12th Annual International Conference in Real Options
Rio de Janeiro, Brazil, July 9-12, 2008
Draft Paper: Lauferts/Van Den Durpel

Exploring Real Option Analysis in Nuclear Energy Assessment Studies

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Abstract – *The application of Real Option Analysis (ROA) isn't yet widespread in the nuclear industry. Although there are interesting approaches from the academic side, the economic potential of nuclear is still assessed by classical discounted cash-flow (DCF) calculation, often based on crude heuristics, negative experience from past like projects and unconscious bias of the assessing team. Due to high front-up costs, hurdle rates far above average and uncertainty about future revenues, undervaluation of nuclear projects is the consequence of not being able to quantify the strategic potential of this technology. Although generating technologies using fossil fuels come along with high sensitivity towards fuel prices and carbon taxes, there are only some 30 new nuclear power plants under construction, only two of these in Western Europe and US. A worldwide increasing number of license applications suggest that utilities are being aware of the strategic benefits of nuclear, yet in the western hemisphere they intuitively exercise the option to wait until some of the institutional uncertainty has cleared off.*

Against common understanding, the nuclear fuel cycle is full of optionalities. If spent nuclear fuel is a liability or a valuable source of energy depends mainly on how the nuclear industry is able to add a positive economic value on an infrastructure of advanced nuclear systems. To go ahead and consequently take current Gen-III technology into a transition towards more sustainable systems, modern analytical methods need to be applied to reveal the economic potential and feasibility.

This paper gives a short overview about the levelized cost of electricity resulting from classical evaluation methods, comparing Light Water Rector, Fast Reactor and the modular High Temperature Reactor technology. In a second step optionalities are being drafted qualitatively, a) pointing at the value of current technologies in a portfolio based approach and b) revealing choices and opportunities in the transition to a deployment of advanced nuclear systems.

By using a quantitative, consolidated approach, it can be demonstrated that a new generation of modular design can add value by reducing sales risk and adding market liquidity. The result is being compared with an economy of scale design, a technology that is only deployed under current market conditions if long term power purchase agreements come along with the investment.

Proceeding from the flexibility bonus evaluated in this Real Option Analysis, a fair discount rate for large industrial end users is being discussed, if market participants are willing to enter into bilateral off take contracts to hedge against the volatility associated with electricity markets.

I. INTRODUCTION

In the process of liberalization and decentralization of the electricity market two seemingly contradicting trends can be observed: a shift towards technologies with short amortization periods like gas fueled power plants on one hand and a worldwide increase of license applications for new nuclear capacity on the other.
Nuclear has always been a technology with a lot of economic and social-political objections and represents by far the most upfront risk loaded investment opportunity for generating technologies.
Traditional valuation approaches like the net-present-value (NPV) analysis are very sensitive to the choice of discount rate and electricity price assumptions. Both are time dependant input parameter, only taken into account as an average over the entire lifetime. Although the levelized cost of electricity (LCOE) is competitive at current market conditions and the average mean NPV of a standard nuclear plant is positive, it has a wide range of possible outcomes. The irreversibility of such a 60-year lifetime project and average payback times beyond 20 years make it less attractive to potential investor's, who naturally like to avoid taking the significant financial risk coming along with nuclear generating technologies.
The feasibility of a large scale nuclear project is therefore mainly determined by the required equity IRR (Tab.1) and as practice shows, subject to a smart financing scheme together with long power purchase agreements (PPA).
A standard approach for large public private partnership projects is to determine the leverage and costs of dept and then to apply the required rate of return to the balance of funding.
It is obvious that standard discounted cash flow (DCF) evaluations are part of an iterative financing process and not the outcome of the decision making process itself.

TABLE 1

Nuclear project phases and requirements for equity IRR

Phase	Equity IRR, required
Construction	12-14% (12-19%[1])
Ramp-up	10-12%
Long-term Operation	8-10%
Decommissioning	12%

[1] max. range mentioned for nuclear in survey from 1998 to 2002

II. The nuclear fuel cycle - Real options are plenty

II. A. The fuel cycle today: LWR in once through mode

Nuclear generating technologies are worldwide dominated by the economy of scale' light water reactor LWR design in a once-through cycle. As part of the front-end of the fuel cycle, Uranium needs to be mined, converted and enriched to fabricate fuel. Although Uranium resources have a high medium term availability, the nuclear industry is already having a close look at bottlenecks and shortages beyond that scope to secure an undisturbed 60 year's operation of the next generation of light water technology.
After irradiation in the reactor the fuel undergoes cooling in interim storage before it is finally disposed in a geological storage. At this point the, nuclear fuel still contains a significant source of energy that is until now mostly untapped with the spent fuel treated as waste. Cooling of the spent fuel represents a significant step in the back-end of fuel cycle and is often used in a "sit and wait" strategy until a decision for a geological repository has matured. This time span of a few decades reflects a real option to change policy and adopt technologies to make use of the valuable resource.

II.B. A vision for tomorrow: LWR-FR-HTR with a closed fuel cycle

Since the beginning of industrial nuclear application research was done on R&D level aiming towards a more sustainable semi-closed fuel cycle with a synergetic use of different reactor types; Fast Reactor (FR) technologies in breeder and burner mode, as well as High Temperature Reactor (HTR) in a modular design with a wide range of industrial applications. Future market developments will indicate if such reactor types might be viable though closure of the nucear fuel cycle will surely demand the deployment of FRs.
Ambitious plans for an employment of FR technologies were dismissed in times of low Uranium prices accompanying various technical but, above all, political obstacles.
Now, this effort is being revived in international projects like the Generation IV (GEN-IV) or global nuclear energy partnership (GNEP) pointing towards unique opportunities in the front- and back end of the nuclear fuel cycle.

III. The feasibility depends on the evaluation method

III.A. DCF

Based on some published generic cost date for the three types of reactors, discounted cash flow calculations indicate an average increase in LCOE of 12 \$/MWh for FR (n^{th} of a kind estimate) technologies (see figure 1). This is mainly due to higher capital cost of the FR reactor plant. The HTR takes advantages out of the modular design and may gain 5 $/MWh in comparison to the LWR.

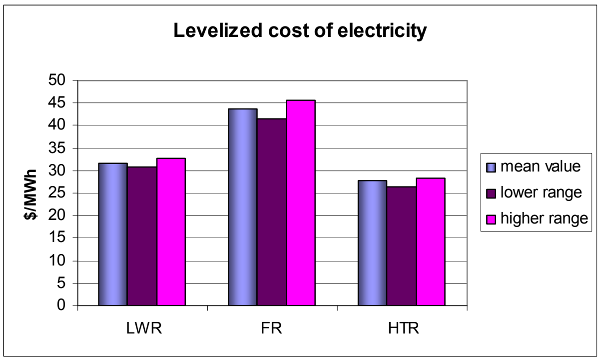

Fig.1: Discounted cost of electricity: LWR and next generation nuclear technologies

Translated to an investors need, the minimum market price for an IRR of about 10% has to be 58$/MWh for an LWR, 83$/MWh for a FR and 53$/MWh for an HTR design (Fig.2). While the HTR and LWR is competitive with coal and gas generating technology under current market conditions, the FR approach looses out under classical economical considerations.

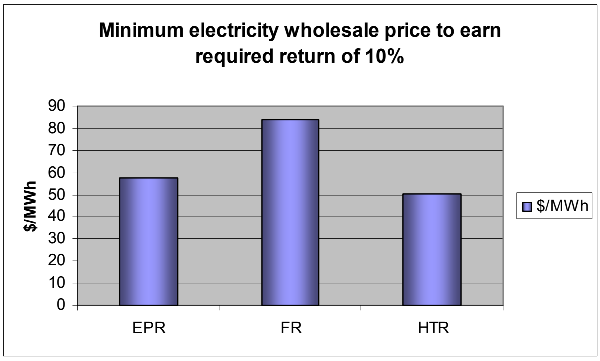

Fig.2: Market price to support feasibility of nuclear

The question about the strategic value behind Fast Reactor technologies as a milestone towards advanced fuel cycle systems needs to be raised as this technology is not meant only to deliver cheap electricity production.

III.B. The Real Option Approach:
To start with the ROA, real options in a nuclear system need to be pre-spotted. Academic research has been started applying Real Option Analysis pointing at the advantages to deal with uncertainties [4]. A significant objective of those studies is the quantification of a strategic value to hedge against fossil fuel price volatility or carbon taxes. As part of this work, other important long term uncertainties in liberalized and deregulated electricity markets were investigated and are listed in Table 2A. The main source of uncertainties on the supply side arises from volatilities in fossil fuel technologies. Long term uncertainties in electricity price trends and demand for centralized, large scale base-load technologies do not reveal any major optionalities for current large scale LWR designs.
Another field of interest is to further uncover the added value of deploying standard LWR with Gen-IV, FR and HTR technology in a transition towards advanced nuclear systems with (semi-)closed fuel cycles. A table of front and back-end fuel cycle optionalities is drafted in Table 2B which will be investigated using ROA. This paper is a first one starting to apply ROA in the analysis of these various identified optionalities in nuclear energy systems.

TABLE 2A
Options in a portfolio of fossil and nuclear generating technologies

Side	*Nuclear/Fossil*	*Long-term uncertainty of utilities with high market share*	*Possible trend*	*Real Optionality in Nuclear technologies*
Supply	Front-end	• gas/coal price	up/down	Lower price volatility of Uranium Negative Uranium / Oil price correlation [3]
		• supply gas	Down	Well distributed and abandon Uranium resources
	Back-end	• carbon market beyond 2012	Carbon tax: up/down/collapse	Hedging with nuclear as carbon free technology
Demand	Market	Electricity Price risk	up/down	No optionalities in nuclear
		Volume risk	Appetite for long term off-take: down	

TABLE 2B
Intra-nuclear options in advanced nuclear systems

Side	*Intra-Nuclear*	*Long-term uncertainty in the nuclear industry*	*Possible trend*	*Technical Optionality in the nuclear fuel cycle*	*Translation into real option*
Supply	*Front-End*	U-price	Up / down	Reprocessing & recycle Breeding Re-enrich Thorium-cycle	Switching input
		Pu-price	Up / down	Substitution of U vs Pu	Switching input
		Conversion price	Up / down		
		Enrichment price	Up / down	Change DU-tails Re-enrich	Switching / flexibility in front-end fuel cycle / switching of fuel cycle
		Fabrication price	Up / down	Capacity expansion / reduction	
	Back-end	Interim SF Storage capacity availability	Up / down	Expand / Reduce Reprocess Duration of interim SF storage	Expand Delay
		Interim HLW Storage capacity availability	Up / down	Expand / Reduce Duration of interim HLW storage	Expand Delay
		Repro-capacity availability	Up / down	Expand / Reduce	Expand
		Reprocessing price	Up / down	Reprocessing fraction Recycling fraction	Delay
				Expand / Reduce repro-capacity	Expand (for LWR also abandon)
				Separated Fissile Material (e.g. Pu) Pricing	
		Waste Disposal Facility availability	Yes /No	Delaying decision	Delay
		Nuclear waste fee	Up / down	Interim Storage (wait for disposal) Reprocess	Delay Delay
	Reactor	Technological Availability	Yes / No	Expand R&D Investments	Invest
		Economic competitiveness FR in electricity market	Yes / No	Value fuel cycle services by FR, i.e. transfer pricing of, f.i., TRU-burning / breeding	Switch fuel cycle
		D&D Funding	Insufficient / Guaranteed	Up-front / life-time fund accumulation	
Demand	*Electricity Market*	Price Risk	Wholesale: up/down	Switching output	Switching output
		Volume Risk	Load sold: < 100%	Modular design	Modular
	Process Heat Market	Price Risk	Wholesale: up/down	Switching output	Switching output
		Volume Risk	Load sold: < 100%	Modular design	Modular
	Combined elec / H_2	Price Risk	Wholesale: up / down	Switch fractions markets served Store H_2	Switching output Switching output Delay
		Volume Risk	Load sold: < 100%	Store H_2	Delay

III.C. Economy of scale vs. modular design: A consolidated approach

A comparison was made between a LWR and a modular HTR-design in order to investigate the value that can be assgined to a more fleixble power plant deployment based on such modularity. A 1600 Mwe LWR is compared to a modular set of 300 Mwe HTR-modules.

1) Base case scenario without flexibility

In line with the consolidated approach as described in Copeland's Practitioner's guide on Real Options [1] we chose the economy of scale LWR design as basis scenario to evaluate the project without flexibility. This technology stands for a full commitment base load plant with almost no managerial flexibilities. There is no flexibility to postpone the operation, to abandon the project, to adjust or switch output to the demand in the electricity market. Once the first concrete is poured, construction has to be completed in a strict time frame in order to amortize the high front-up costs in an economic lifetime of about 40 years. The economic assumptions for the economy of scale and modular reactor are listed in table 3.

TABLE 3

Basic data taken into account for further calculation

	Economy of Scale Design	Modular Design
Electric Power [MWe]	1600	N units a 300MWe
Capital Cost [$/kW]	3000	2400
O&M Cost [$/MWh]	8	8
Fuel Cost [$/MWh]	4.1	8.8
Technical lifetime [years]	60	60

2) Relevant Input uncertainties

Long pay back periods beyond 20 years are specific for economy of scale nuclear technologies and naturally increase volatilities of forecasted revenues.

Monte Carlo tools are being used to analyse and to model cross correlations on the volatility of the project value (tab. 4). Next to capital costs, the electricity price and quantity are main contributors to cash flow uncertainties (fig.4).

TABLE 4

Monte Carlo simulation results

Name	NPV
Minimum	-111.657
Mean	53.08853
Maximum	262.0035
Std Dev	76.49632
Variance	5851.687
Skewness	0.388416

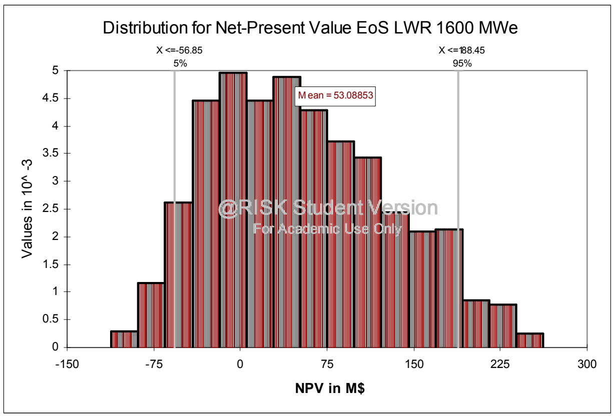

Fig. 3 Classical distribution of a nuclear project with a probability of 90% to achieve an NPV between -111 and +262 M$

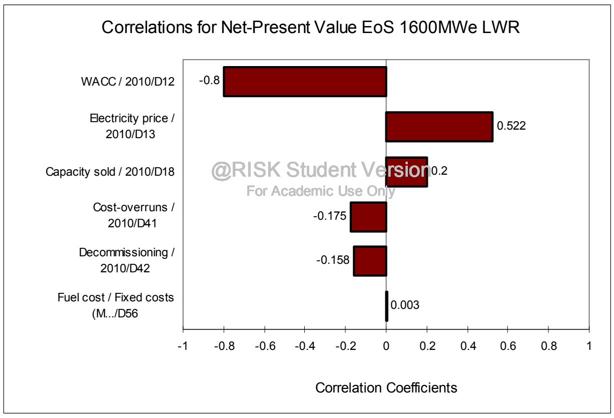

Fig.4 Sensitivity of discount rate and electricity price for NPV outcome. (WACC = weighted average cost of capital)

3) Construction of the binominal tree

For our approach we set up a present value PV based binominal tree for an inflexible LWR plant with 1600MWe output. According to the draft in fig.5 this basis scenario is being compared with a multi block HTR approach with 300MWe output in order to reveal project flexibilities.

Four blocks will only provide electricity, while two blocks are being installed in a decentralized cogeneration infrastructure to have the flexibility to switch output according to market needs. This second strategy provides the flexibility to produce process heat for industrial application according to fig.6, e.g. to produce Hydrogen or to stop the operation of one block if market conditions are sub-optimal. As the economic lifetime of a nuclear reactor accounts to 40 years, time steps of 5 years have to be applied in order to manage the amount of possible outcome.

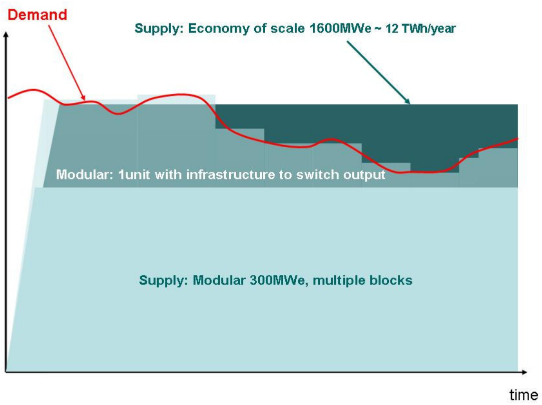

Fig.5: Volatility of demand; inflexibility of large scale LWR and flexibility of modular technologies to follow demand

TABLE 5
Basis data for different HTR design

	HTR+electricity	HTR+cogenaration
Output [MWth/MWe]	600/300	600/300
Capital Cost [$/kW]	2400	3000
O&M Cost [$/MWh]	8	8
Fuel Cost [$/MWh]	8.8	8.8
Technical lifetime [years]	60	60

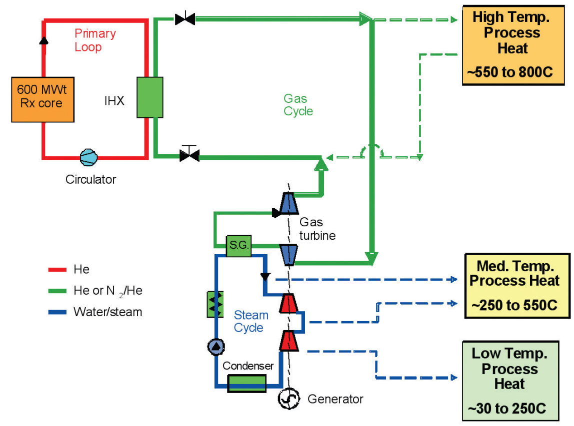

Fig.6: Example of output flexibility in cogeneration for decentralized markets

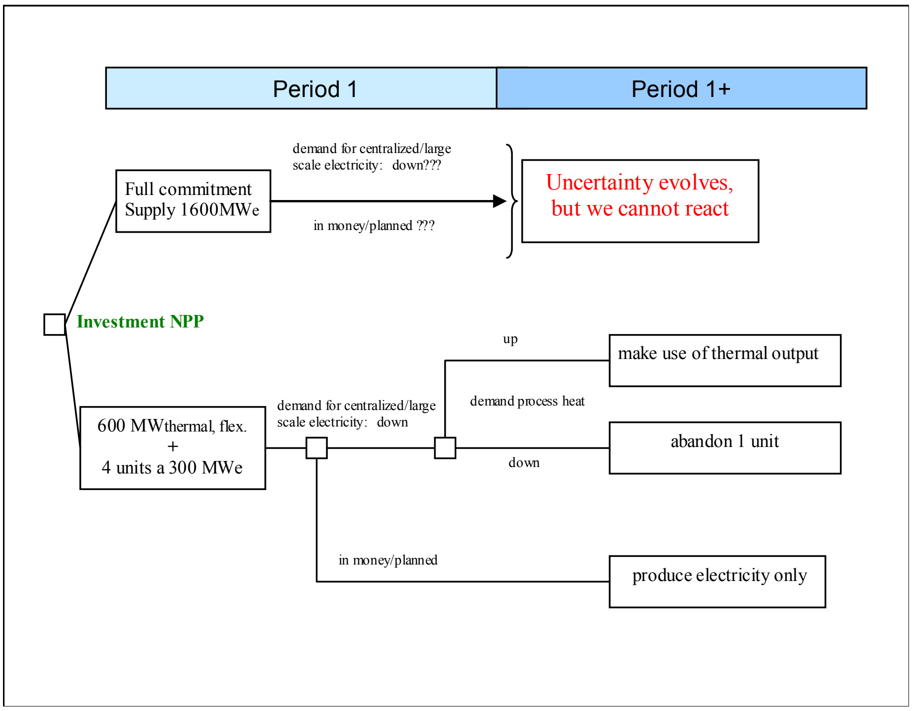

Fig. 7: Underlying event tree of an investment into new nuclear capacity

Fig. 7. represents the investment option that is developed in order to illustrate an option of building modular capacity with flexible output.

Hypothetical scenario: At year zero the current power plant will come to the end of its lifetime and replacement is needed in order to keep market share. The demand at time of replacement is 1600 MWe and the decision maker sees two alternatives for investment: a 1600MWe economy of scale LWR and multiple blocks of modular design HTR with a flexible infrastructure to also make use of the 600 MW thermal output.

We defined the value of flexibility in line with [5]

Flexibility option value=
NPV (with flexibility) – NPV (without flexibility)

Our preliminary results reveal a flexibility option value of 14.8M$ with a project NPV of the modular choice of 67.88 M$ and a NPV of 53.08M$ from an economy of scale basis scenario.
Bringing these values in line with the levelized cost of electricity and decreased volatility of cash flow generation, we find that a discount of 10% on the forward electricity market prices is a fair basis to initiate bilateral contracting negotiations.

IV. CONCLUSIONS

The volatile electricity market represents one of the major challenges for current economy of scale nuclear technologies. Long term contracts take an important role when new generation capacity has to be built, but only little is known about the contracting process and the pricing.

In a first step approach applying Real Option Theory we could point at the diversity of technical and economic options inherent in advanced nuclear systems of both reactor and fuel cycle technologies. We demonstrated, that evaluation based on classical DCF analysis will lead to an undervaluation of nuclear projects with a high technical potential.

This first step was followed by a quantitative, consolidated approach using a value based decision tree to reveal the strategic advantage in a generation of modular, HTR technologies. From preliminary results we can conclude that the gain of flexibility in switching output and following market demand is worth 14.8 M$ for the targeted strategic horizon.

We discuss that this value reveals a good indication for finding a fair discount price to trigger the appetite of retailer, large scale end user and utilities to engage into long term off take contracts.

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