COST REDUCTION ON LWRs — THE MAIN FEATURES

J.A. BOARD, D. NORMAN
Nuclear Electric plc,
Knutsford, Cheshire,
United Kingdom

Abstract

For effective generation cost reductions to be achieved while maintaining safety levels, the impact of each of the above element and their interactions must be fully assessed, together with the effects of uncertainty on commercial risk. The amount of interest during construction which must be paid can be minimised by adopting designs, output ratings (unit size), and construction methods which minimise construction time. However this must be done without unduly increasing specific capital cost. Total capital costs can be reduced by sharing design and project launching costs and front-end design and licensing costs, across a series of identical plants.

The paper is reviewing costs and performance factors such as those above with the aim of identifying the strategies which might be necessary within and between countries in order to create an environment which would enable cost reductions on LWRs to be made.

1. INTRODUCTION

The many factors which make up the ultimate cost of electricity generation are outlined in this paper, together with their interaction. It is important to include every cost element so as to understand its impact. It is also important to minimise costs (or maximise output) whenever this is worthwhile. However there are three particular influences which look likely to have the most major impact on generation cost. These are the method used to finance each project and the need for the shortest possible time to design, construct, commission and begin commercial operation, both of which influence interest during construction (IDC); and the potential benefit from widespread use of the same designs (and their common associated safety cases) in order to share front end development costs and operational support costs as widely as possible. Thus, while the paper indicates how every factor influences ultimate generation costs and how the size of each influence can be forecast, its main message is to recognise the collective benefit that arises from the development of a few international designs and safety cases, and from their construction and operation, internationally, in sufficient numbers and in a short enough time frame for this benefit to be realised.

2. COST ELEMENTS

Nuclear power plants generation costs are governed by five principal elements:

Capital charges - which cover the repayment of total capital and interest.

Operating costs - which include salaries, overheads, technical support, maintenance and materials, rates, taxes and insurance.

Fuel cycle costs

Backend provisions - which include station decommissioning, fuel reprocessing, and waste management.

Station operating performance - which includes output rating, lifetime and availability.

2.1 Capital Charges

On nuclear plant capital charges represent a major element in the overall generation costs, typically representing two-thirds of the cost when interest charges are included. The capital cost of the station covers all the costs incurred in taking the project from the decision to proceed through to its handover for commercial operation. Thus this heading includes, first, all those overnight costs which would be incurred solely as a result of a decision to construct the station being appraised. The term 'overnight costs' means that interest charges accumulated up to commissioning are not included. Interest charges are covered later. In the general power station case the following breakdown is typical:

Direct Costs

- Land and land rights
- Structures and site facilities
- Reactor plant equipment
- Turbine generator plant equipment
- Electrical plant equipment
- Miscellaneous plant equipment
- Heat rejection system and equipment.

Indirect Costs

- Construction services
- Engineering and HQ services
- Field supervision and field office services

These costs added together represent the base cost.

Other Costs

- Taxes and insurance
- Staff training
- Owner's general and administrative
- Spare parts
- Contingencies (Start to finish allowance)

Other costs plus base cost equals Overnight cost

Some cost breakdowns include indirect costs attaching to specific plant or civil contracts under these contract headings rather than as separate items. The same applies to taxes and insurances, and (in part) to contingencies. In the latter case allocations change from a global start-to-finish allowance to individual risk margins, ending up as part of committed capital, as the project moves through its construction phase. Exactly how the costs are allocated is less important than ensuring that they are all included, although one agreed capital costing framework would simplify comparisons and cross-checking.

All of the above costs must be included in order to provide a complete input to 'costs-of-ownership' calculations and to ensure fair like-with-like comparisons between options. If the proposed station represents a significant change in direction from existing stations, a capital sum representing the costs of training and equipping its future operators and maintainers prior to commissioning, to cover such items as simulators and mock-ups, will need to be included. For absolute cost estimates, any additional pre-commissioning corporate cost overheads arising from increases in staff or plant must also be included. These will cover activities such as personnel management, industrial relations, public relations, finance and commercial, corporate or system planning, legal, licensing, R & D and computing.

Finally, appropriate strategic spares costs and grid extensions to 'green field' sites or reinforcements to existing sites must be covered. Where the above costs continue after commissioning, they are probably more properly included under O&M costs rather than being capitalised throughout life.

To derive a realistic technical assessment essential to a capital cost forecast, the following technical assessments must be made:

- Full hardware and software scope of the project - is everything there - are capital spares included ?
- Are 'associated' costs (e.g. simulators/special tools/support staff and training) included?
- Level of confidence in each cost estimate - is the item/task novel or proven?
- How much work is expected to establish a safety case?
- How much development work remains? How is this reflected in cost uncertainties?
- How much less will successive units cost compared with the early ones? To what extent does this apply to plant modules also used on other types of station?
- Are any software costs 'hidden' in any contract package costs? We must avoid double-counting.
- What needs are there for contingencies, start-to-finish allowances, risk margins?

Technical assessments desirable for a capital cost forecast cover the following:

- How do the cash flows relate in time to the programme?
- When are capital spares orders/payments needed?
- To what extent can a capital spare for one unit or station double as an advance order for another?
- How many operational staff will be needed before commissioning date?

Any lowering of capital costs of the second and subsequent units in a replicated series, whether built for the utility making the estimate or elsewhere, which arise from shared costs, avoided first costs, or learning-by-doing, must be taken into account. As many of the above questions imply, the ability to share the 'first costs' associated with the development and licensing of a design will have an important impact on overall costs. These first costs could represent as much as a fifth of the capital cost of a single unit station if it were the only one of its type to be built.

2.2 Construction programme - Interest During Construction

The design and construction programme is relevant to costing because of its impact on cash flows during construction, on overall interest-during-construction (IDC), on the value of electricity used or generated during commissioning, and on the value of electricity sold or of sales lost if commissioning is earlier or later than planned. In cases where construction costs can be traded off against construction time (perhaps through modularisation or round-the-clock working) the cost of each option will need evaluation. This will be especially true when costing the construction of a series of small units or a sequence of units on the same site. Again the value of learning curves across a series of identical units, and of having a firm design, construction plan and safety case will reduce the time taken (and its uncertainty) to reach commercial operation.

At any realistic interest rate IDC will form a significant part of total capital cost. It will increase with construction time. Although interest rate is an important cost determinant both directly and as a means of reflecting economic risk, it cannot, in itself, assist in reducing the intrinsic cost of nuclear power. High interest charges penalise all capital-intensive projects without discrimination! Interest charges are an incentive for lowering basic capital costs and shortening construction times. Good planning and design and extensive replication are the actual means of achieving these. This is reflected in the following questions which must be answered when forecasting programme length and IDC.

- How much risk or uncertainty is there in the critical path or in the near critical paths? How flexible is the programme? In what ways?
- What would be the knock-on impact of delays in any of these paths, or any other programme changes?
- To what extent could modularisation, standardisation and multi-unit sites reduce programme length? How would this be done?
- Under what working arrangements would each design/construction/commissioning phase be carried out?
- Would any of the options for streamlining the manufacturing or construction programmes create maintenance, reliability or repair problems during operation? What would these be?
- At what point does the programme first require cash inputs? - When do cash flows rather than cement flows begin?
- At what point does commissioning begin? - When is first synchronisation? - When will the unit become 'commercial'? (formal commissioning date) - What will precommissioning electrical generation and electrical demands be?

2.3 Station Output

The sent-out capability of the station, taken with its availability, will determine the amount of energy that it could produce for sale if there were a market for it. It will be necessary to have a realistic estimate of output capability throughout station life if there is any likelihood of significant variation with time because some economic calculations will involve discounting.

Final dependable electrical output will depend on the performance of a series of in-line systems and on the definitions of operating conditions used by each supplier. To optimise output and therefore get the most out of a capital investment it is necessary to:

- Ensure that operating conditions ('average cold spell'; 'winter peak', 20° cooling water.....) are defined.
- Identify 'proven' plant and determine basis for forecast outputs (paper study, rig tests, prototype or scale model tests)
- Establish what thermo-dynamic and other models are used to calculate overall outputs, control system responses, variations in output through fuel cycle or seasons etc.
- Determine to what extent could rating of each plant item be 'stretched' to provide more output.
- Forecast to what extent will the rating of each plant item be reduced during its operating life (e.g. Steam Generator output reductions through tube plugging).
- For 'ranged' systems establish what effect the loss of some, but not all, plant items will have (e.g a 3 x 50% BFP system will provide nearer 60% from a single pump).

Answers to the above questions, and therefore the optimisation of a design from a cost and an operations standpoint, will be much more precise if based on wide experience on similar plant. Evolutionary designs offer advantage here.

2.4 Availability

This is the other parameter which determines potential earning capability. Significant losses through life, particularly through slow early-year build-up, must be minimised. Overall availability will be a function of plant reliability, maintainability and repairability, fuel cycle length and refuelling duration, and the safety-related or commercial-risk-orientated demands for periodic test and inspection. Again all of these factors can be improved by fully utilising past experience. This is most effective if:

- each design series is built in substantial numbers.
- successive design series develop past designs rather adopt revolutionary jumps.

This is an area where initial investment can have a sometimes dramatic effect on operating performance. If greater working space, or special 'in situ' workshops are provided, down times for repair or maintenance and associated staff numbers can be reduced. The provision of standby equipments or surplus capacity, for example 3 x 50% boiler feed pumps rather than 2 x 50%, can greatly increase unit operating reliability if on-load repairs are practicable. The more strategic spares are held, such as reactor coolant pumps, the lower are the chances of a long downtime while a replacement is awaited. Sophisticated tools such as multi-stud tensioners for the RPV, or robot inspectors, can both speed up maintenance work and reduce dose levels. However, in every case cost calculations must establish a net reduction in generation cost in order to justify the expenditure. Provided replicated designs are used, cheaper alternatives are to share strategic spares, special tools and specialist repair and maintenance crews across stations - a further reason for replication.

2.5 Operations and Maintenance Costs

O&M costs begin when the station is formally commissioned and represents about 20% of generation cost, including capital additions. They cover the wages, salaries, training, equipment and overheads of all the staff needed to operate, maintain and support the station, whether on-site or off-site, contracted-in or permanent. They cover repair; maintenance and operational materials; supplies and spares; hire of equipment; technical support and R & D; regulatory fees and insurance; rates fees and taxes. During shutdown they also cover on-site power demands.

2.6 Lifetime and capital additions

During a long life, any station is likely to require some major refurbishments and modifications, and perhaps a few major repairs. Quantitative judgements are therefore necessary on the nature, timing and costs of such capital-intensive activities. Note, however, that if such an item is self-financing, (for example life-extension), it ceases to be a real cost (but it may need inclusion to take account of earning capacity changes).

Although at most realistic discount rates levelised costs are fairly insensitive to changes in lifetime beyond about 35 years because of possible Post-operational Capital Additions it is necessary to take account of plant item and total station lifetime. Equally, it is clear that any substantial amounts of energy which can be generated late in station life will probably be at low marginal cost. Whenever it is economic, therefore, designs should take account of future life extension needs, or of the need to replace major plant items, as a cheaper alternative than building a new generating unit.

2.7 Fuel and fuel cycle

The costs involved here, throughout life, will be a function of energy produced. However, efficiency may vary through changes in fuel design and operating practice (burn-up etc), and availability can also be influenced by varying fuel cycle length. Since fuel design and fuel cycle design both carry first costs, the extent to which these can be shared will influence potential fuel cycle cost savings. This will also be true of on-going design and safety-related fuel studies, whether they be to improve fuel cycle economics or to solve operational problems.

In view of the costs and the controversy associated with fuel reprocessing and waste management, the concentrating of expertise and facilities in this area may offer cost benefits, provided the commercial difficulties of single-tendering can be overcome. Typically fuel cycle costs, including reprocessing, represent only about 10%-13% of total generation costs.

2.8 Decommissioning

Even taking the most pessimistic view of the decommissioning costs, the decommissioning provision charges only represent about 1% of total generation costs. However, because they are politically sensitive and because the task involves substantial planning and design elements, it is again an area where the sharing of these first costs will be fruitful.

3. COST REDUCTION STRATEGY

The above brief outline of generation cost contributors shows the large impact which engineering activities have on capital cost and hence on capital charges. Reducing capital charges can be done most effectively by sharing first-time engineering costs across as large a replicated series as possible. Since it is unlikely that any nation will be in a position to adopt the French approach (which was in effect a successful practical demonstration of the extensive replication strategy) this will mean international cooperation at the design and licensing phase of the life cycle. Such cooperation is developing for the operating phase through INPO, WANO and the IAEA.

It also seems necessary at the front end of each tranche of designs, if significant capital savings are to be made. This means:

a. A few 'international' designs must be developed which satisfy utilities' needs and are supported by large international consortia, both in design and financial terms.

b. The safety and licensing aspects of each design must be such that the same safety case will achieve a license in any country without modifications - in other words, a realistic international safety standard which will permit one-step licensing in each country is an essential (and short-term) goal.

c. Plant ordering must be coordinated to achieve the benefits of learning-by-doing through (and between) each design tranche and to avoid manufacturing, construction, licensing and commissioning bottlenecks.

d. Single-tender contractual procedures such as option agreements must be developed which constrain prices on subsequent orders, so as not to lose any benefits which wider competition between contractors is said to provide.

If these steps can be achieved there will be corresponding savings from pooled designs and resources throughout the operating and decommissioning phases of the life cycle. These will arise from shared technical support, shared operator and maintainer training, shared tool developments, and so on. While it is clear that any well-developed and proven technical development will offer future cost savings, the amplification of these savings through the avoidance of a multiplicity of differing 'local' designs will be much more significant than the size of the original saving.

STANDARDIZATION OF PWR POWER PLANTS: IMPACT ON CAPITAL INVESTMENT COST

C. VINCENT
Direction de l'équipement,
Electricité de France,
Paris, France

Abstract

The french program is certainly specific to the french context but it is a large and a real experiment of standardized series of units from which we can abstract the main ideas and ranges available in different contexts. It was estimated that the standardized part could reach more than 60% of the capital cost and this percentage does not take into account a regionalized part which also could have been standardized. The main condition is a large program which could be issued from a country or a partnership between different countries. That means, common terms of reference, lists of standardized equipment, same design documents. With a levelized rhythm of erection, beneficial effects of the series could be expected. The scale effect is fairly wellknown, also we can wonder for instance about the choice between five units of 600 MW and three units of 1000 MW. The answer is depending on the number of units and on the discount rate.

I MAIN CHARACTERISTICS OF NUCLEAR POWER PLANTS STANDARDIZATION

The standardization of nuclear power plants is based on the decision for a single technology, the choice of a sole architect-engineer, and the definition and application of precise design and construction specifications, in order to build a series of identical units.

1.1 Goals and advantages of standardization

The general goal of nuclear power plants standardization is to dispose, at the lower cost, of electricity generation facilities, which form a safe and high-performance industrial tool capable of assimilating, mastering and improving the technology of nuclear power plants.