Proceedings of ICONE10
10th International Conference on Nuclear Engineering
Arlington, VA, April 14-18, 2002

ICONE10-22173

THE ECONOMICS OF IRIS

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ABSTRACT

IRIS (International Reactor Innovative and Secure) is a small to medium advanced light water cooled modular reactor being developed by an international consortium led by Westinghouse/BNFL. This reactor design is specifically aimed at utilities looking to install new (or replacement) nuclear capacity to match market demands, or at developing countries for their distributed power needs.

To determine the optimal configuration for IRIS, analysis was undertaken to establish Generation Costs ($/MWh) and Internal Rate of Return (IRR %) to the Utility at alternative power ratings. This was then combined with global market projections for electricity demand out to 2030, segmented into key geographical regions. Finally this information is brought together to form insights, conclusions and recommendations regarding the optimal design.

The resultant analysis reveals a single module sized at 335 MWe, with a construction period of 3 years and a 60-year plant life. Individual modules can be installed in a staggered fashion (3 equivalent to 1005 MWe) or built in pairs (2 sets of twin units' equivalent to 1340 MWe).

Uncertainty in Market Clearing Price for electricity, Annual Operating Costs and Construction Costs primarily influence lifetime Net Present Values (NPV) and hence IRR % for Utilities. Generation Costs in addition are also influenced by Fuel Costs, Plant Output, Plant Availability and Plant Capacity Factor. Therefore for a site based on 3 single modules, located in North America, Generations Costs of 28.5 $/MWh are required to achieve an IRR of 20%, a level which enables IRIS to compete with all other forms of electricity production.

Plant size is critical to commercial success. Sustained (lifetime) high factors for Plant Output, Availability and Capacity Factor are required to achieve a competitive advantage. Modularity offers Utilities the option to match their investments with market conditions, adding additional capacity as and when the circumstances are right. Construction schedule needs to be controlled. There is a clear trade-off between reducing financing charges and optimising revenue streams.

Keywords: Module Size, Net Present Value, Generation Costs, Financing, Internal Rate of Return %, IRIS, Pedigree

INTRODUCTION

IRIS has grown from the US DOE Nuclear Energy Research Initiative programme which in late 1999 funded Westinghouse and a number of leading Universities to develop a low power, proliferation resistant Generation IV reactor. It is now a fully-fledge international effort developing commercial scale modular designed reactor for world-wide deployment.

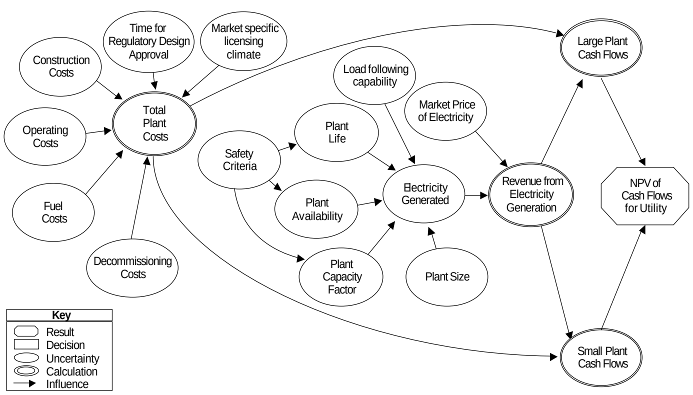
BACKGROUND

In order to understand the physical and market conditions in which IRIS would operate a cross functional group of experts gathered together and participated in a structured process. The first task was to develop a comprehensive list of issues that would influence IRIS deployment. These included Commercial, Regulatory, Governmental, Utility based, Technical First of a Kind and Production issues. These issues were used to define a "Vision Statement" for the project, focusing on what is to be achieved, why it is necessary and how we might fail. This Failure analysis was used to develop an action plan that also included critical success factors.

The group then examined potential alternatives for moving the project forward, considering the current programme, accelerating the time frame, investing additional resources, teaming with a Utility (ies) and pursuing the opportunity solely internally. A series of Key Decision points was then established, together with a corresponding list of options (for these decisions). These were then combined to provide a map of interaction between all the alternatives considered.

Extensive reference was made to existing sources, including capital build programmes for completed LWR designs and archive information on other small modular reactor concepts. A high level diagram of those factors influencing value to the Utility was developed in the workshop (Figure 1). Its purpose is to understand the decisions Utilities face when choosing which type of design to invest in. e.g. a small modular reactor vs. a large conventional design.

Figure 1.
High Level Influence Diagram



Data was then collected for each uncertainty (ellipse in Figure 1), for each of the alternatives considered. The resultant pedigree of information forms the basis of the analysis and has been Peer Reviewed by a group of Senior Executives, with many years' experience, but not directly involved with the IRIS project.

The basis of the assessment chosen for comparing alternatives is lifetime Net Present Value (NPV) of cash flows (Figure 2). Each alternative was subjected to a rigorous analysis, to understand the implication and number of technical challenges and on their ability to achieve the design and construction schedule, leading to market deployment early in the next decade.

The analysis focused on determining the optimal configuration for IRIS to establish Generation Costs ($/MWh) and Internal Rate of Return to the utility (IRR %) at alternative power ratings for IRIS. This was then combined with global market projections for electricity demand out to 2030, segmented into key geographical regions. Finally this information is brought together to produce insights, conclusions and recommendations regarding the key features and optimal design parameters for IRIS.

The resultant analysis reveals a single module sized at 335 MWe, with a construction period of 3 years and a 60-year plant life. Individual modules can be installed in a staggered fashion (3 equivalent to 1005 MWe) or built on site to match demand in pairs (2 sets of twin units' equivalent to 1340 MWe).

Having derived the complete data set, those responsible then subjected the information to an extensive internal Peer Review during which the validity of each data point was questioned and adjusted as required and all supporting information gathered together to form an auditable pedigree. The internal team then signed off the data as being appropriate and fit for purpose.

To further enhance credibility and to seek an outside perspective an external Peer Review was then undertaken by a group of industry experts, not connected with the project. After a challenging and thorough examination, agreement was reached as to validity and applicability of the data set and its use as the basis of the analysis.

ANALYSIS

The analysis context was to assess the viability of deploying an IRIS reactor (of varying electrical (MWe) output) in 8 key geographic regions of the world.

- North America
- Western Europe
- Industrial Asia
- Eastern Europe / Former Soviet Union
- Developing Asia
- Middle East
- Africa
- Central and South America

Comprehensive financial modeling of reactor cash flows was used as the basis for comparing "Generation Costs" in $/MWh for the different versions of IRIS and for conventional LWR designs. The analysis included a full sensitivity assessment of the key parameters (Figure 1), together with their supporting subset developed during financial modeling. Deterministic Sensitivity analysis (Figures 2 and 3) ranks all parameters in their order of importance, focusing attention on those vital to success. The final area of modeling completed a probabilistic analysis of the top 10 parameters (as identified by Deterministic Sensitivity), to understand how changes in these parameters would impact overall Net Present Value and Generation Costs.

Figure 2.
Key Input Parameters
Lifetime Net Present Value ($m)

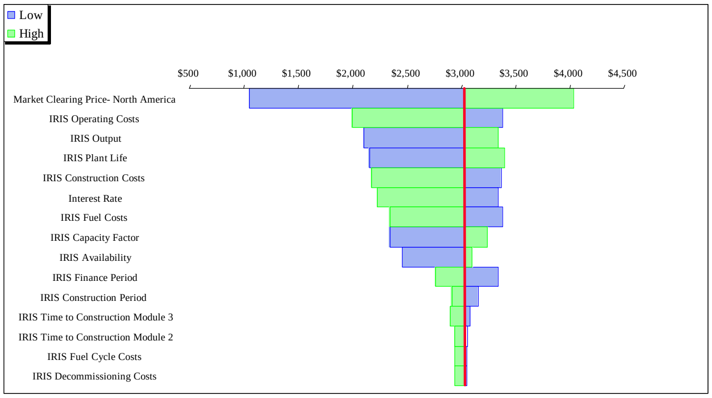
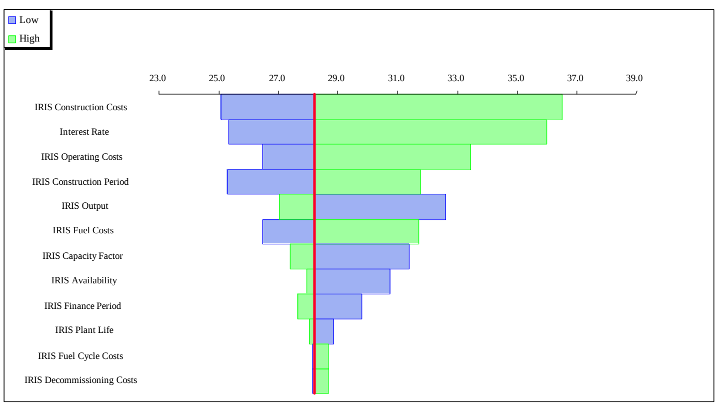


Figure 3.
Key Input Parameters
Generation Costs $/MWh



INITIAL FINDINGS

Output from the IRIS financial modeling indicates that Market Clearing Price ($/MWh), Construction Costs ($m) and Reactor Power Output (MWe) are the key factor in driving value. A commercially sized IRIS (335 MWe) is capable of competing in all world markets, with generation costs of approximately 30.0 $/MWh. The modular design and smaller output of IRIS is particularly suited to the developing markets, where there is a major opportunity to install new nuclear generating capacity. Between 2000 and 2030 electricity consumption (in the developing countries) is predicted to grow at twice the rate of that in the developed nations. The stagger installation approach also enables Utilities to match their investment programmes with rises in demand for electricity, minimising their financial exposure. It also avoids those issues, which would disrupt local market conditions by connecting say a single large plant of 1000 MWe capacity.

Table 1 presents a summary of the Base Case Lifetime Net Present Values ($m) for a site consisting of 3 IRIS modules each rated at 335MWe. Financing periods of 10, 20 and 30 years are compared to highlight the impact of alternative approaches.

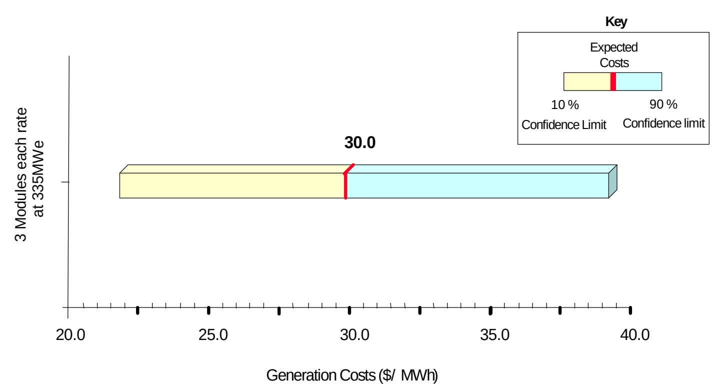
Table 1.
Summary Base Case Values $m

	Geographic Regions							
Title	NA	WE	IA	EEF	DA	ME	AF	CSA
30 Year Finance IRIS 335	3,030	4,030	6,020	4,030	5,020	4,030	4,030	3,030
20 Year Finance IRIS 335	3,330	4,330	6,320	4,330	5,320	4,330	4,330	3,330
10 Year Finance IRIS335	3,620	4,680	6,610	4,680	5,610	4,680	4,680	3,620

NA = North America
WE = Western Europe
IA = Industrialised Asia
EEF = Eastern Europe / Former Soviet Union
DA = Developing Asia
ME = Middle East
AF = Africa
CSA = Central and South America

Figure 4 illustrates the probabilistic assessment of the likely range of Generation Costs, based on the top 10 input parameters as identified by Deterministic Sensitivity.

Figure 4.
Probabilistic Analysis of Generation Costs



Expected Costs (of Generation), a single number that can represent the probability distribution shown in Figure 4, are 30.0 $/MWh. There is an 80% chance that Generation Costs will be in the range $22.0/MWh to $39.0/MWh, as shown by the 10% and 90% confidence limits.

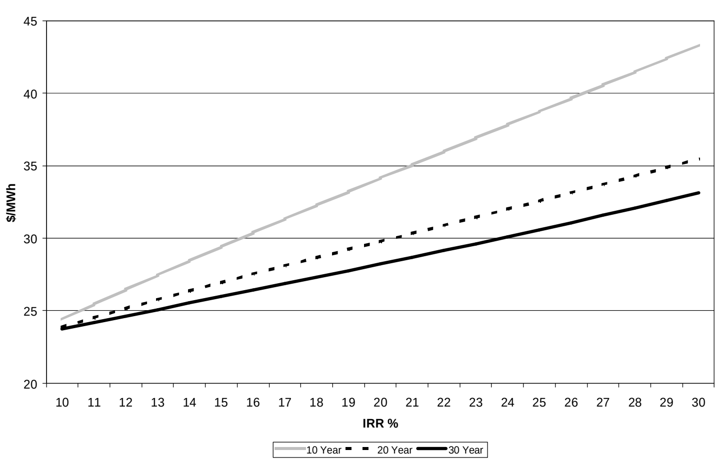
Probabilistic analysis adds further emphasis to variability in the key input parameters and clearly demonstrates their impact of Generation Costs. It focuses attention and articulates the circumstances in which costs would be reduced, whilst highlighting those areas requiring effort to prevent costs increasing. It provides a map of project risks, be they Commercial, Regulatory, Market driven or Technical.

Based on the data set for an Nth-of-a-kind plant and including a full lifetime analysis of all costs and revenues, the major components of generation costs are shown in Table 2. To aid comparison and to illustrate the likely benefit to a Utility, the Generation Costs shown will achieve an Internal Rate of Return (IRR) of 20%. To further highlight the competitiveness of IRIS and its ability to compete over a broad range of market conditions Figure 5 shows a comparison of Generation Costs with IRR over the range 10% to 30%, for 10, 20 and 30 year finance periods. All data is for a site in North America, having 3 IRIS modules each rated at 335MWe.

Table 2.
Generation Costs to achieve and IRR of 20%

Cost Category	$/MWh
Construction (Financing Charges)	17.8
Operating	5.2
Fuel	3.4
Decommissioning	1.0
Fuel Cycle Costs	1.0
Total	28.5

Figure 5.
Generation Costs $/MWh v
Internal Rate of Return IRR%



INSIGHTS

The analysis to date focuses attention on the Commercial environment in which IRIS would operate and on the key performance characteristics. Lifetime Net Present Values (from a Utility perspective) are driven by uncertainties in:

- Market Clearing Price
- Finance Rate
- Major Plant Parameters
- Finance Period

These factors dominate the traditionally held industry view that all efforts should be focused on reducing Construction Costs.

The modular staggered design of IRIS allows Utilities to match their build programmes with capacity demands. It avoids issues of depressing local market clearing prices by connecting say 1000 MWe to the grid in a single instance. Financing charges can also be effectively managed, minimising exposure to fluctuating economic conditions.

The current economic analysis demonstrates that IRIS is able to compete in all geographic regions, with other nuclear designs and other energy forms of producing electricity. This competitive position will be further enhanced as the design develops and uncertainties are comprehensively quantified and then eliminated. Attention should in the first instance focus on improving the following major plant parameters:

- Capacity Factor
- Operating Costs
- Constructions Costs
- Fuel Costs
- Plant Life

Investing an IRIS plant will provide a Utility with a commercially competitive IRR. Over the range 10% to 30% (Figure 5), Generation Costs vary between 24.0$/MWh and 33.5 $/MWh (30 year finance period). This is well within the range of market clearing prices forecasted to remain at or above 40 $/MWh.

CONCLUSIONS

The assessment of IRIS economics is based on a robust data set (pedigree) generated by experts with many years' experience in the field. This pedigree has been Peer Reviewed both internally and externally to ensure that it is valid and fit for purpose. The assessment has successfully identified and ranked those issues essential for viable operation. Of these, Plant size (Output) is critical to achieving commercial success in world electricity generation markets. There is a clear correlation between individual module size and total capacity required. If the intent is to install say 1000mWe of capacity, the optimum configuration would 3 modules of 335MWe output. There would be significant economic penalties for say having 4 modules of 250MWe output.

Having established the optimum configuration, sustained (lifetime) high factors for Plant Output, Capacity Factor, and Plant Availability are required in order to attract further investment, achieve a competitive advantage and deliver lifetime value.

ACKNOWLEDGMENTS

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