The Sizewell B Project

John G. Collier

atomwirtschaft
Vol. XXXXI
Issue 11
January 1996

1. Introduction

The *Sizewell B* project has demonstrated the capability of the UK's manufacturing industry to undertake large projects and to meet the most demanding international standards – it is a triumph for the UK nuclear industry. This paper outlines the background to the decision to build *Sizewell B*, it runs through the design and construction phases and completes the cycle with the station's commissioning and connection to the UK electricity grid.

2. The lead up to Sizewell B

Britain has in the past been unique in pursuing gas-cooled reactor technology, although on a number of occasions consideration was given to introducing light water reactor technology for civil nuclear electricity production. The earliest occasion was in 1954 when a study of an 80 MWe PWR was completed. This project (code named LEO) was for a four-loop PWR very similar to *Shippingport* in the US. In 1958/59, arrangements were made with *Westinghouse* to purchase an S5A submarine reactor for Britain's first nuclear submarine "Dreadnought". All subsequent British nuclear submarines have used home-based technology developed by *Rolls Royce and Associates*. In 1964, when consideration was being given to what technology to adopt for the second stage of Britain's nuclear programme, tenders were invited for both BWR and PWR plant. However, the British-designed but untried AGR was then preferred over the overseas designs.

A further attempt to introduce PWR technology into Britain was made in 1973 by the *Central Electricity Generating Board (CEGB)*. At this time there were concerns about the integrity of the reactor pressure vessel and again a uniquely British design of heavy water moderated pressure tube reactor was preferred. This project, however, was aborted in 1977 when a comparative study (the Thermal Reactor Review) between the heavy water reactor, the advanced gas-cooled reactor and the PWR was undertaken. Although this study clearly showed the overall merits of the PWR, it was concluded – correctly as it turned out – that it was not possible to introduce it rapidly into the UK. As a result, in 1979, two further AGR stations were ordered and the Government agreed that in order to establish the PWR option, the *CEGB* should proceed with the construction of a single PWR power station. This belated move to PWR technology reflected the changes taking place internationally in the development of nuclear power. In particular, light water technology had become established as the mainstream, with a rush of ordering for PWRs and BWRs from utilities in the US, Europe and Japan.

In January 1981 a planning application was made for *Sizewell B*. It was to be a 1,200 MW PWR based on well-established *Westinghouse* technology. At the time, some eight PWRs of this type were already operating and a further 25 were under construction. The *Sizewell B* project was the subject of an extended public inquiry from January 1982 until March 1985. In his report to the *Secretary of State for Energy* in December 1986, the Inspector, *Sir Frank Layfield*, declared himself satisfied on all aspects. The project was subsequently sanctioned by the Government in March 1987. Preliminary site work started at the end of June 1987 and first permanent structural concrete in August 1988. In the following year the Government privatised the electricity supply industry, but kept nuclear generation in the public sector. *Nuclear Electric* was established in April 1990 with myself as Chairman. It owns and operates the nuclear generating plant in England and Wales and was given the responsibility for the continuing construction and subsequent operation of *Sizewell B*. (This paper refers to *CEGB* and *Nuclear Electric* as appropriate to the context.)

At privatisation the construction of three follow-on units was deferred, and this had a significant effect on the cost of *Sizewell B* as all of the up-front, first of a kind engineering costs then had to be carried by this single project. The revised capital cost estimate in 1987 prices was £ 2030 million. The project has been completed within this budget.

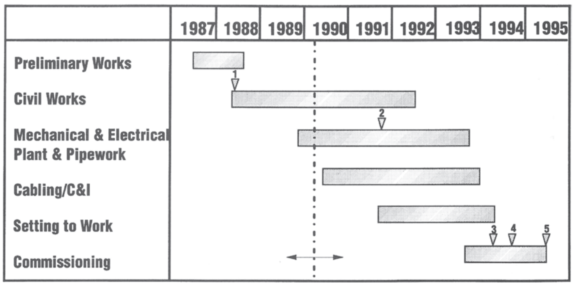

Fig. 1.
Construction Programme. 1 First permanent structural concrete. 2 Start NSSS. 3 Hot functional testing. 4 Load fuel. 5 Full load.

3. Pre-construction activities

Some six and a half years elapsed between the submission of the planning application and the start on site **(Figure 1)**. It would of course have been preferable for that period to have been shorter, but the long Public Inquiry process forced that extended lead time. However, this had the advantage that effective use could be made of that time to transfer the technology from the US, and here we gained much from both *Westinghouse* and *Bechtel*; to develop the design to make it suitable for application in the UK, and in particular, so that it met the stringent safety requirements set by the *CEGB* and the *Nuclear Installations Inspectorate (NII)*; to establish a first-class project organisation to undertake the project; to establish contracts with mainly UK contractors, many of which had to undergo considerable upgrading of their facilities, and introduce quality assurance programmes which were far more rigorous and demanding than most of UK industry had been used to.

Indeed, the *Sizewell B* contract was the first major project in the UK on which a comprehensive Quality Assurance programme was applied through all aspects of the project, including the design and engineering of the plant. A further feature of the pre-construction phase was the need to undertake development on a limited number of plant items on which changes in design or manufacture were judged sufficient to require a test Programme. Examples include a primary circulator test rig at Weirs and a valve test facility at Marchwood. In addition, due to the considerable emphasis placed on ensuring the absolute integrity of the reactor pressure vessel, an *Inspection Validation Centre (IVC)* was established by the *Atomic Energy Authority (AEA)*. This centre undertook validation of the inspection techniques

– both manual and automated – and certified the inspectors who were undertaking the manual inspection. This validation was a considerable enhancement of the non-destructive examination (NDE) normally associated with high integrity pressure components.

4. Design

Before dealing with the project management and construction aspects of *Sizewell B*, it is worth expanding on the subject of design and engineering. A high-tech project can only really be successful if it has a sound engineering basis. We must learn from past experience. Previously the *CEGB* had repeatedly introduced many innovations into each new project, and indeed were often building essentially prototypes – being clever rather than successful. For *Sizewell B* emphasis was placed on mature and proven technology with the minimum of innovation compatible with building a plant which fulfilled the necessary safety and performance requirements. To this end a Task Force, chaired by *Sir* (now *Lord*) *Walter Marshall* with representatives from the major interested parties, was set up in 1981 to establish a sound basis for the *Sizewell B* design.

The *Bechtel Standardized Nuclear Unit Power Plant System (Snupps)* design, at that time being built at Callaway in Missouri, was chosen as the reference plant. The *Snupps* design had been developed by *Westinghouse* and *Bechtel* as a standard design for series ordering in the US. In the event only two were built due to the collapse of the US orders for new plant in the late 1970s. Nevertheless it proved to be a sound basis for developing *Sizewell B*. The late 1970s and early 1980s, when *Sizewell B* was being designed, was a period of rapid development in the light water reactor field. Besides the accident at *Three Mile Island-2 (TMI-2)* in 1979, from which the lessons learned needed to be incorporated into new designs, there were also major developments which included:

- The need for the design to deal both with internal and external hazards. This was highlighted by the fire at Browns Ferry in 1975. Further, the awareness of seismic hazards increased, requiring the seismic design and qualification of buildings and plant to be addressed in greater detail.
- The publication of the Rasmussen Report in 1975 highlighted the importance of Probabilistic Safety Assessment (PSA) and the need to employ highly reliable safety protection Systems with sufficient diversity and redundancy to give satisfactory reliability. Indeed the *Sizewell B* design, has been subjected to probably one of the most rigorous and wide ranging PSA of any plant to date. This allowed informed decisions to be made during the development of the design. The PSA has demonstrated that the *Sizewell B* design provides a high level of reliability and safety, which compares favourably with other current advanced reactor designs.
- Also during the period there were rapid strides in the concept of quality assurance and its application to nuclear power plant, resulting in the publication of very demanding quality assurance requirements by the *US Nuclear Regulatory Commission (NRC)* and the *British Standards Institute*.
- Major advances in the techniques of fracture mechanics and non-destructive testing and inspection were also occurring. The *Organization for Economic Cooperation und Development (OECD)'s Nuclear Energy Agency* programme of large scale tests on the effectiveness of flaw detection gave a powerful injection of realism to these developments. And of direct relevance to *Sizewell B*, a Light Water Reactor Study Group was set up in 1974 under the Chairmanship of *Walter Marshall* to examine the factors determining the integrity of the reactor pressure vessel. The Group, of which I was a member, reported its initial findings in 1976 and the report was updated in 1981.
- Particularly as a result of TMI, there was increased realisation of the vital importance of the Operator of nuclear power stations, with greater emphasis placed on the man-machine interface. This had a strong influence on control room design, and design for ease of maintenance. The importance of highly trained operators increased the pressure to have a full-scope, high-fidelity simulator available for training the *Sizewell B* operators, well in advance of the operation of the plant.
- The rapid progress being made in the field of control and instrumentation had a major impact on the development of the design. The introduction of micro-processors into the reactor protection system required both thoroughly verified software and an extremely high level of quality control.

The design work was undertaken by a dedicated team of engineers drawn from the *National Nuclear Corporation* and the *CEGB*, who developed the *Snupps* design to meet specific UK requirements using information provided by *Westinghouse* and *Bechtel* through technology transfer and licensing agreements. During the initial phase of the design, *Westinghouse* and *Bechtel* engineers were integrated into the design team to ensure maximum benefit was gained from their experience. At its peak the design team was over 1000 strong and was supported by a number of engineering and safety analysis consultancies. The design team made full use of Computer aided design (CAD). A very detailed engineering model at 1 : 20 scale of the nuclear plant became an important part of the design work, including routing of pipework, *Heating, Ventilation und Air Conditioning (HVAC)* ducting, and cabling: undertaking hazard reviews and optimising the design for in-service inspection, ease of construction and operation.

On the *Sizewell B* project emphasis was placed on achieving a high level design completion at an early stage to ensure: accurate costing; a realistic project programme; detailed specification of contracts; and advanced availability of design information to Support the construction programme. In this respect, the long lead time which resulted from the extended planning consent process was a help. The importance of achieving a secure safety case, agreed with the *NII* was also recognised. This was essential to minimise the likelihood of delays during construction arising from problems with the licensing body. The preconstruction safety report was, in the event, issued in May 1982, some five years in advance of the start of construction and this allowed ample time to resolve any outstanding safety issues with the licensing authority, and ensure that the results of this exchange were included in the design and contracts. Special attention was paid to the management of this interface with a licensing group charged with responsibility for ensuring the timely submission of documents to the *NII* and early resolution of any problems. This arrangement was underpinned by high level, regular meetings between the Project Director and the NII Chief Inspector. The quality of the *Sizewell B* design, particularly with regard to safety was demonstrated when the design was examined against the lessons learnt from the *Chernobyl* accident which took place 1986. The design stood up well to the test. No modifications were necessary as a direct result of the *Chernobyl* accident.

5. Project management

In the early 1980s, it was recognised that performance in the past on large projects undertaken by the *CEGB* and others had been very variable. In particular, the Isle of *Grain* and *Dungeness B* projects signalled the importance in future projects addressing the weaknesses that led to the poor performance on those earlier projects. This led in the late 1970's to significant changes in the *CEGB's* approach to the project management and contracting for the coal-fired station at *Drax B* and the nuclear station at *Heysham II*. The result was that both these projects were successful, being completed close to budget and programme. For *Sizewell B* the *CEGB* built on this good experience, but in a significant change from past practice, chose a unified approach the design, contracting and construction the project, with the *CEGB* itself undertaking the leadership of the project. This decision reflected the risk carried by the *CEGB* on large unitary investment where they could not afford for the project to go wrong. The arrangement was also consistent with the discharge of the *CEGB's* responsibility for the quality of the design, the integrity of the safety case, procurement policies, and the expenditure and control of the *CEGB's* monies. So it was decided to undertake *Sizewell B* through a client managed project team, with a comprehensive architect/engineer constructor role which the *CEGB* as client placed direct contracts with the contractors.

The *PWR Project Group (PPG)* was set up with responsibility for: compiling the safety case; determining the station layout; acting as architect/engineer for the station systems; specifying the equipment; managing the procurement; managing the construction site; conducting the commissioning; and managing the overall project. This was the first time that all of these functions had been combined for a major nuclear power station project in the UK. The concentration of skills, cohesion of effort, and elimination of traditionally difficult interfaces, proved to be of major importance to the success of the project. The project management arrangements had been subjected to intense scrutiny at the Public Inquiry into *Sizewell B*. *Sir Alastair Frame* was called as an expert witness and set out the elements of project management that the *CEGB* should introduce for the *Sizewell B* project to be successful. In particular he highlighted the need for high quality leadership and stressed the importance of the task of Project Director. This challenging post was filled by *Brian George* who had led the project from its initiation through design and into the Public Inquiry. *Sir Alastair* also stressed the importance of having a supervisory board to supervise the project team. This approach was indeed complied with by the setting up of the *Project Management Board* to oversee the *Project Team*. As you would expect, great attention was paid establishing high quality project planning, progress monitoring and cost control arrangements, making use of the best available computerised systems. In addition, single project data base – "Total Project Information" (TPI) – coupled with a robust information system was established at the start of the project. This ensured that all those involved in the project had access to common set of information. Another important element was the early establishment of a quality assurance programme covering not only manufacture and construction, but also design. The quality assurance programme was backed by detailed procedures for all aspects of the project and this was an important element in ensuring the quality of the design, the equipment, and the civil works, so necessary in a project which has to meet stringent requirements from the licensing authorities.

Lastly, particular attention was paid to the arrangements for site industrial relations, these included:

- Giving robust support to the *National Agreement for the Engineering Construction Industry (NAECI)* and its *National Joint Council (NJC)* with a *Project Joint Council* for *Sizewell B*.
- Establishing industrial relations requirements for the project through an industrial relation specification which was part of the contract with each supplier.
- Establishing a Management Group involving *Nuclear Electric* (as client) and the contractors to establish guidelines for harmony of wages and conditions, and ensure a consistent application of industrial relations policy across the project.

As a result, loss of working hours due to industrial relation disputes were about 1 % – lower than on any previous *CEGB* power station project.

6. Contracting

The contract strategy adopted on *Sizewell B* was to divide the work into a number of contract packages (110 in all). The contracts were placed through a competitive bidding process wherever possible, and firm price lump sum contracts were adopted which covered design detailing, manufacture, erection and testing. The only exception to this policy were in areas where the work was logistically complex and design was not complete. In these cases such as the major civil works and cable installation, firm rates and estimated quantities were used. Negotiated contracts had to be employed in two specific cases: The primary circuit contract because *Westinghouse* was the developer and owner of the design and were uniquely able to offer the necessary warranties and performance guarantees, and the high integrity pipework contract where the size and complexity of the job made it necessary to bring together the three UK contractors with experience of the design, manufacture and erection of high quality pipework. This prevented competitive bids being sought.

The contracts were placed to support the target construction programme and were appropriate incorporated penalty and incentive arrangements. The incentive arrangements were set early in the contract and were reviewed jointly to the best mutual advantage for the project management and the contractors to achieve win-win situations. In placing contracts, considerable attention was paid to ensure that each contractor was a quality contractor with a good performance record and with sufficient capability to give confidence that he could fulfil his obligations. With very few exceptions, the contractors more than came up to our expectations. Throughout the project, contract issues were identified early and dealt with quickly. Claims were also settled quickly. Payments to the contractors were reviewed against the achievement of milestones. A key dates procedure in which cash flow and resources were discussed at director level was an important element in the overall management of the contractors.

7. Construction

Construction of the permanent works was preceded by a preliminary works period of 13 months which ran from July 1987 to August 1988 **(Figure 1)**. The approach adopted for construction of the permanent work was so called "fast tracking" in which there was a high degree of overlap between the building of the civil structures and the progressive installation of equipment and services. The target programme against which the contracts were let and the programme monitored was 69 months from first

Fig. 2.
Sinking into place part of a sea-water cooling culvert.

permanent concrete placement to commercial load with a commitment to the executive of 78 months i.e., commercial load by the beginning of March 1995. In the event full commercial load was achieved in June. The project kept close to the target programme through the construction phases, but regressed to the commitment programme during the commissioning phase. This is a problem common to many technically complex projects, and in part reflects the cautious approach to commissioning taken on a reactor type which was new to the UK. The cost control data for the project mirrors the events in the programme. Annual budgets were held to closely, until the latter Part of the project. Even then the overspend was readily covered by the 'risk margin' which had been set aside for just such a contingency. The site labour force at *Sizewell B* peaked at around 5,000, and the size of the workforce closely followed that planned at the beginning of the project. Only in the last two years of the project was the work force increased over that planned, to ensure that the project met the programme commitment to the executive.

In retrospect, the overall programme was ambitious by comparison with achievements on similar plants elsewhere in the world, particularly when one bears in mind that this was the UK's first construction of a PWR. I am proud of the way in which the construction was executed close to programme and within the budget confirmed by *Nuclear Electric* at its formation in 1990. The preliminary works period is of course used to prepare the site in advance of construction of the permanent works and a key element in this preparation is to ensure that the site is properly drained and dewatered. This is conventionally achieved by continued pumping of surface water when the foundations are at a level substantially below ground level, which was the case at *Sizewell B*. At *Sizewell* it was decided to overcome this problem by building a diaphragm wall which was 50 m deep, and penetrated down to the base clay level. It completely surrounded the construction site. At the time this was one of the largest diaphragm walls ever constructed and was installed within programme and proved extremely successful.

The civil works were on a massive scale involving the rapid placement of large quantities of high quality concrete and characterised by very high density rebar in many of the key areas associated with the containment. The high density rebar made rapid concrete placement extremely difficult but the high rates of concrete placement needed to meet the programme were achieved. The main containment comprised a pre-stressed cylindrical containment with an hemispherical dome lined with 6 mm steel plate to ensure leak tightness and this was used as shuttering during construction. The containment structure was modelled at 1 : 10 scale to test the pressure bearing capability of the containment and validate the codes used to analyse the containment.

A novel feature of the civil works was the cooling water culverts which ran out into the North Sea for some 750 m **(Figure 2)**. These culverts were constructed offsite at Teeside and floated down the 240 miles of open sea and sunk into trenches in the sea bed offshore at *Sizewell*. Thus avoiding the need for tunnelling which would have been difficult in the gravel beds.

The civil engineering works were essentially completed by Summer 1992. They included the placing of 400,000 m^3 of reinforced concrete and 70,000 t of reinforcement bar. The reactor building's primary containment was subjected to its structural over-pressure test in December 1993. This involved pressurising the building internally with dry air at a pressure of 4 bar, followed by integrated leak rate testing at 3 bar over a period of 24 h. The mechanical and electrical equipment required the manufacture and installation of a large number of high quality components and extensive piping and cabling associated with this type of plant. The central feature is of course the reactor pressure vessel (RPV) which was installed in August 1991 **(Figure 3)**. As mentioned earlier the RPV has received an immense amount of scrutiny because its integrity is critical to the safety of the reactor. Hence considerable attention was paid to the design and analysis of the pressure vessel; to its manufacture; and to its rigorous inspection at all stages of manufacture. The pressure vessel was fabricated by *Framatome* using forged rings, the forgings having been produced by *Japan Steel*. The inspections carried out to prove the vessel's integrity alone cost more than twice the vessel's purchase price.

Installation of mechanical and electrical services was completed in Autumn 1993. High levels of productivity were achieved. For example, the performance on the laying and termination of the main cables was by far the best ever achieved on any power station construction in the UK by a factor of two in the best month. The test of any major project organisation is its reaction to the inevitable problems which arise during construction and have to be

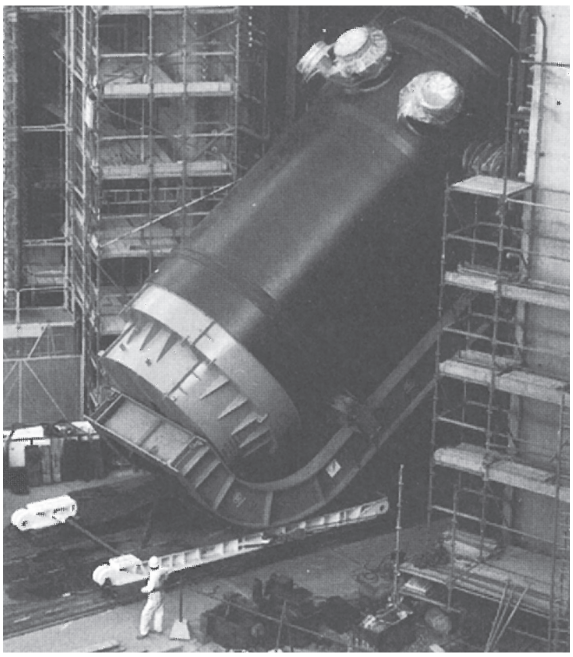

Fig. 3.
The reactor pressure vessel being lifted into the reactor building through a special portal in the containment (August 1991).

rapidly resolved if the programme is to be maintained. In the case of *Sizewell B*, perhaps the biggest challenge came when in early 1991 it became apparent that the development of the control system for the station (including the management of data acquisition and analysis), known as the Integrated System for Centralised Operation (ISCO), was falling behind programme. It was clear that the programme commitment would not be achieved. Following a careful assessment of the situation, it was decided to change contractors and bring in Westinghouse to supply the ISCO system. To its great credit, *Westinghouse* delivered the complete system only a few months later than originally planned, and it proved possible to recover this time and maintain the overall project programme.

Commissioning of the plant started in earnest in January 1994 when the primary coolant circuit, and associated fluid systems were subject to the mandatory hydro test. This was the first large-scale operation at the station in which the many systems were brought together and co-ordinated from the main control room by the operations team. This was followed by functional testing, at full operating temperature and pressure, of the primary circuit and the associated fluid Systems in April 1994. During this testing the steam dump systems were checked and the first turbine generator run at full speed. Fuel was loaded into the reactor in September 1994 and first criticality was achieved in January 1995. Following low power physics tests, power raising commenced in mid-February and power was raised in stages at around 25 %, 50 %, 75 % and finally full power. This cautious approach was particularly important when commissioning a reactor type new to Nuclear Electric; and checking and validating the operating instructions and plant surveillance procedures resulted in a stretching out of the commissioning programme. During this phase of the commissioning besides pre-planned tests and outages, a number of relatively minor problems had to be dealt with which required the plant to be shut-down for short periods. As is so often the case the problems were largely on the conventional plant – turbine vibration, steam leaks and valves requiring attention. Notwithstanding these outages, the plant achieved full power in June 1995.

8. Summing up

To sum up, the *Sizewell B* project is a success Story. From *Nuclear Electric's* point of view as a utility, we have a high quality plant performing well and generating revenue. It achieved commercial load very close to programme and within budget. At the privatisation of the electricity industry the construction of three follow-on units was deferred, and this had a significant effect on the cost of *Sizewell B* as all of the up-front, first of a kind engineering costs then had to be carried by this single project. However, it should be noted that significant improvements in the plant capability have been made during the development of the project and these have more than compensated for the increased cost. Hence I am confident that *Sizewell B* will pay handsome dividends in the future and that it represents a sound investment.

The *Sizewell B* design is currently the only station to have been designed and built, and to operate to state of the art technology requirements for Advanced Light-water Reactors, as defined by the US *Electric Power Research Institute (EPRI)*; although other international vendors have designs which have recently qualified on Paper. This offers an excellent opportunity for participating in the international market for new nuclear power plants.

The development of the design cost was of the order of £ 700 M. This included establishing the detailed design and safety case and the project infrastructure necessary to construct the plants. This sort of investment only makes sense if a family of replicate plants is to be built. Herein lies the commercial and political dilemma. Such developments involve very long time-scales and while Nuclear Electric was able to anticipate the technical developments and produce a state-of-the-art design, it cannot control changes in the political regime or changes in the commercial environment. During the development of the project, major changes have taken place in the structure of the Electrical Supply Industry (ESI) and the introduction of highly competitive Combined Cycle Gas Turbines (CCGTs) have strongly influenced the prospect for capitalising on the *Sizewell B* design by building future replicate plants in the UK.

The success at *Sizewell B* has also demonstrated the capability of the UK manufacturing and construction industry to undertake mega projects successfully. What are the ingredients that led to success and what are the lessons to be applied in the future? In Summary they are:

- The application of proven technology based on an established design. This must be complemented by a high level of design completion in advance of construction, and in the case of nuclear plant the licensing basis for the plant must be secure before commitment to construct.
- Project management arrangements must reflect the allocation of risk between client and contractors – we have demonstrated that a unified organisational structure works well for such a complex and interactive project; you must get the right man as project director; and the management systems, QA, planning, cost control and information systems must be of a high quality. An effective industrial relations approach must be adopted.
- The contract strategy must be sound and reflect the risks being carried by the parties. The contracts must clearly define the scope and responsibilities of contractors, and most importantly, the work must be placed with quality contractors.
- Contract management must instil a disciplined approach. For example by the use of the key dates procedure. And a good working relationship between the client and the contractors is crucially important – it has to be a partnership creating a win-win situation.
- There is still room for improvement in the way in which consent applications are processed and Public Inquiries are conducted. On *Sizewell B* it took over six years from application to consent and for the proposed station at Hinkley – a replica plant, over three years.

New rules for Inquiry Procedure were introduced in 1990. While these tightened up the timescales between making a planning application and the start of a Public Inquiry, the new rules will do nothing to constrain the breadth and hence the length of the Inquiry itself. Looking to the future, we have in the Sizewell B design an excellent product and a successful formula for undertaking large nuclear power station projects; I hope that in the private sector the company will get the opportunity to exploit to the full these valuable assets.

Author
John G. Collier
FRS FEng, Chairman, Nuclear Electric plc
Barnett Way
Barnwood, Gloucester GB-GL4 7RS