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CHAPTER 1

Introduction

Nuclear power is now at a crossroads. New orders for nuclear plant have almost completely dried up and many of the technological, economic, political and energy policy premises on which nuclear power's attractions were based have proved unfounded. The expectations that factors such as learning and scale economies would mean that the cost of nuclear-generated electricity would become significantly and substantially cheaper through time have not been fulfilled. The performance of reactors remains disappointing and capital costs have increased steadily in real terms so that financing new reactors has become a severe, and in some cases, insuperable barrier to further orders.

In energy policy terms, mainly for long-term structural reasons, electricity demand has not grown as anticipated and the need to substitute for fossil-fuels, which seemed imperative after the first oil crisis, no longer seems so urgent. Politically, the scale of public opposition that has occurred was not anticipated and the expectations that fears would recede as they were either proved groundless or the dangers at least became familiar have not been fulfilled. The accidents at Chernobyl and Three Mile Island have ensured that any developments or incidents relating to nuclear power are extensively reported and that proposals to build nuclear power plant anywhere are likely to be subject to the closest scrutiny.

However, the hiatus in ordering would appear to give the opportunity to re-evaluate nuclear power thoroughly. Such a re-evaluation would be timely as a sufficient body of experience is now accumulating to allow nuclear power to be properly evaluated on the basis of actual rather than anticipated performance. From this experience, it should be possible to address a number of issues concerned with the performance of the technology. These would include:

- an assessment of the available technologies to examine whether they are the most appropriate and what improvements should be made to them

- a review, to establish how to ensure good practice in building and operating nuclear plant
- a re-evaluation of state-support for nuclear power, particularly the effectiveness of national atomic energy research organisations and national research budgets
- a review of the role and methods of the safety regulators
- an analysis of what adjustments are necessary to the nuclear power plant supply industry and what positive steps are needed to achieve them

Whether the past history of nuclear power has created so many rigidities and entrenched positions that the nuclear industry is incapable of the degree of change required remains to be seen but if past lessons can be thoroughly learnt it may be possible to ensure that the nuclear power industry is fully able to respond, if substantial orders for nuclear power plant are again required.

More generally the development of nuclear power technology raises and illustrates a number of issues on the development and commercialisation of large-scale technologies. It is especially relevant to technologies that are seen as being of strategic importance and which have such long lead-times and development costs that private industry has been unwilling to undertake their development alone. Some of the issues raised include:

- the importance of learning by experience as a means of technology improvement
- the impact of scale economies on costs
- the role of technology standardisation
- the incorporation and use of prototype and pre-commercial experience

The scope of the book

There is little understanding why, even though nuclear reactors have been supplying electricity to consumers for 30 years, there is still a wide variation in the success of nuclear power programmes. Some countries have been able to build nuclear plant quickly and cheaply, and operate it effectively, whilst others have been much less successful. This book examines the contrasting records of four of the major users of nuclear power, the USA, the Federal Republic of Germany, Canada and France, and seeks to identify the factors which have been important in determining the success or otherwise of their nuclear power programmes.

In particular, the operating performance record is examined highlighting the major technological weaknesses. Capital costs and construction times are also examined identifying trends and the underlying factors behind them. These technological and economic factors are then related to the specific environment for nuclear power in each country. This includes the constitution and strengths of the main organisations involved, such as the electric utility, the plant vendor and the safety regulator, the extent and form of government support and the form and rigour of regulatory activity prior to, and during, construction and during operation.

The world context

There are now about thirty countries worldwide operating or building nuclear plant and, for nearly all of them, this represents the most challenging project, technologically, logistically and politically, that these countries have undertaken. In technological terms, nuclear power requires the highest standards of design, engineering and operating practice and has imposed unprecedented regulatory requirements. Logistically, the enormous complexity of these plants creates problems in communication and co-ordination in the construction and operation phases.

The public image of nuclear power has changed radically over its history. In its early days, up to about 1970, public reaction to nuclear power was generally very favourable. The reasons for this are complex and difficult to summarise, but some of the main ones include:

- civil nuclear energy was a more acceptable fruit of the vast amount of effort poured into nuclear research than nuclear weaponry – in some way it salved the public's conscience over Hiroshima
- it appeared to epitomise modern technology producing the modern fuel, electricity, cheaply and also more cleanly than the fossil-fuel alternatives

However, public opinion had begun to polarise by the early 1970s. To its strongest opponents, nuclear power had not broken free from its military links (see for example Patterson, 1984) and, increasingly importantly, the safety hazards did not compensate for the benefits of apparently cheap power. By contrast, its strongest supporters remained unshaken in their belief that nuclear power was the only acceptable way of securing energy supplies for the long-term. Increasing costs and disappointing performance were ascribed to the action of intervenors and poor regulation, rather than to failings within the industry. This degree of polarisation, which has remained through the past 15 years, is a feature unique to nuclear power. For no other civil technology is it possible to categorise such a high proportion of the population as being 'anti' as a matter of principle.

Whilst it is quite legitimate to argue for or against a technology on grounds of principle, such arguments have dominated nuclear power and the quality of economic and technological argument has generally been low. Much of the analysis that has been produced uses the data to reinforce a prior position whilst more neutral analysis is branded as 'pro' or 'anti' according to the conclusions reached.

Two of the major factors to consider in evaluating nuclear power programmes are the variety and sometimes confusion of motives countries have had in adopting nuclear power and the route to nuclear power these countries have taken. Particularly in the early phases, military considerations were often of importance either directly by determining technology choice or indirectly by giving particular technologies a head start. (The importance of the links between the military and civil programmes is strongly argued by Roth (1982).)

In the USA, the light water reactors (LWRs), which now dominate the world market, were given a considerable lead over their competitors by their prior use as submarine propulsion units and the pre-existence of uranium enrichment facilities required by the weapons production programme. In the UK, the first reactors in the gas-cooled reactor programme were controlled by the government and were primarily designed to produce plutonium for weapons (see Williams, 1980). Electricity was a by-product.

In Canada, the civil nuclear programme has been least affected by military considerations, Canada having renounced nuclear weapons soon after the Second World War. However, even here, its programme of heavy water reactors was assisted by the experience it had gained in that war producing and supplying heavy water to US military establishments.

Nowadays in most countries civil and military nuclear programmes are largely separated, although suspicions remain about the motives of some of the countries developing nuclear power capabilities.

Nevertheless the result of this military legacy has been the continuance of large subsidies, often to government laboratories, to develop nuclear power technology further. This has meant that the ultimate users, the electric utilities, have often had little influence on the choice of technology and the direction of technology development. The early vision of the way in which nuclear power technology would develop has persisted even when its grounding tenets no longer seem valid. This vision held that 'thermal' reactors, that is, reactors which could only use a small part of their uranium fuel, would be rapidly succeeded by 'fast' reactors, which use a much higher proportion of the uranium (see Walker & Lonnroth, 1983). The abundance of uranium and the slower than expected development of nuclear power has meant that such a transition is now seen as increasingly distant if indeed it ever becomes necessary. Nevertheless, government funds still reflect past perceptions and are heavily concentrated on fast reactor development. Development of commercial reactor types has been carried out largely by private industry since the first commercial orders and has often followed a 'fire-fighting' reactive approach rather than an innovative approach.

As military imperatives have diminished, civil nuclear power programmes have been increasingly driven by energy policy and economic policy objectives. In the early to mid-1950s, before oil had acquired its status as a cheap, plentiful and reliable fuel source, nuclear power was seen in some countries as a natural replacement for coal as indigenous reserves were exhausted. This influence weakened through the 1960s as oil production from the Gulf States increased, returning to prominence following the first oil crisis of 1973–74 but since then waning yet again. A second energy policy objective, that of reducing the cost of electricity supply, was established by the milestone US Oyster Creek nuclear power plant order of 1963. Here, for the first time, an order was placed for a nuclear plant because, on the basis of bids received, it was the cheapest option available to the utility. (For further details see Bupp & Derian, 1981.) As with the 'fuel-shortage' objective, the attractiveness of this argument was weakened by falling real oil prices and rising real nuclear capital costs. It was given a new lease of life by the oil crisis before losing ground again as capital costs continued to escalate and oil and coal prices failed to rise as anticipated.

A third energy policy motive, that of increasing the diversity of electricity generating capacity, has emerged strongly since the second oil crisis. This has arisen because of fears that electricity supply systems that were heavily dependent on one particular fuel would be vulnerable if supplies of that fuel were interrupted or its price rose quickly.

Economic and industrial policy motives are often less overt but have nevertheless played an important role. The high-technology nature of nuclear power persuaded governments and companies that it was strategically important to establish capabilities in this field in order to pick up a share of what was seen as a rapidly expanding and lucrative world market and to keep abreast of what were seen as the skills and techniques of the future. More recently, rapid fluctuations in oil prices have increased the attractiveness of energy sources such as nuclear power which do not cause unpredictable strains on the nation's balance of payment. For many countries the cost of importing oil has been a major drain on resources and has been seen as a barrier to economic growth. However, the escalating cost of nuclear plant has diminished nuclear power's attractiveness in this respect. Countries such as Mexico, Brazil, Argentina, the Philippines and even France are finding that their nuclear power programmes are a major contributor to their international debt. (For example, a more detailed account of Mexico's debt problems can be found in *Nucleonics Week*, 1986c, p. 11.)

The strategies open to a country adopting nuclear power may be constrained by its underlying motive. For example, France decided to reduce dependence on imported oil radically and very quickly by substituting nuclear power for oil-fired electricity generation and, further, by substituting electricity for the direct use of oil. Given the scale of programme envisaged, probably the only viable strategy if costs were to be controlled and schedules met was to impose centralised, autocratic control, use standardised, apparently proven technology and build up a high level of indigenous component supply. In other countries, such as India and Pakistan, suspected connections between the civil and military nuclear programmes have restricted these countries' ability to purchase equipment and fuel on the world market.

Corresponding to these changes and differences in motives have been changes in the location of decision-making. This has lain variously with atomic energy (and weapons) research agencies, utilities, vendors, politicians and the public. These changes in location have often brought about a re-evaluation or change in the direction of nuclear power policy.

One further factor that has had an important influence on the way in which electric utilities view nuclear power has been the history of technical innovation in the electricity supply industry. Throughout this century there has been a steady and remarkable stream of innovations in the electrical power generation sector. Up to the 1960s thermal power stations were generally sited in city-centres and produced unpleasant local pollution. Economies of scale, improved pollution control equipment (especially for particulates), higher stream conditions at the turbine generators and improved transmission technology have all served not only to steadily reduce the real cost of electricity, but also to reduce the cost of electricity relative to other energy forms. In addition, it has allowed the increasing demand for electricity to be met by fewer power stations which have usually been sited in remote areas. By the late 1950s and early 1960s the 'all-electric' home had become an advertising cliché for advanced lifestyles. However, by this time generation technology was running up against diminishing returns. The benefits of building larger power stations, producing steam for the turbines at higher temperatures and pressures and transmitting electricity at higher voltages were no longer substantial. In this situation, to many in utilities and governments, nuclear power seemed to open up a whole new stream of innovation and challenges and, in a phrase that has rebounded on the electricity supply industry, promised 'power too cheap to meter'.*

On a range of other issues, electric utilities have failed to respond quickly to changing circumstances. Such issues include:

– the rising real cost of nuclear power. Utilities have tended to blame rising costs on disruption caused by intervenors, and unnecessary safety

* This phrase was used by Lewis Strauss, the then-Chairman of the US Atomic Energy Commission at a National Association of Science Writers' Founders' Day Dinner in New York (September 16 1954).

requirements imposed by hostile regulators. As is argued in this book, these may have been factors but they by no means account for all the real cost increases

- the long-term reduction in electricity demand growth rates. Utilities have tended to attribute these reductions to short-term interruptions caused by the oil crisis rather than long-term effects based on factors such as demand saturation and industrial restructuring away from heavy energy-intensive industries
- the scope for energy conservation. Utilities have been slow to realise the scope for energy (and electricity) conservation that energy price rises have produced. For many utilities, particularly where the costs of new plant are highest, the sponsoring of conservation schemes is a more cost-effective route to the utility than allowing demand to rise and building new plant
- the attractiveness of technologies competing with nuclear power. Such alternatives include fossil-fuel based technologies such as combined heat and power and combined cycle plant, and renewable technologies such as wind, tidal and wave power. Either explicitly or implicitly, more stringent financial targets were placed on these technologies than were applied to nuclear power and they have tended to be developed more slowly than they would merit
- the availability and attractiveness of fossil-fuels. Following the oil shocks, utilities have tended to overestimate how quickly direct use of fossil-fuel would decline in response to depletion and the supposed greater user-attractiveness of electricity. This has led them to overestimate the future price of fossil-fuels and underestimate their availability

These factors should have led electric utilities to adopt a cautious approach with respect to plant ordering, spreading research over a range of non-nuclear technologies and investigating demand-side measures such as conservation and load management.* However, many utilities have been reluctant to reduce their plant ordering. In the USA, because of the system of economic regulation of utilities which does not allow utilities to recover all the costs of unnecessary plant from consumers, this has resulted in a vast number of cancellations of nuclear (and other) plant. In countries with less stringent economic regulation of utilities, nuclear plant has been completed and has either not been fully utilised or has caused other plant to be underutilised or prematurely retired.

* Load management covers a number of options, but of most interest in this context are those which reduce peak demands on electricity systems by switching off (with the agreement of the consumer) non-essential uses. This can effectively reduce the amount of plant required to meet the same overall demand.

The current status of nuclear power

The current status of nuclear power is summarised in Table 1.1. Nuclear power contributes about 10% of the World Outside Communist Areas' (WOCA) electricity generating capacity and this proportion is likely to rise somewhat as nuclear capacity increases by a little less than 50% by 1995.*

Nuclear power in Communist countries. As was amply demonstrated by the Chernobyl accident, nuclear power programmes in the Communist world can have a profound effect on Western countries. However, little detailed analysis of the performance of these nuclear power programmes is possible. This is because few analytical data are available from which a worthwhile assessment of performance and procedures could be made. No cost data have been published and COMECON countries have not submitted the detailed accounts of performance to the IAEA on which the analyses of operating performance contained in this book are based.

Nevertheless, a number of points should be made about these programmes. Not surprisingly the dominant influence is the Soviet Union which has by far the largest number and capacity of reactors and which has supplied most of the plant in operation or under construction (see Table 1.1).

The Soviet Union's programme is based on two technologies, their own design of pressurised water reactor (PWR) and a light water cooled, graphite moderated reactor (LWGR) known as RBMK design (the design installed at Chernobyl). This latter design represents about 60% of installed nuclear capacity but only represents about 25% of capacity under construction. There are two current designs of RBMK type reactors, the RBMK 1000 and the RBMK 1500 (with capacities of about 1000 MW and 1500 MW respectively). However, no reactors of this design have been exported.

The PWR, which is likely to dominate future orders also comes in two sizes, the VVER 440 and the VVER 1000 (with electrical outputs of about 440 MW and 1000 MW respectively). All the exported units, including the only units exported outside the Communist Bloc, the two units at Loviisa in Finland† are of the VVER 440 design. For future orders the Soviet Union has recently withdrawn the VVER 440 design and all the PWRs under construction in the Soviet Union are VVER 1000s.

The only COMECON country to order reactors from a Western vendor is Romania which concluded a deal with AECL of Canada in 1978 for up to

* The proportion will rise because nuclear power represents a large proportion of plant under construction. Note also that some of the nuclear plant currently in service will be retired before 1995 although this is likely to be only small old plant and that some of the plant under construction may be cancelled.

† The operating record of the two Loviisa units is outstandingly good.

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Table 1.1. *World capacity[a] of nuclear plant*

Country	Main technology[b]	Capacity (no. of units)	
		Capacity (MW) at 1.1.86	Probable additions[c] (MW) to 1.1.95
World Outside Communist Areas (WOCA)			
USA	LWR	77 106 (91)	29 893 (27)
France	PWR	33 365 (39)	27 581 (22)
Japan	LWR	23 640 (33)	8 736 (8)
FR Germany	LWR	16 068 (16)	6 846 (7)
Canada	PHWR (CANDU)	9 487 (15)	5 630 (7)
Sweden	LWR	8 325 (12)	—
UK	GCR	5 825 (22)	6 180 (10)
Belgium	PWR	5 465 (7)	—
Spain	LWR	5 577 (8)	1 902 (2)
Taiwan	LWR	4 984 (6)	—
South Korea	PWR	3 580 (5)	3 686 (4)
Switzerland	LWR	2 882 (5)	925 (1)
Finland	LWR	2 310 (4)	—
South Africa	PWR	1 844 (2)	—
Italy	LWR	1 285 (2)	1 964 (2)
India	PHWR (CANDU)	1 034 (5)	1 100 (5)
Argentina	PHWR	935 (2)	692 (1)
Yugoslavia	PWR	632 (1)	—
Brazil	PWR	626 (1)	1 229 (1)
Netherlands	PWR	481 (1)	—
Pakistan	PHWR (CANDU)	125 (1)	—
Mexico	BWR	—	1 308 (2)
Philippines	PWR	—	620 (1)
Total WOCA		205 576 (278)	98 292 (100)
Central Planned Economics (CPE)			
USSR	PWR, LWGR	25 977 (42)	34 725 (35)
DR Germany	PWR	1 702 (5)	2 448 (6)
Bulgaria	PWR	1 620 (4)	1 906 (2)
Czechoslovakia	PWR	1 570 (4)	4 068 (9)
Hungary	PWR	1 224 (3)	408 (1)
Romania	PHWR (CANDU)		1 887 (3)
Poland	PWR		880 (2)
Cuba	PWR		816 (2)
China	PWR		288 (1)
Total CPE		32 093 (58)	47 426 (61)
Total world		237 669 (336)	145 718 (161)

[a] Capacity figures are expressed net of power station own use.
[b] Main technologies:
LWR = light water reactors including both pressurised water reactors (PWRs) and boiling water reactors (BWRs)
PHWR = pressured heavy water reactors
CANDU = Canadian deuterium uranium reactors
GCR = gas (carbon dioxide) cooled reactors
LWGR = light water cooled, graphite moderated reactors
[c] Includes only plant under construction or firmly ordered; any orders not already placed are highly unlikely to have entered service before 1995. For plant in Communist countries, includes only plant reported as being under construction.
Source: Nuclear Engineering International, Power Reactors 1985, August 1985.

six units of which three are under construction. Progress on these units has been very slow and the completion dates consistently revised back.

China has been seen by many of the Western vendors as a major new market with expectations of 12 units, each of about 1000 MW being installed this century. However, contracts have been slow to be finalised and the only unit under construction is a 300 MW PWR of Chinese design. There is reported to be a commitment to purchase two 900 MW PWRs from Framatome of France but a firm order had not been placed at the time of writing. China now appears to be placing more emphasis on coal for future power generation than nuclear power.

Overall, the commitment to nuclear power in Communist countries seems stronger than in Western countries with nuclear capacity expected to increase by nearly 150% over the next ten years. However, this impression may be misleading. It reflects that relatively few reactors have been installed in Communist countries. In addition, these countries are subject to the same pressures, particularly financial, that have drastically reduced expectations of the amount of additional capacity that will be installed in the West. The difficulties of gathering reliable data mean, however, that the nuclear programmes of Communist countries are not considered further in this book.

The assessment of nuclear power

Despite the long history of nuclear power plant operation there has been little feedback of actual operating experience into decisions about technology choice. There are three main reasons for this.

First, long construction times and rapid product change have meant that, at least until the mid-1970s, the reactors available for order bore little resemblance to those in operation. This meant that it was hard to draw any meaningful conclusions, based on actual experience, about the merits of various reactor systems until the mid-1970s. By this time most countries that are now users of nuclear power had already chosen their technological route. The choice of reactor system often led to the construction of dedicated production facilities, the training of high-grade engineering and scientific talent to operate with the given design and the expenditure of considerable funds to research the system and set up a well-trained regulatory establishment. Such decisions and actions tend to generate a momentum which is difficult to halt or reverse.

Second, due to safety implications and the demanding nature of the technology, some countries have been wary of adopting technologies other than the market leaders. These seem to give greater security and back-up in the event of something going wrong, even where the alternatives may appear more attractive.