

## Chapter 3

# Nuclear Energy and Nuclear Power

### Introduction

At least five types of peaceful uses of nuclear energy are theoretically possible: propulsion; civil engineering and mining; research; medical, agricultural, and industrial uses of isotopes; and electricity production. Despite several attempts during the 1960s to use nuclear power as a civilian propulsion source, its development in this role has been largely restricted to naval use by the five nuclear-weapon states recognized by the NPT. Similarly, after extensive test programmes in the 1960s, the use of nuclear explosives for civil engineering and mining purposes has now been abandoned with the opening for signature of the Comprehensive Test Ban Treaty in 1996. Research activities and the use of isotopes continue to be developed, but the most extensive use of the technology for peaceful purposes is in electricity production. This is also the peaceful nuclear activity which has the closest links with the production of fissile materials for military explosive purposes.

In the 1950s, nuclear energy was seen as the leading technology in the expansion of electricity production. Initially, it was believed that this expansion would not pose a weapon-proliferation risk as plutonium created in the efficient operation of power reactors was thought to be incapable of being used for explosive purposes. When this assumption was accepted to be incorrect, the IAEA was created to implement safeguards measures to monitor the operations of power reactors, their associated facilities and the nuclear materials they utilized. The IAEA never aspired to prevent the misuse of such facilities or materials in this context: rather its aim was, and is, to deter such misuse by providing the international community with early warning of any diversions from declared uses.

Following the oil supply crisis of 1973, many nuclear power reactors were ordered, *inter alia*, to offer enhanced security of electricity supply. However, the costs and time involved in their construction, and concerns over the environmental, health and other risks associated with their operation and the disposal of their waste products, led to the cancellation of some of these orders. By the later 1980s, a slow but steady decline in support for the technology could be observed in several of the states which had been the leaders in its development.

Relatively few non-nuclear-weapon states currently have significant nuclear energy programmes, but the theoretical proliferation risk posed by their ability to produce militarily useful fissile materials remains. One obvious way to reduce this risk is to impose a global ban on all production and use of the fissile materials associated with nuclear weapons, namely highly enriched uranium and plutonium. The dismantling of a significant percentage of the nuclear arsenal of Russia and the United States during the 1990s has facilitated a global ban on the operation of any facility dedicated to the production of U-235 and Pu-239 for military purposes in the five nuclear-weapon states. It has also, at least in theory, opened the way for strengthening the technical foundations of the nuclear non-proliferation regime by imposing more comprehensive restrictions on the production and use of fissile materials.

These proposals have, however, conflicted with plans evolved after the 1973 oil supply crisis to develop and build a new generation of power reactors which both use and produce plutonium as a fuel [fast-breeder reactors], and with arguments that nuclear waste (used fuel) can be most effectively disposed of through separation and recycling in existing reactors as part of their fuel load [MOX fuel] rather than by indefinite storage in the form in which it emerges from power reactors. Japan, France and the United Kingdom are the focus for this debate, the latter two because they operate plants which are contracted to reprocess fuel from Japanese and German electricity utilities, the former because it is the sole non-nuclear-weapon state currently operating both enrichment and reprocessing plants. The availability of plutonium from dismantled nuclear weapons, and the low cost of natural uranium, has been perceived to undermine the economic case for implementing, under current conditions, these plans for separating and using plutonium created in power reactors. This has served to extend the range of disagreement between those seeking to implement these plans and those arguing for a stronger technical foundation to the nuclear non-proliferation regime.

The degree of reliance to be placed on technical, as against political, solutions to nuclear proliferation is thus an issue that has persisted for half a century. In its current form, advocates of 'technical fix' solutions suggest either closing down all nuclear energy activities, particularly power reactors, or just those facilities which are regarded as proliferation sensitive (i.e., those used for the recovery of plutonium from used fuel or the high enrichment of uranium). While this technical solution is appealing, as intentions are more open to rapid change than capabilities, its advocacy also has the unfortunate effect of implicitly undermining faith in political non-proliferation commitments and the global nuclear non-proliferation regime.

### Current nuclear power projections

The global nuclear energy industry grew substantially during the period 1969–1979. After 1979, the industry suffered a slow-down in new orders, which has continued into the 1990s. The causes of this depression in new plant ordering include: the costs of constructing new reactors; the increasing lead-times involved in construction; little or no growth in the demand for electricity; questions over nuclear waste disposal; and safety fears in the wake of the 1981 Three Mile Island accident in the United States, the 1986 Chernobyl accident in Ukraine, and well-publicised problems with older reactors in Eastern Europe and the Russian Federation.

Current electricity generation derived from nuclear power is approximately 17 per cent of the global total. Altogether, 34 states have 429 nuclear power reactors between them with a total capacity of 345 GW(e) for the production of electricity, while another 30 units, with a total capacity of 33 GW(e), are under construction. Lithuania derives 86 per cent of its total electricity generating needs

from nuclear power, the highest share for any state, followed by France with 76 per cent.

Future expansion of the share of nuclear power in electricity generation is most likely to occur in East and South Asia with South Korea, Japan, China, Taiwan (Province of China) and India at the forefront. In Japan, for example, its 'Long-Term Program for Development and Utilization of Nuclear Energy' has identified nuclear power as a key energy source for the future and estimates that 40 new 1000 MW(e) plants will be needed to meet projected demand. Similarly, India's government wants to increase the share of nuclear energy in electricity generation by early next century from the current level of 2 per cent. But elsewhere, nuclear power is not being expanded and, in some cases, such as Sweden, there are plans to phase it out completely. In Spain and Switzerland prohibitions have been placed on further reactor construction; the United States has placed no new orders for nuclear plant since 1975; and Italy has confirmed its 1989 decision to abandon nuclear power.

Projections of the expansion in total nuclear generating capacity have continually been downgraded since the high point of such growth estimates in the 1970s. Current assessments are that total global capacity in 2005 will be approximately 350–365 GW(e). The range of uncertainty in the estimates increases after that date because of the problematic impact of technical, economic, environmental and political factors. In particular, if lead-times from initial planning to commissioning are in the order of 8–15 years, decisions taken now to build reactors are unlikely to reach fruition before 2010. Much will therefore depend on decisions made over the next decade. Current projections of the situation in 2015 range from a low of 375 GW(e), which represents a decrease in nuclear power's share in the world's electricity supply from its current 17 to 12 per cent, to a high of 535 GW(e), implying a lesser drop in its share in total electricity generation from 17 to about 14 per cent.

These projected figures could be affected by several factors, including:

- *the total demand for energy.* The assumption is that global demand for energy will continue to expand, given estimates of both population growth and industrial development in both the developed and developing worlds. The world's population is expected to grow from 5.4 billion in 1991 to 8.2 billion by 2021, an increase of 52%. The greater share of this expanding energy market, given historic trends, is expected to be accounted for by electricity. Similarly, the World Energy Conference (WEC) has estimated that during the period to 2021 electricity growth rates in the developed world will be between 1 and 2.5% per year, and in the developing world between 2.5 and 5.5%;
- *the long-term influence of environmental factors.* Concerns about global warming could see a re-assessment of nuclear power's contribution to the predicted increase in global energy demand. Conversely, attention could focus on energy conservation, rather than on generation, and on the environmental risks and consequences of nuclear power production, including problems over the disposal of radioactive waste;
- *the demand for electricity within total energy demand.* The rate of growth in electricity consumption has been falling since 1980 and it has been the nuclear plants which have been the first to be cancelled, owing to high

construction costs and thus capital investment; lack of standardization; and the increasing costs of complying with regulatory provisions;

- *the share of nuclear energy in supplying the total quantity of electricity required.* It is extremely difficult to assess the relative costs of nuclear and other alternative sources of electricity production beyond 2000, given the volatility of energy resource and fuel markets, the as yet unquantified costs associated with the decommissioning of nuclear reactors, and the uncertain long-term interest rates on borrowed money;
- *the future economic life of existing power reactors.* Some first generation power reactors have already been retired. Some are approaching the end of their economic production lifetimes and will soon be ready for decommissioning. The safety and operational problems with the RBMK and VVER reactors in the former Soviet Union and in Eastern Europe, for example, have resulted in plans to decommission some of these reactors and others may follow. Elsewhere, research, experimental and demonstration reactors are in various stages of decommissioning and dismantlement. However, many of the larger Pressurized Water Reactors (PWRs) were not commissioned until the 1980s and are therefore not planned to be shutdown until well into the next century. Moreover, it has been suggested that some of the more advanced nuclear plants currently in commission could have their planned operating lifetime extended significantly at relatively low cost, through activities such as replacing their turbo-generators with more modern standardised equipment;
- *the willingness of utilities to place orders in the near future for new nuclear power reactors, and of governments to facilitate such decisions and the resulting construction process.* Nuclear electricity's share in total production will depend heavily on whether new nuclear plant will be ordered over the next decade to replace the existing nuclear stock, and whether its capacity will be larger or smaller than the capacity it is replacing. This in turn will depend on the relative cost competitiveness of nuclear generating plant, general perceptions of the utility and safety of nuclear power plants, and attitudes of individual national governments towards such nuclear power programmes. Where such programmes are not underwritten by an express political will for their retention, either through direct state control or some form of legislative underpinning, the outlook for them is likely to be uncertain.

#### **Fuel requirements**

Uranium is no longer regarded as the scarce raw material it was once thought to be. The global uranium market has recently witnessed the appearance of additional supplies of uranium from a variety of sources, including the nuclear weapons reduction process in the former Soviet Union and the United States. On 18 February 1993, an agreement was signed between Russia and the United States which commits both parties to cooperate in the rapid conversion of High-Enriched Uranium (HEU) into Low-Enriched Uranium (LEU) and for the United States to purchase 500 tons of HEU from the dismantling of nuclear weapons in Russia. As a consequence, global uranium production, fuel fabrication and enrichment capacities are currently in excess of projected demand.

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These developments, when coupled with improvements in fuel design, fuel management technologies and fuel burn-up levels, reduce the demand for replacement fuel assemblies, and offer assurance of fuel supply for the foreseeable future. Even if there were to be a major increase in the total number of operating power plants, uranium resources would still be able to meet the demand. There are thus few current incentives to expand these 'front-end' element of the fuel-cycle infrastructure.

At the 'back end' of the fuel-cycle, plutonium and uranium recovered from the reprocessing of used fuel can be used to manufacture fuel elements for use in both light water and fast reactors. By recycling plutonium and uranium in the form of MOX and reprocessed uranium (RepU) fuel, it is possible to reduce still further uranium requirements. Fourteen states have adopted reprocessing as a means of spent fuel management. Major plutonium separation programmes are underway in Europe (France and the United Kingdom), the Russian Federation and Japan. In the latter, the recycling policy has been designed specifically to meet its expected future energy demand, reduce its dependence on external energy sources and thus enhance its energy self-sufficiency. Although there is increasing acceptance that such recycled fuel is currently more costly to produce than that made from newly mined uranium, this is judged in some cases to be more than offset by the energy security and radioactive waste disposal advantages that can be derived from it.

### ***Nuclear safety***

The accident at Chernobyl in the former Soviet Union, which resulted in the release into the atmosphere of significant quantities of radioactive material, has prompted international concern about nuclear safety standards and had an immediate effect on the global nuclear industry. Programmes to expand nuclear energy were curtailed in several states as concern about the consequences of the Chernobyl accident led to a re-assessment of plans.

One consequence of the Chernobyl accident has been greater international oversight of nuclear safety criteria and pressures to improve existing standards and to shut-down those reactors deemed potentially dangerous. Improvements in East-West relations have led to better co-operation on nuclear safety issues and the establishment of the World Association of Nuclear Operators (WANO), a non-governmental organization which seeks to improve the flow of information on reactor design, operation and safety standards. The IAEA has also taken a lead in providing greater international oversight of safety standards through its Operational Safety Review Teams (OSARTs), which visit nuclear plants and assess issues relevant to their safe operation, such as maintenance and training standards. In 1994, the Convention on Nuclear Safety was signed under the auspices of the IAEA.

Concern about operational safety hazards has had a marked affect on public attitudes to nuclear energy around the world and this will be a significant factor in assessments of the role of nuclear energy in the future. Hopes for reviving interest in nuclear energy lie in part with research into, and development of, 'inherently safe' reactors, though no firm orders have yet been placed for such plants.

### ***Environmental factors***

A number of environmental factors impinge upon the operations of nuclear plant. It has been argued that the nuclear generation of electricity is less environmentally harmful than coal-fired generation on the grounds that the latter involves extensive mining, causes air pollution, and could contribute to global warming from a build up of greenhouse gases resulting from the combustion of fossil fuels. Thus amid growing concern over the environmental impact of nitrogen oxides, sulphur dioxide and carbon dioxide released from the combustion of fossil fuels, it may be argued that nuclear energy is one of the few available methods of large scale electricity generation which does not involve potentially damaging releases of gases from combustion.

The major environmental problem associated with the nuclear industry, apart from the possibility of contamination by radioactive fall-out resulting from a nuclear accident, is the disposal of radioactive waste. Although there have been technical advances in methods of its disposal, and the development of repositories for low level and intermediate waste, the issue remains controversial. The repositories are not considered satisfactory, especially for long-term storage and for high level waste, and have generated significant local political opposition, as well as being regarded as future 'plutonium mines' if used for the disposal of irradiated fuel.

### ***Economic costs of nuclear power***

It has been argued that in many regions of the developed world nuclear power is commercially cost-effective. Critics of nuclear power claim that such calculations, based on the running costs of nuclear reactors, are misleading since they fail to take into account a number of long-term and often hidden costs, such as those associated with the disposal of radioactive waste and the decommissioning of old radioactive plant. Costs that could also affect nuclear power's competitiveness in the future include those resulting from efforts to improve safety standards and government regulatory oversight, public opposition and construction delays. In the developing world, these factors, in particular the severe capital cost over-runs on some programmes, have also affected many power plants under construction and have led to some cancellations.

### ***The Future of Nuclear Power***

The NPT states in Article IV that all its States Parties have an inalienable right to share in the use of nuclear energy for peaceful purposes. Since the early 1980s, reduced fossil fuel prices and the increased fuel-efficiency of the plants that use such fuels have made nuclear energy programmes unattractive to many states. The cost of embarking on a nuclear programme is now considered prohibitive for most developing states, unless extremely preferential assistance can be offered. Attempts have been made to set up such assistance, including arrangements which might offer preferential treatment to NPT parties. However, a study conducted by the IAEA on the possibilities for preferential financing of nuclear plants in developing countries offered few concrete solutions to this problem. Thus for many developing states, Article IV continues to offer industrial rights which currently cannot be realized.

The slow-down in the ordering of new nuclear-power reactors since the end of the 1970s seems set to continue.

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Global nuclear power capacity will slightly increase in the short term because plants now under construction are due for completion. Further into the future, the picture remains one of uncertainty, as retirements of plant parallel any new construction.

Areas of the nuclear industry where growth can be confidently expected for the remainder of the century and

beyond are in the decommissioning of older generation nuclear plant (including plant entombment, partial demolition and final dismantlement) and nuclear waste management. In addition, current trends suggest a geographical migration of construction of any new nuclear-power reactors away from North America and Western Europe towards Asia.