity growth and comparative analysis of nuclear power and other energy options should be pursued.

Ministerial Communiqué, 8 May 1983, Annex I (Conclusions) [IEA/PRESS(83)6]

8. To fulfil its important potential for contributing to overall long-term energy security which is the concern of all industrialized countries, nuclear power will have to play a major and increasing role in many countries. Ministers:

– stressed the importance of encouraging stable trade in nuclear equipment, fuel cycle services and nuclear fuel. Export and import regulations must be predictable, and based on the strict respect of current non-proliferation policies;

– agreed that Member countries would maintain reliable standards of nuclear reactor safety and continue to co-operate in various fora on these matters. Procedures for the approval of reactors and nuclear facilities should be as clear and expeditious as possible;

– stressed the importance of international co-operation on spent fuel storage and waste disposal. They appealed to the governments of those countries in a position to do so to stimulate further progress in developing and applying effective and timely methods for managing the back end of the fuel cycle in ways best suited to their national situations and compatible with international agreements. The IEA and NEA were requested to work together on periodic consultations on the progress of Member governments in the waste disposal programme;

– requested the IEA and NEA to identify for prompt examination new possibilities for research and development in advanced technologies that support these conclusions.

Action on these lines will provide the basis for both institutional impediments and public acceptance concerns on nuclear power to be vigorously addressed and allayed wherever possible.

Ministerial Communiqué, 9 July 1985 [IEA/PRESS(85)6]

Electricity, Coal, Nuclear Power and Other Energy Sources

Ministers affirmed the need for strong and effective policies to enable electricity to make its appropriate contribution to economic development and energy security of Member countries, as already decided by the Governing Board on 27th March 1985. Ministers noted especially the roles of coal (including lignite and other solid fuels) and nuclear power, as well as hydro-power and renewables, in electricity generation, the role of each depending on national circumstances.

Nuclear energy now accounts for over 15 per cent of IEA electricity generation. Ministers noted the progress recently made in a number of Member countries in developing their nuclear power programmes, and are aware of the slowdown in progress of the nuclear programmes in other Member countries. They agreed that further action, such as streamlined licensing procedures, standardized designs, and appropriate waste management programmes should be undertaken in order to realise the potential contribution of nuclear power in the future consistent with appropriate environmental and safety requirements, and strict respect of current non-proliferation policies.

Ministerial Communiqué, 11 May 1987 [IEA/PRESS(87)4]

14. Ministers noted that:

(d) *Nuclear energy.* After the Chernobyl accident, which was specific to a particular type of plant, those Member countries for which nuclear energy is a relevant option have carefully assessed the safety of types of reactors used in their countries. A group of countries, which account for the bulk of electricity generation in the OECD region, consider that the standards of safety in their reactor systems and procedures are so high that the risk of major accidents is too remote to justify a change in policy. They therefore intend to continue their nuclear power generation programmes in order to secure the economic and environmental advantages which flow from them. A few countries still have their programmes under review. Other countries have decided not to produce nuclear power either because they have other non-oil resources available or because they consider the long-term environmental impacts and the residual risks of nuclear energy production, even under the highest safety standards, to be unacceptable. One country has decided to discontinue its existing nuclear programme by early in the next century.

15. A significant limitation of any of these options, in particular of coal or nuclear, for the IEA as a whole would increase demand for other energy sources and thus the costs of achieving energy security. The IEA will continue and deepen its analysis of the different options for electricity generation. However, each IEA country will have to decide on the mix of fuels used in generating stations best suited to its particular circumstances. All will, however, seek to achieve a mix which takes into account considerations of energy security, environment, safety and the possible effects of their decisions on other countries. Ministers noted that, despite differing perceptions about the appropriate balance, many and useful international consultations and information exchanges about these decisions were taking place.

16. The safety issues associated with the production of electricity are of fundamental importance, particularly in the case of nuclear energy. IEA countries have already made important progress in this area and will continue their efforts to ensure the highest standards of safety in all aspects of waste management and of the planning, design, construction, operation and dismantling of nuclear installations. They will give full political and technological support to arrangements for international co-operation on nuclear safety which exist, or are being developed, particularly within the Nuclear Energy Agency of the OECD and the International Atomic Energy Agency.

Ministerial Communiqué, 30 May 1989 [IEA/PRESS(89)4]

(b) Diversity of Energy Supply

Ministers agreed that diversification of energy supply must be further pursued, in order to avoid greater dependence on oil and to make economic use of available resources. They therefore agreed to pursue further diversification by means of:

– appropriate investment conditions for oil exploration and development and competitive industry and market structures;

– more environmentally acceptable use of solid fuels;

– greater use of natural gas from diversified sources;

– greater use of renewables where available technology and local conditions make them economic, and greater efforts to make them more competitive;

– provision of adequate and diversified electricity generation capacity.

Ministers recalled their decision in 1987, in view of the different positions which exist in IEA countries regarding nuclear power, that each IEA country will have to decide on the mix of fuels used for electricity generation best suited to its particular circumstances, taking account of energy security, environment, safety and the possible effects of their decisions on other countries. Some countries have adopted the nuclear option, and they intend to continue their nuclear power generation programmes in order to secure the economic and environmental advantages which they consider flow from them. All IEA countries agree upon the necessity for continuing to apply the highest available standards of nuclear safety in all its aspects, particularly operation and waste management.

Ministerial Communiqué, 3 June 1991 [IEA/PRESS(91)7]

13. Ministers recognised the substantial contribution that nuclear energy makes in a number of Member countries and, consequently, to the overall energy supply and mix of IEA countries. They noted that a number of countries are also of the view that the use of nuclear energy because it emits no sulphur dioxide, nitrogen oxides or greenhouse gases, provides an important response to the challenge of stabilizing of greenhouse gas emissions. Ministers of those countries expressed the view that the nuclear option must therefore be maintained as an essential element of the diversification of their primary energy supply. Ministers agreed that it was essential to maintain and further develop the highest available standards of safety, and in particular encouraged continued and strengthened international co-operation in approaches to the safe operation of nuclear facilities, to waste management and to the development of new reactor systems. Ministers recognised that each IEA country will have to decide on the mix of fuels used for electricity generation best suited to its particular circumstances, taking account of energy security, environment, safety and the possible effects of their decisions on other countries.

Ministerial Communiqué, 4 June 1993 [IEA/PRESS(93)8]

III. Emergency Preparedness and Diversification of Energy Sources

12. *Nuclear:* Nuclear energy makes a substantial contribution in a number of Member countries and, consequently, to the overall energy supply mix of IEA countries. Ministers of a number of countries are of the view that the nuclear option must be maintained as an indispensable element of the diversification of their primary energy supply. It is essential to maintain and further develop the highest available standards of safety, and in particular to continue and strengthen international co-operation in approaches to the safe operation of nuclear facilities, to waste management, to decommissioning and to the development of new reactor systems. The role of the OECD Nuclear Energy Agency was emphasized in this regard. Ministers recognise that each IEA country will have to decide on the mix of fuels used for electricity generation best suited to its particular circumstances, taking account of energy security, environment, safety, and costs, and the possible effects of their decisions on other countries.

IV. Energy and Environment

A. Areas for Improvement

18. *Non-Fossil Fuels:* Since the amount of energy that non-hydro-based renewable energy technologies contribute is quite small compared to the technical potential, increased government support of renewable technologies is warranted. Regarding nuclear power, a number of IEA countries are of the view that the use of nuclear energy, because it emits no sulphur dioxide, nitrogen oxides or greenhouse gases, provides an important response to the challenge of stabilising greenhouse gas emissions. A number of other IEA countries are of the opinion that those advantages do not offset the environmental concerns over the use of nuclear energy and have decided not to utilise nuclear power.

Ministerial Communiqué, 23 May 1997 [IEA/PRESS(97)9]

II. Energy Dimension of Climate Change

5. Ministers, recognising the importance of the lead that the developed countries can provide in responding to climate change, endorsed the "IEA Statement on the Energy Dimension of Climate Change", which was submitted earlier this year to the Ad Hoc Group on the Berlin Mandate under the UNFCCC (United Nations Framework Convention on Climate Change) to assist participants in preparations for negotiations for COP-3 (Third Conference of the Parties). The "IEA Statement" describes the main energy aspects of the climate change issue; these include the following:

- the use of energy has been decisive in economic development but has also resulted in increased CO_2 emissions from the consumption of fossil fuels;

• the promotion of sustainable economic development requires the provision of expanded energy services while reducing their energy and CO_2 content to the extent possible;

• the overall carbon content of IEA countries' energy requirements has been decreasing over the past 20 years, due in particular to the development of nuclear power in response to energy security concerns after the two oil shocks and to increasing use of natural gas, whose combustion contributes to less greenhouse gas emissions than oil and coal;

• the observed rate of "de-carbonisation" of energy in IEA economies is unlikely to be maintained in the absence of specific responses, in part because nuclear programmes have now been slowed or halted in most countries; [...]

Ministerial Communiqué, 25 May 1999 [IEA/PRESS(99)7]

9. Ministers welcomed the Secretariat's comprehensive analytical work, including its *World Energy Outlook* and its "energy indicators" project, which explores the link between human activity, economic growth and carbon emissions. They asked the Secretariat to continue assessing the full range of energy issues and choices, including renewable energy and nuclear power, and the implications of an emerging market value for carbon.

ANNEX III

THE NUCLEAR FUEL CYCLE

The "fuel cycle" is the series of activities for producing nuclear fuel, recycling portions of that fuel after it has been used and discharged from reactors and disposing of radioactive wastes arising from these activities. It is typically divided into three stages (NEA, 1994):

- The "front end" which encompasses the mining of uranium ore through to the production of fuel assemblies ready for use in reactors.

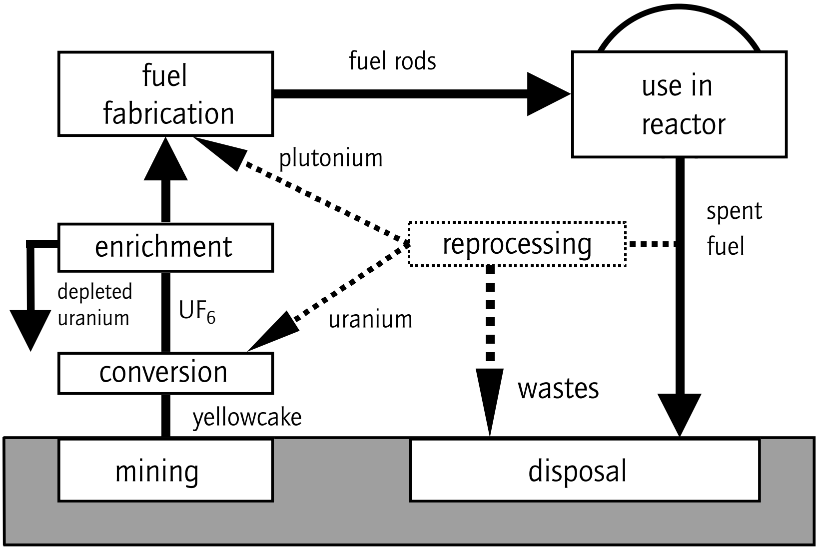
- The use of fuel in reactors.

- The "back end" which encompasses the removal of spent fuel from reactors through to its ultimate disposal. A reprocessing step can be included to extract plutonium or other components from the spent fuel.

The individual steps in the fuel cycle are shown in Figure 32. Box 3 describes how nuclear fuel is prepared from uranium. Once uranium ore has been mined and milled to produce yellowcake (uranium oxide powder), it is chemically converted to a form suitable for use in enrichment plants (uranium hexafluoride), it is enriched in uranium-235, and fuel is prepared from the enriched uranium. These steps constitute the front end of the fuel cycle. Fuel cycle facilities and production capacities in the OECD are listed in Chapter 3. Once the uranium fuel has been used in the reactor to generate electricity, it is removed and placed into temporary storage. It may then go either to a disposal site or to a reprocessing plant. If spent fuel is sent directly to disposal, the cycle is called "once-through" or "open." If spent fuel is reprocessed and fissile materials are recycled, the cycle is called "closed."

Figure 32

Schematic Steps of a Fuel Cycle for Light Water Reactors



Notes: This figure applies to the use of uranium in light water reactors. The dashed lines show material flows in a closed fuel cycle. UF_6 is uranium hexafluoride.

Magnox and Candu reactors can use natural uranium fuel. Conversion and enrichment are therefore not needed to prepare fuel for these reactor types.

A fuel cycle based upon thorium rather than uranium is also feasible. No currently operating commercial plants use thorium.

Reprocessing

Reprocessing involves processing used nuclear reactor fuel to extract plutonium and uranium from spent fuel which can be recycled in nuclear fuel and to produce from the remaining fuel waste a

Box 3

Preparing Nuclear Fuel from Uranium

The three basic steps in preparing nuclear fuel from natural uranium are conversion to uranium hexafluoride, enrichment, and fuel fabrication.

- *In the conversion step, natural uranium in the form of uranium oxide (U_3O_8) or yellowcake is converted to a chemical form suitable for subsequent processing. The form needed for enrichment is uranium hexafluoride, a gaseous material above 57 °C.*
- *In the enrichment step, a physical separation process dependent on a gaseous feedstock is used to increase the concentration of the isotope uranium-235. This is the isotope that undergoes fission in the reactor. Naturally occurring uranium has 0.7% uranium-235, whereas fuel typically requires its concentration to be 3 to 5%. The amount of energy required to enrich fuel is measured in "separative work units", or swu's.*
- *In the fuel fabrication step, the uranium hexafluoride enriched in uranium-235 is converted to uranium dioxide (UO_2), shaped into cylindrical pellets, and loaded into tubes. These tubes (fuel rods) are in turn mounted in special assemblies that are placed in the reactor.*

Magnox and Candu reactors are able to use uranium with the naturally occurring concentration of uranium-235, so uranium enrichment is not required for their nuclear fuel. Natural uranium is converted to uranium dioxide, which then enters the fuel fabrication step.

concentrated high-level waste consisting mainly of fission products and a small fraction of radioactive elements heavier than uranium. Spent fuel from heavy water reactors is not reprocessed, for economic reasons, because of its low content of plutonium and fissile uranium. Reprocessing involves remotely shearing nuclear fuel elements into short lengths, dissolving the uranium, plutonium and nuclear materials in strong acid, and then separating them using chemical processes. High-level waste is typically mixed within a glass-like material, or "vitrified."

Belgium, France, Germany, Japan, the United Kingdom and the United States all had programmes to develop reprocessing technology as part of an overall strategy for the development of nuclear power and, specifically, breeder reactors. Belgium, France, Germany, Japan, the Netherlands, have encouraged or required utilities to reprocess their spent fuel. France and Germany have had the strongest commitment to reprocessing. Nearly all French and German plants have sent their spent fuel to reprocessing facilities. However, in June 2000 the German government and utilities agreed that reprocessing of spent fuel would end in 2005. Japan's policy is that all spent fuel must eventually be reprocessed.

Much of the investment in today's reprocessing facilities was based upon long-term contracts signed in the 1970s and 1980s. Long-term contracts provided security both to utilities and reprocessing plant owners. Utilities wished to make sure that their spent fuel would be reprocessed over a long period, and reprocessing plant owners that their heavy investments in reprocessing facilities would be recovered. The British Thermal Oxide Recovery Plant (THORP) at Sellafield and the French UP3 facilities at La Hague were financed largely through customer prepayments (NRC, 1996: p. 422).

Reprocessing reduces the quantity of high-level waste per unit of generation (grams/MWh) because only some of the components in the spent fuel are sent to disposal. If the plutonium is included in the waste stream (not re-used in MOX fuel), the mass of high-level waste is reduced by about 95% compared to the mass of spent fuel. The remainder is uranium that can be disposed of as low-level waste or re-used in an enrichment plant. If the plutonium is re-used in MOX fuel, the overall arisings of high-level wastes increase. The full volume of spent fuel from a MOX-fuelled reactor is treated essentially as high-level waste, as in the case of a once-through fuel cycle, because reprocessing of spent fuel from MOX is not currently economic. Given current characteristics of MOX fuel and reactors, reprocessing combined with MOX fuel use can reduce high-level waste production by roughly 50 to 85%, compared with the alternative of direct disposal.

Box 4

Components of Fuel and Spent Fuel

Standard nuclear fuel for light water reactors contains 95% to 97% of the uranium-238 isotope and 3 to 5% of the fissionable uranium-235 isotope which provides most of the energy released within the reactor. During reactor operation, some atoms of uranium-238 absorb neutrons to create plutonium. A part of the plutonium formed in this way will be fissioned, contributing to the energy output of the plant, but some will remain in the fuel removed from the reactor. Some fissionable uranium will also remain.

For a plant using ordinary enriched fuel (not MOX), spent fuel typically has 3 to 4% fission products, slightly less than 1% uranium-235, slightly less than 1% plutonium, and 0.1% of other elements heavier than uranium. The remainder is uranium-238 and an unfissionable isotope of uranium (less than 0.5% of uranium-236).

Magnox reactors and heavy water reactors, such as the Candu design, can use the naturally occurring mixture of uranium isotopes in their fuel (0.7% uranium-235). Fuel for these reactors does not need to be enriched in uranium-235. Spent fuel from these reactors has smaller proportions of uranium-235 and plutonium than spent fuel from light water reactors.

Materials that can be split by nuclear fission, including uranium-238 and plutonium, are called fissile materials.

MOX Fuel

Research and development programmes on re-using plutonium in fuel were started in the 1950s and 1960s when it was recognised that plutonium arising from spent fuel reprocessing would probably be in excess of requirements for feeding fast breeder reactors, where plutonium is technically best used. Up to the early 1980s, MOX fuel (fuel with a mix of uranium and plutonium oxides) was not used in commercial reactors. In the last decade, there has been a growing interest in recycling of plutonium in MOX fuel. This is because there are large and growing stocks of separated plutonium from reprocessing and the plans for fast breeder reactors have largely been abandoned (Zarimpas and Stevens, 1997).

MOX fuel can be used safely in conventional reactors, though plant operators must take special precautions (*ibid.*). The means to ensure safe control of the reactor and other safety characteristics are affected by the substitution of MOX fuel for uranium fuel. For this reason, the fraction of reactor fuel elements using MOX fuel is limited to 50% in existing plants. Specially designed reactors (not in current use) could allow 100% of the fuel elements to be MOX.

The use of MOX fuel decreases existing stocks of separated plutonium, but does not decrease the total amount of plutonium in existence. This is because, as MOX fuel is consumed, additional plutonium is generated from uranium-238 within the MOX fuel, as well as within ordinary fuel elements also in the reactor. The use of MOX fuel does decrease the rate of plutonium generation. Depending on many technical conditions, plutonium generation can be decreased by 20 to 85% per reactor. More plutonium can be consumed than created when the fraction of MOX fuel in the reactor is above 50%.

Stockpiling of plutonium for use in MOX plants poses a technical difficulty related to changes in plutonium characteristics as it ages. As plutonium from spent fuel ages, it forms americium, a radioactive material that requires special handling to avoid increased radiation doses to plant workers. MOX fuel fabrication facilities are designed to handle reprocessed plutonium with limited amounts of americium. If reprocessed plutonium remains unused for more than 2 to 7 years (depending on the fabrication facility), it may need to be processed again to remove the americium. Therefore, reprocessing fuel to recover plutonium can be wasteful if the plutonium is not used within several years.

Fabrication of MOX fuel is about four times more expensive than fabrication of ordinary uranium fuel owing to the increased need for radiation protection measures (NEA, 1994: p. 41). On the other hand, use of MOX fuel displaces one-quarter to one-third of the uranium and uranium enrichment that would otherwise be required if using 100% conventional fuel. There are also differences in cost related to differences in fuel management, storage and disposal.

Most assessments conclude that, under today's economic conditions, the total fuel cycle cost of using reprocessed or military plutonium in MOX fuel is greater than simply using ordinary uranium fuel. A British assessment estimated that, for similar costs of fuel disposal for mixed-oxide fuel and uranium fuel, the use of mixed-oxide fuel would cost a minimum of 20% more, but most likely would be 1.6 to 2.0 times more expensive (Mackerron, 1993). A study by the Institute of Energy Economics of the University of Cologne (Hensing and Schulz, 1995) reviewed three cost estimates, all of which found the use of mixed-oxide fuel to be more expensive by roughly a factor of 1.5 if the entire fuel cycle were taken into account. The reference case for an NEA cost study (NEA, 1994) indicates the use of MOX fuel to be 14% more expensive, although either uranium or mixed-oxide fuel could be the most economical depending on the economic assumptions adopted for the estimates. Using the NEA estimates as a basis, a US study (NRC, 1996: p. 7) concluded that the reprocessing route, not including MOX fabrication, would be 70% more expensive in the United States, assuming private financing. Considering overall fuel cycle costs, the long-term comparison of using uranium fuel compared to MOX is not clear because of uncertainties in the various cost components, particularly the prices for uranium, enrichment services, reprocessing, and high-level waste disposal.

Decisions on use of existing reprocessing facilities will differ from the analysis described above for new facilities since the capital cost of the facilities is sunk and only operating costs need be considered in the short term. Other factors are also relevant, such as policy on spent fuel management and national energy strategy, both in the country where the reprocessing facility is located and in other countries.

Fuel Cycles and the Future

Numerous studies on the nuclear fuel cycle show the complexity of options to be considered. It is difficult to assess how nuclear fuel cycles are likely to evolve in the future. There are many views on how reprocessing, MOX fuel, new reactor technology and waste disposal will or should evolve in both the near term and the long term. The features sought in the fuel cycle, including nuclear reactor technology, depend crucially on the long-term expectation for nuclear power development. The main issues are:

- High-level waste disposal.
- Long-term energy supply.
- Non-proliferation.
- Timing.
- Economics.

High-level waste disposal is a critical link affecting the nuclear fuel cycle in the near term. It is a link that must be developed to dispose of existing plant wastes, but also one that must be forged with a long-term perspective if nuclear power plants are to continue operating in the long term. The technical choices made in reactor type and in reprocessing of spent fuel affect the amount, characteristics and timing of wastes generated. Some waste disposal concepts rely on special-purpose reactors to reduce the period of time over which wastes remain dangerous and to reduce their volume. Therefore, planning for the disposal of wastes from spent fuel must be considered together with the overall outlook for nuclear power, including power plant type, reprocessing, and fuel markets.

Long-term energy supply. An important issue for the long-term future of nuclear power is how well the nuclear fuel cycle uses uranium's energy content. Today's fuel cycle with thermal reactors uses only about 2% of the energy available from natural uranium. Most of the energy remains unused in depleted uranium and in plutonium in spent fuel.

Breeder or "fast" reactors can generate additional plutonium from ordinary or depleted uranium. By recovering and recycling the plutonium in spent fuel and by generating plutonium in breeder reactors, a much greater fraction of natural uranium's potential energy can be captured. Roughly 75% of natural uranium's energy could be captured if recycling and breeding were used over the long term.

Present views are that using plutonium is the only means of extracting the full energy potential from natural uranium. Current strategies for using the nuclear energy resource do not generally preclude the later development of fast reactors and extracting additional energy from spent fuel, though they may not be the least expensive or technically optimum strategies.

Non-proliferation is a potential concern. Reprocessing technology can be used to extract bomb materials from either civilian or military materials. Separated plutonium from power reactors can be used in nuclear weapons, though not as convenient as plutonium made in special-purpose military reactors. A number of countries, including the United States and Sweden, have specifically excluded reprocessing and the use of plutonium because of risks of nuclear weapons proliferation. Other elements of the nuclear fuel cycle, such as enrichment, also pose risks of proliferation.

At present, reprocessing plant capacity is greater than the capacity of MOX fuel plants, so plutonium stockpiles are currently growing. Approximately 50 tonnes of plutonium are generated in OECD civilian nuclear plants each year. Of these, between 20 and 25 tonnes of plutonium are separated from spent fuel, and about 10 tonnes of separated plutonium are fabricated into MOX fuel. At the end of 1997, OECD civilian stockpiles stood at roughly 150 tonnes of separated plutonium and 750 tonnes contained in spent fuel (Albright and Barbour, 1999). The growth in MOX fabrication and use is expected to begin decreasing stockpiles of separated plutonium in the next few years. Nonetheless, governments and the nuclear industry are under pressure to consider how plutonium separation could be better matched with its near-term consumption (decreased reprocessing of spent fuel, increased MOX production capacity and use in reactors) and whether plutonium separation is needed at all in the absence of a clear long-term picture for plutonium use.

Timing. The flows within the nuclear fuel cycle are not continuous and are affected by the timing of each operation. If the capacity of each operation is not sized to handle the flow of materials at the time they appear, stocks of materials can build up at different points in the cycle. Currently, the capacity of facilities in the back end of the fuel cycle is smaller than the flow of spent fuel generated in plant reactors. In particular, without operational facilities for high-level waste disposal, spent fuel and high-level wastes are accumulating in all countries. This has led to the development of interim storage facilities and large on-site storage capacities for spent fuel at power plants. Delay in developing high-level waste disposal could also lead to an emphasis on reprocessing to minimise near-term waste volumes. As noted immediately above, plutonium stocks are accumulating because the capacity of commercial reactors able to use plutonium fuel (non-MOX) is currently zero and the capacity of MOX fuel fabrication plants is smaller than reprocessing capacity. "Early" introduction of reprocessing (before the arrival of fast reactors) has led to an emphasis on MOX use.

Economics. Costs of uranium, enrichment, reprocessing, waste disposal and power plant operation all interact in evaluations of fuel cycle economics. Three economic trade-offs are worth noting. First, higher prices for uranium and enrichment improve the economics of reprocessing because reprocessing reduces the need for natural and enriched uranium. Second, higher prices for uranium and enrichment tend to improve the economic evaluation of breeder reactors since breeders can produce fissile material and reduce the need for uranium. Third, higher waste disposal costs improve the economics of reprocessing because it can reduce the quantity of waste sent to final disposal. At current economic conditions, neither reprocessing nor breeders appear cheaper than once-through fuel cycles. Other trade-offs arise when considering new reactor types and waste disposal concepts.

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ANNEX IV

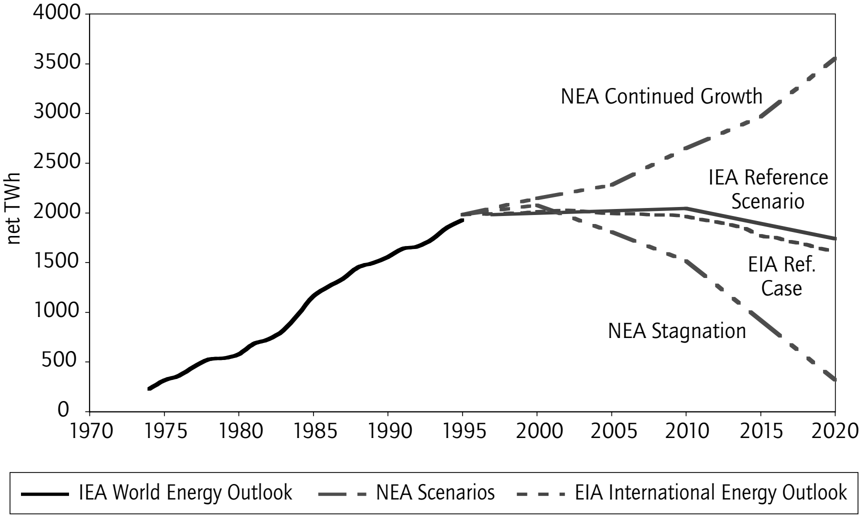
PROJECTIONS FOR FUTURE NUCLEAR POWER GENERATION

There is a wide range of estimated nuclear generation among projections from different sources. Scenarios can be constructed that range from one-fifth to twice today's level of nuclear generation by 2020. Figure 33 presents several scenarios for nuclear generation in the OECD up to 2020. The lowest curve is derived from a scenario by the OECD Nuclear Energy Agency that assumes political decisions are taken to close nuclear plants and forbid new ones. The highest curve is based on an opposite NEA scenario that assumes continued growth in nuclear power, aided by political decisions to develop new plants. The NEA scenarios were developed to explore their implications for climate change policies.

A middle path is represented by the "Business as Usual" scenario of the IEA's *World Energy Outlook* and the US Energy Information Agency "Reference Case". This path assumes no new policy decisions either in favour of or against nuclear power, but rather assumes existing policies remain unchanged. In this case, new plant capacity broadly balances plant retirements, keeping total nuclear generation nearly constant out to 2010. From 2010 to 2020, an increasing number of plant retirements tends to reduce total OECD nuclear generation. Nuclear power generation decreases in share from almost one-quarter to about half this value. This is the result of a scenario in which nuclear power grows little or shrinks while total electricity generation increases to meet growing demand. Nuclear power in other regions of the world except China would similarly decrease in share of total electricity generation (Figure 34).

Figure 33

Historical and Projected OECD Nuclear Power Generation, 1974 to 2020

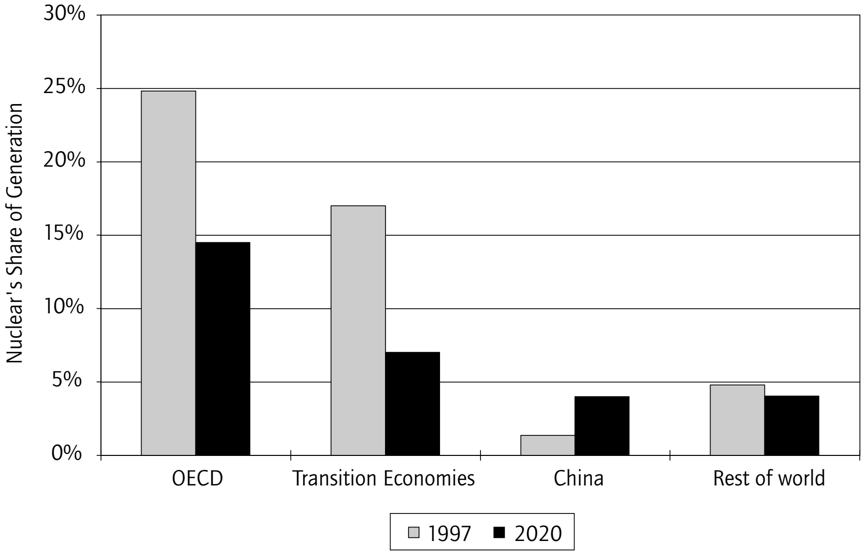


Note: NEA curves derived from NEA world scenarios assuming a constant OECD share of total world nuclear generation.
Sources: EIA, International Energy Outlook 1999, *DOE/EIA-0484(99); IEA,* World Energy Outlook 2000; *NEA,* Nuclear Power and Climate Change *(1998): Figure 2.*

The only OECD countries with new nuclear plants under construction are the Czech Republic, Japan and Korea. Few additional orders for new plants are expected in the near term. Therefore, as matters stand, the prospects for total nuclear generation within the OECD in the coming decades depend mostly on the operating status and utilisation of existing power plants. The IEA *World Energy Outlook* and US Energy Information Administration estimations of future nuclear generation assume that nuclear plants will generally cease operation after forty years. Increasingly, however, it appears that existing plants are likely to operate for 50 or 60 years before retiring. If there are no changes in policy towards nuclear power, plant lifetime is the single most important determinant of nuclear electricity production in the coming decades.

Figure 34

Nuclear Power's Share of Total Generation by World Region, 1997 and 2020



Note: Figures are based on the "Business as Usual" analysis. Transition Economies include the countries of non-OECD Europe, the former Soviet Union, and Poland.
Source: IEA World Energy Outlook 2000.

UNITS AND ABBREVIATIONS

AGR	advanced gas-cooled reactor (a British nuclear plant design)
BWR	boiling water reactor
Candu	Canada Deuterium Uranium reactor (a Canadian nuclear plant design)
CCGT	combined-cycle gas turbine
CEA	Commissariat à l'Énergie Atomique (French Atomic Energy Commission)
EU	European Union
G7	the Group of Seven countries: Canada, France, Germany, Italy, Japan, the United Kingdom and the United States
GJ	gigajoule (10^9 joules)
GWe	gigawatt electrical capacity (1 000 MWe)
HM	heavy metal. For fuel fabrication this refers to uranium or plutonium
IAEA	International Atomic Energy Agency, an agency of the United Nations
INES	International Nuclear Event Scale
kg	kilogram
kt	kilotonne
kWe	kilowatt electrical capacity
kWh	kilowatt-hour
m^3	cubic metre
Magnox	gas-cooled reactor using fuel with magnesium alloy cladding (a British nuclear plant design)
MOX	mixed oxide fuel (contains both uranium and plutonium oxides)
Mt	million tonnes

Mtoe	million tonnes of oil equivalent - an energy unit = 4.1868 x 10^7 GJ
MWe	megawatt electrical capacity
MWh	megawatt-hour
MWth	megawatt thermal capacity
NEA	Nuclear Energy Agency, an agency of the OECD
OECD	Organisation for Economic Co-operation and Development
O&M	operations and maintenance
PWR	pressurised water reactor
R&D	research and development
swu	separative work unit (a unit of uranium enrichment service)
TWh	terawatt-hour (10^9 kWh)
t	metric tonne (1 000 kg)
U	uranium
VVER	Soviet-design pressurised water reactor
yr	year

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