NUCLEAR TECHNOLOGY OPTIONS FOR SOUTH AFRICA

PAY MORE FOR NUCLEAR : Report 1

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Contents

Executive Summary

South Africa's call for tenders for nuclear power plants failed because the costs were high and because the requirements to obtain funding were not politically acceptable. The response to this failure seemed to be that pursuing a wider range of technical options and partners would produce a cheaper and more readily financed offer. The new options mooted include reactors from Korea, China and Russia. The perception that these options will be cheaper is likely to be an illusion. In addition, the designs are unproven and raise serious issues of verifying that they meet the required safety standards.

The 2008 tender was answered by the French company, Areva NP, with its EPR (European Pressurised Water Reactor) design and Toshiba-Westinghouse with its AP1000 design and these designs would also be expected to compete again. However, while these designs have undergone full review by Western safety regulators, they are still unproven in operation and all the sites at which they are under construction have seen significant and in some cases catastrophically bad cost and time overruns. In addition, the expected cost of these options has risen significantly since 2008 partly because of the decline in the value of the Rand but also because of real price increases. For example, in 2008, the bid for the EPR was reported to be about $9.6bn, but in October 2013, the UK agreed to pay $12.8bn for the same design. If we translate these into Rand using the exchange rates of the time ($1=R8), the 2008 bid would have translated into R77bn. At the exchange rate applying in July 2014 ($1=R10.7), $12.8bn would equate to R137bn.

In the aftermath of the failed tender of 2008, the option of going back to earlier designs, which were assumed to be cheaper was considered. However, a combination of the Fukushima disaster and the unwillingness of the vendors to supply old designs means this option has been ruled out and the South African government has stated that only designs meeting the latest standards will be considered.

China has provided the vast majority of reactor orders in the past few years, 33 orders since 2007. A common perception is that reactors supplied by China will be of good quality but will be much cheaper than those from other countries. However, all but six of these use an old design, similar to the existing Koeberg reactors, which the French government will not allow the owners (Areva NP) of the Intellectual Property to export. The other six orders are for the two designs tendered in 2008, the EPR and the AP1000. China is developing advanced designs that it claims will meet current standards, including the CAP1400 (a Chinese up scaled version of the AP1000), but none of these designs is complete, much less has been ordered even in China.

Korea's latest design (APR1400) has been ordered for Korea and for the UAE but is not yet in service. However, while the prices offered for UAE were low, the Korean authorities acknowledge this design does not meet current standards. How far the UAE order was a loss-leader and whether the cost advantage would still exist if the design was uprated to meet current standards is unclear. Russia's latest design, AES2006, is claimed to meet current standards but this claim has yet to be tested outside Russia and limited cost evidence suggests the price might be no lower than its competitors. A further option, the ABWR, offered separately by Hitachi-GE and Toshiba has some operating experience but only using a 1986 design. An updated design was completed in 1997 but never ordered and the design is being updated again now. So this design must be regarded as unproven. There is no evidence it will be cheaper than its competitors.

The belief that widening the net of reactor design options will bring in cheaper, more financeable but equally safe options as the two bid in 2008 is likely to prove mistaken and a renewed call for tenders is likely to fail for the same reasons as the 2008 tender.

1. Introduction

The failed call for tenders for nuclear power plants in 2008 led to some soul-searching amongst South African policy-makers on the options for new nuclear orders. The call was answered by two companies: Areva NP (France) offering the European Pressurised Water Reactor (EPR) and Toshiba-Westinghouse[1] offering the AP1000 design of Pressurised Water Reactor (PWR). It failed for two basic reasons: first, the costs were massively higher than expected, more than double; and second the difficulties of obtaining finance.

There was a perception amongst policy-makers that cheaper options were available and that some of these other options would be able to offer a financial package that solved the issue of finance. A first option was to consider older designs with lower safety standards than those now required in Europe and USA, in particular, the designs used as the basis for most of China's nuclear power plants, but also a Korean design that won a call for tenders in the UAE in 2010. The old Chinese design was not an option because the French government, which controls Areva NP the owner of the Intellectual Property, was unwilling to allow China to export it.

However, the Fukushima disaster led to abandonment of the option of using old designs and South Africa is now committed to choosing designs that are of the same standard as are imposed in Europe and USA, so-called Generation III+. There are six main options that meet this requirement:

- Areva NP EPR;
- Toshiba-Westinghouse AP1000;
- New advanced Chinese designs;
- An upgraded Korean design, APR1400;
- The latest Russian design, AES2006;
- The Advanced Boiling Water Reactor (ABWR) offered separately by Toshiba and Hitachi-GE.

This paper reviews these options according to the following criteria:

- What commercial experience exists of building and operating the design;
- For designs that have not yet been ordered, how complete is the design;
- What processes of regulatory review have been undertaken;
- What are the likely bid prices;
- What financial packages are the vendors likely to be able to offer?

[1] The Westinghouse nuclear division was sold to Toshiba in 2006. It is primarily located in the USA and brands its products as Westinghouse but its ownership is wholly Japanese.

2. Safety regulatory approval

Prior to discussing the six main options, it is useful to review the safety regulatory processes and the major influences on nuclear design changes. There have been four major accidents and one other incident in the past 40 years that have had a major influence on the required safety features for a nuclear power plant. These accidents were all complex and still not fully understood and there were many lessons to be learnt.

2.1 Major design influences

Browns Ferry 1975.[2] In 1975, an electrician with a lighted candle looking for an air leak in the cable area accidentally set fire to the cables simultaneously disabling many of the safety systems for all three reactors on the site. By great good fortune, the reactors were all in a condition where they could be shut down rather than overheating and melting down.

Three Mile Island 1978.[3] In the Three Mile Island accident of 1978, an equipment malfunction was compounded by operator errors leading to the meltdown of one of the two reactors at the site.

Chernobyl 1986.[4] The events that led to the meltdown and total destruction of one of the four reactors at the Chernobyl site are still poorly understood but appear to have been the result of design flaws with the reactor (not a type used outside the Former Soviet Union) and operator error.

Fukushima 2011. There is still no authoritative picture of what the sequence of events that led to the meltdown of three of the six reactors at the site beyond the occurrence of a large earthquake leading to a huge tsunami. More than three years later, the site is still far from under control and access to much of the wrecked reactors is impossible.

9/11 2001. Although unrelated directly to nuclear power plants, the potential to use planes or missiles to wreck nuclear power plants was clear and a requirement that new reactors be able to withstand an impact from a large civil aircraft is now a requirement in Europe and North America.

What the four accidents have in common was that all were not regarded as credible by nuclear designers prior to their occurrence and all involved some degree of operator error. After Chernobyl, the nuclear industry understood that another accident could have been fatal to the nuclear industry so they took the opportunity to have a major re-think of nuclear designs. This was also meant to deal with the economic issues of continuously escalating costs that, even in the absence of further accidents, threatened the future of the nuclear industry.

2 www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0361/s1/sfpe1.pdf
3 www.threemileisland.org/downloads/188.pdf
4 www.nrc.gov/reading-rm/doc-collections/fact-sheets/chernobyl-bg.html

2.2 Generation III+ designs

The result of this re-evaluation was so-called Generation III+ designs. Under this concept, Generation I designs were the prototypes and early demonstration reactors; Generation II designs include the majority of reactors ordered in the 1970s and 1980s (including Koeberg); Generation III reactors were those designed after Three Mile Island and taking account of the lessons from that accident. Generation III+ designs are post-Chernobyl designs. There is no clear definition of what the technical characteristics of a particular design generation is and, inevitably, reactor vendors tend to characterise their current designs as Generation III+. Even nearly 30 years after the Chernobyl disaster, no Generation III+ design is in service.

The rhetoric behind Generation III+ was that designs had become complex and expensive as layers of safety were added to the old designs to take account of the accidents. The promise for Generation III+ was therefore that these designs would be safer, but simpler, therefore cheaper and less prone to delays in construction.[5] A particular feature, to deal with the risk from operator error, was 'passive safety', so that in the event of an accident, the reactor would automatically shut itself down.

The promises for Generation III+ have proved dramatically misconceived. Around the year 2000, the nuclear industry was projecting a construction cost of $1000/kW for these designs so that a 1000MW reactor similarly to the reactors at Koeberg would cost $1bn.[6] The agreement of 2013 between the UK government and EDF to build two EPRs was based on a construction cost of about $8000/kW. The first Generation III+ reactor on which construction started in 2005 is now at least 9 years late and nearly 3 times over-budget and all the Generation III+ designs now under construction – Finland (1), France (1), China (6) and USA (4) - are now late and over-budget.

A French government inquiry (2009)[7] chaired by a former CEO of ElectricitDF) found that one of the problems with the EPR was its complexity: 'The complexity of the EPR comes from design choices, notably of the power level, containment, core catcher and redundancy of systems. It is certainly a handicap for its construction, and its cost. These elements can partly explain the difficulties encountered in Finland or Flamanville [France]'. The Chief Executive of Areva NP (supplier of the EPR), Anne Lauvergeon, acknowledged: 'the cost of nuclear reactors has "always" gone up with each generation, because the safety requirements are ever higher. "Safety has a cost,"'[8].

2.3 Regulatory processes

In the past, regulators have given approval for reactor construction without reviewing the details of the design, resolving detailed issues as they arose during construction. In addition, reactors were often customised for user's requirements so even for established designs, a new order might differ significantly from its predecessors. This is still the case for many countries and, for example, construction of the EPRs in France, Finland and China began before a full design review had been carried out and each country's design will differ to some extent from that of the others. The US and UK versions will differ from each other and from their predecessors. This way of doing business was increasingly seen as contributing to construction problems as design issues arose that led to delays in construction while they were resolved. In 1992 in the USA and

5 nuclear.gov/home/11-21-03.html
6 www.psr.org/nuclear-bailout/resources/roussely-report-france-nuclear-epr.pdf
7 For an English translation, see www.psr.org/nuclear-bailout/resources/roussely-report-france-nuclear-epr.pdf
8 Nucleonics Week, 'Lauvergeon: French lost UAE bid because of expensive EPR safety features' January 14, 2010, p 1.

in 2007 in the UK, safety regulators introduced 'generic' design reviews, termed Generic Design Assessments (GDA) in UK, which would resolve all major design issues for a given design before construction was allowed to start, meaning that a utility wanting to build such a design would know that the only regulatory issues remaining were site-specific and therefore limited. How far the failure to carry out a full generic review has contributed to delays in France and Finland has contributed to the delays is difficult to determine but it appears to have been a significant factor.[9] Typically, a generic design review takes at least five years.

For countries with limited nuclear capabilities, like South Africa, it makes no sense to duplicate the reviews carried out by an experienced and transparent regulator like the US Nuclear Regulatory Commission (NRC) or the UK Office of Nuclear Regulation (ONR) and 'licensed in country of origin' is often used as a proxy. This does not absolve the local regulatory body of the responsibility to review and very fully understand the design, but it can rely on the work of more experienced peers. How far the failure of the Pebble Bed Modular Reactor commercialisation programme in South Africa, where the South African regulator was the first and only safety regulator to be reviewing the design, can be attributed to its inexperience is difficult to determine, but it may have been a factor.[10]

3. Candidate designs

As noted above, by mid-2014, none of the Generation III+ designs had entered service, so there is no full construction experience with any of them and no operating experience whatsoever.

3.1 EPR[11]

The EPR has been under development by the French reactor vendor (Framatome, later re-named Areva NP) and Siemens of Germany. It was the first Generation III+ to receive an order, in 2004 for the Olkiluoto plant in Finland and subsequently received an order for France (2007) and two orders for China (2008). It has been selected as the design for two reactors to be built at Hinkley Point in UK but there are a number of hurdles to be overcome before the order can be placed.

It completed a generic design review in the UK in 2012[12] and it has been undergoing review by the US NRC since 2007.[13] A previous target completion date for the US process of 2015 has been dropped and the NRC no longer has a target completion date. Given that the EPR has little chance of being ordered in the USA, it is not clear whether Areva NP will choose to complete the process.

The Olkiluoto order, placed by the Finnish utility, TVO, was for a fixed price of €3bn with construction starting in 2005 expected to be completed in 2009. By 2014, there was no longer a projected completion date but it was said to be no earlier than 2018 and the latest cost estimate, from 2012, was for €8.5bn. Areva NP is not honouring the fixed price deal and the vendor and the utility are countersuing each other for about €2bn of the excess costs.[14]

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9 www.nirs.org/reactorwatch/newreactors/eprcrisis31110.pdf
10 S D Thomas (2011) 'The Pebble Bed Modular Reactor: An obituary' Energy Policy, vol 39, 5, 2431-2440
11 www.nirs.org/reactorwatch/newreactors/eprcrisis31110.pdf
12 www.onr.org.uk/new-reactors/gda-issue-close-out-uk-epr.htm
13 www.nrc.gov/reactors/new-reactors/design-cert/epr/review-schedule.html
14 See for example, WNISR "Nth Delay Announced for Olkiluoto 3 in Finland" February 11, 2013. www.worldnuclearreport.org/Nth-Delay-Announced-for-Olkiluoto.html, accessed, June 5, 2014 and

Construction of the Flamanville order, placed by the French utility, EDF, started in 2007 and was due to be complete in 2012. By 2013, construction was at least 4 years late and the estimated cost was at least €8.5bn.[15]

The two Chinese orders were placed by a consortium comprising 70% China General Nuclear (CGN, formerly China Guangdong Nuclear) and 30% EDF. CGN is also one of the three Chinese nuclear reactor vendors and is most experienced in terms of orders won. For the two Chinese orders, at Taishan, there is much less authoritative information and reports have generally portrayed progress as smooth. However, in February 2014 in a presentation to the IAEA, a Chinese official acknowledged that the two reactors were more than a year late and would not be on-line before mid-2015.[16] No estimate of any cost over-run was given.[17]

In terms of cost, the bid for South Africa of 2008 was reported to be $6000/kW.[18] In Canada in 2009, a tender for nuclear capacity was also run, which also failed. It was reported that Areva NP's bid for one EPR was US$21bn ($6500/kW). This was denied by Areva NP but they did not reveal the actual figure.[19] The figure was reported to be high because the authorities were asking the vendors to take on much of the construction risk.

In December 2009, it was announced that a tender for the UAE had been awarded to a Korean consortium for four APR-1400 units at a price of US$20bn ($3600/kW). According to Korean media reports, the Korean bid was almost 30% lower per kW than the EPR bid ($5100/kW).

In October 2013, an agreement between the UK government and EDF to build two EPRs was announced based on a construction cost of about $8000/kW.[20] It is far from clear whether this order will go ahead and, if it does, the price is likely to be subject to renegotiation when the order is formally placed, perhaps in 2016.

For a long time, the French nuclear industry has been able to offer a coordinated package of support for buyers, building on its ownership control of Areva NP, EDF and the apparent willingness of the government to provide financial support. For the 2008 tender, Areva NP claimed that the French loan guarantee agency, Coface, was willing loan guarantees for all the finance required.[21] Whether this was accurate is not clear. In 2004, it did supply loan guarantees for the Olkiluoto plant, but these covered only €600m of the expected cost of €3bn.[22] No guarantees appear to be on offer for the potential UK orders.

Areva's problems with the EPR were reflected in its results for the first half of 2014, when it made a loss €694m. It has not sold a new reactor since 2007 and a target to sell 10 reactors by 2016 has been abandoned.[23]

WNISR "Nth Delay For Finnish EPR » July 21, 2012. www.worldnuclearreport.org/Nth-Delay-For-Finnish-EPR.html, accessed June 5, 2014

15 Nucleonics Week 'French parliamentary commission warns over rising nuclear costs' June 12, 2014

16 Shan Sun, "Challenges during construction of new NPPS", 6 February 2014.

17 Nuclear Intelligence Weekly, "Sanmen — Two-Year Delay Pushes Costs Higher", 14 March 2014.

18 Nucleonics Week 'Big cost hikes make vendors wary of releasing reactor cost estimates' Sept 14, 2008

19 Nucleonics Week 'Areva disputes EPR cost figure as Canadians grapple with risk issue' Jul 23, 2009, p 1.

20 www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley

21 The Star, 'Nuclear Bid Had Funding – AREVA', January 30, 2009

22 S Thomas 'The EPR in crisis' University of Greenwich www.nirs.org/reactorwatch/newreactors/eprcrisis31110.pdf

23 uk.reuters.com/article/2014/08/01/areva-results-idUKL6N0Q71IK20140801

3.2 AP1000

The AP1000 is usually described as being supplied by the US company, Westinghouse, but this is somewhat misleading. In 1997, the Westinghouse nuclear division was taken over by the UK government owned company, British Nuclear Fuels Limited (BNFL). BNFL went bankrupt in 2002 and was broken up into constituent plants. Its reactor design and supply division based on Westinghouse but also including the reactor divisions of Combustion Engineering and ABB was sold to the Japanese company, Toshiba, in 2006 and while the base for development of AP1000 is still in the USA, ownership and control of the company is in the hands of Toshiba.

The roots of AP1000 are in the early 90s when Westinghouse, then an independent US owned company developed the AP600. The designation, 'AP', stands for Advanced Passive. The design received generic approval by the NRC in 1997, but its expected cost was so high that Westinghouse never offered it for sale. Westinghouse chose to use scale economies to reduce costs and scaled the reactor up from about 600MW to about 1200MW for the AP1000. A new review by the NRC started in 2002 and in March 2006, approval was given. However, only two months later, Westinghouse submitted major design changes and the process was re-opened with approval only finally being given in 2011.[24]

The AP1000 entered the UK Generic Design Approval (GDA) process in 2007 and in 2011 was given interim approval but with a significant list of 51 issues yet to be resolved.[25] At this point, Westinghouse chose not to pursue the application because it had no UK customers. However, in 2014, Westinghouse took a stake in one of the consortia (NuGen) wanting to build in UK and has said it will re-open the GDA. However, it does not expect to complete the GDA before 2017.[26] The process is expected to be started in late 2014, but ONR has no forecast of the completion date.

The AP1000 was selected by the Chinese government for four orders (two at Sanmen and two at Haiyang) to be built in collaboration with a Chinese reactor vendor (which has not supplied any reactors by itself yet), State Nuclear Power Technology Corporation (SNPTC). It was expected this design would be transferred to SNPTC and would account for the majority of future orders for China. However, costs have proved higher than expected and this plan is now in serious doubt.

Construction at Sanmen and Haiyang started in 2009 for three reactors and 2010 for the other one with completion expected in 2013-15, the first in December 2013. By February 2014, all reactors were 2 years or more late and reportedly at least 20% over budget with the first reactor not expected to be complete before December 2015.[27]

The AP1000 has also been selected for four reactor orders for the USA, two each for the Summer and Vogtle sites. Construction on these two projects started in 2013. After little more than a year of construction, both projects are going wrong. The first unit at Summer appears to be up to 2 years behind schedule, while delays at Vogtle have been acknowledged but not yet quantified.[28]

[24] www.nrc.gov/reactors/new-reactors/design-cert/ap1000.html
[25] www.onr.org.uk/new-reactors/2011-gda-issues-ap1000.htm
[26] Nucleonics Week 'Toshiba to buy 60% of UK's NuGen, plan AP1000s at Moorside', 16 January 2014
[27] Nuclear Intelligence Weekly, "Sanmen — Two-Year Delay Pushes Costs Higher", 14 March 2014.
[28] Nuclear Intelligence Weekly 'More Trouble for the AP1000 In South Carolina' July 11, 2014

In terms of cost, the AP1000 was the other bidder in the 2008 South African tender and its bid was higher than that of Areva NP, which was reported to be $6000/kW.[29] Similarly, for the Canada tender, the AP1000 price was reported to be higher than that of the EPR.[30] The Summer and Vogtle orders both had a forecast cost at time of ordering of about $15bn, about $6500/kW.[31]

A problem for Westinghouse is its ambiguous nationality. It is not US-owned so cannot expect financial support from the US government, whilst the Japanese government's policy on nuclear power and the extent of its support for its vendors is in disarray after the Fukushima disaster. Japanese vendors have never exported reactors apart from the Chinese and US plants. The Chinese deal was mostly negotiated before the Toshiba take-over whilst the US deals are not really export deals given Westinghouse's physical base in USA.

3.3 Chinese designs

Since 2007, China has started construction on more than 30 nuclear reactors, more than the rest of the world put together, most supplied by indigenous Chinese vendors. The common assumption is therefore that China is able to supply reactors to time and cost, much cheaper than other vendors and to a high quality standard. The picture is more complex than this and it is far from clear whether China has the capability to supply reactors cheaply and with designs that would satisfy Western regulators

There are three entirely separate Chinese reactor vendors: CGN, SNPTC and China National Nuclear Corporation (CNNC). CNNC is the longest established company and led the effort to develop Chinese nuclear weapons technology. SNPTC is a much newer company with limited experience, while CGN is a relatively small company but participated in the project to build China's first large nuclear power plant, the Daya Bay plant, in the 1980s.

CNNC and CGN have supplied most of the reactor orders placed in China using a 1970s design licensed from Areva NP (the design used for Koeberg), with whom both companies collaborate. CGN has won most of the orders. The French authorities, which still own the intellectual property to this design, have vetoed plans for China to supply this old design.

The decision to order AP1000s appeared to leave both companies with a difficult transition with orders likely to go to their competitor, SNPTC. However, as problems with the AP1000 accumulated, both companies began to develop their own Generation III+ designs: CGN with the ACPR1000 and CNNC the ACP1000. It would appear these designs are developed from the EPR but scaled down but technical details are still sparse. However, about a year ago, the Chinese governments began to pressure the two companies to 'merge' their designs into the Hualong design of about 1000MW. It is difficult to obtain clear information on how fully developed any of these designs are and how close to be being able to start construction they are.

Despite this, CNNC has reportedly won a contract to supply two reactors of the ACP1000 design to Pakistan, which, if they go ahead will be the first and perhaps only reactors of this design to be built. By July 2014, it was far from clear which of the three designs – ACPR1000, ACP1000 and Hualong - would actually be brought to market.[32]

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29 Nucleonics Week 'Big cost hikes make vendors wary of releasing reactor cost estimates' Sept 14, 2008
30 Nucleonics Week 'Areva disputes EPR cost figure as Canadians grapple with risk issue' Jul 23, 2009, p 1.
31 Nucleonics Week 'Two **Vogtle** partners get DOE loan guarantees' February 20, 2014
32 Nuclear Intelligence Weekly 'Nagging Questions Over China's Technology Choices' July 11, 2014

SNPTC would have supplied the AP1000, but the problems of cost have led it to develop its own technology based on the AP1000, but scaled up to improve the economics, CAP1400. This design has been mooted as possible candidate for South Africa.[33]

Whether China owns the intellectual property for its advanced designs, all based on Western designs is a moot point.

China has not participated in international tenders, exporting only 3 small reactors (300MW) to Pakistan, and it does not publish costs of reactors built in China, so there is no information on what the cost would be. The Chinese regulatory process is obscure, but no generic design assessment on the scale of those carried out by UK and US authorities is carried out. The French regulatory body, ASN expressed serious concerns about the Chinese safety authorities in June 2014: 'Unfortunately, collaboration isn't at a level we would wish it to be" with China, Jamet [Phillippe Jamet is one of the regulator's five governing commissioners] said. "One of the explanations for the difficulties in our relations is that the Chinese safety authorities lack means. They are overwhelmed."'[34]

China's lack of experience in export markets makes it impossible to know what terms might be offered for exports.

3.4 Korea's APR1400

Korea has a long history of using nuclear power, its first reactor coming on-line in 1977 and by 2014, it had 23 reactors in operation and five under construction. From the 1990s, it has been building a capability as an independent reactor vendor through licensing designs from US vendors. However, it was until 2009 that it attempted to enter the export market when it bid successfully for a tender to build four reactors for UAE.

Its latest technology is based on the System 80+ design produced by US Combustion Engineering which received generic approval (expired in 2012) in 1997 from the US NRC. The intellectual property for this design passed to BNFL and now lies with Toshiba. However, Toshiba is not promoting the design and is therefore unlikely to place restrictions on sales.

First construction in Korea for this design, designated APR1400, was in 2008, with subsequent units in 2009, 2012 and 2013, none of which is yet in service.

In December 2009, the UAE ordered four nuclear reactors from Korea using APR1400 technology, beating opposition from consortia led by EDF (including GDF Suez, Areva NP, and Total with the EPR) and GE-Hitachi.[35] The contract is with Korean Electric (KEPCO) to build and operate the reactors, the first coming on-line at an unspecified site in 2017 and the last by 2020. The terms of the deal and what is included are not clear, although the contract is reported to be worth $20.4 billion. The Korean bid was reported to be $16 billion lower than the French bid.[36] Whether this bid is realistic or whether there is an element of loss-leader to launch the export drive will not be clear until the plants are complete and the costs known. Construction of the first units 1 and 2 started in 2012 and 2013 respectively.

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33 Nuclear Intelligence Weekly 'Sizing Up the South African Competition' March 7 2014

34 Energy Monitoring Worldwide **'China** regulators 'overwhelmed' as reactor building steams ahead' June 21, 2014

35 Korea Herald 'Korea Wins Landmark Nuclear Deal' Dec 28, 2009.

36 Right Vision News 'UAE: Middle East Leads Rally in Nuclear Plant Orders' Jan 12, 2010

The CEO of Areva NP was particularly scathing about the safety feature in the Korean design. Nucleonics Week reported: 'She mentioned in particular that EPR's containment was designed to withstand the crash of a large jet aircraft and had a provision to prevent molten corium from penetrating the reactor basemat if the core melted through the reactor vessel. She likened the Korean reactor — which she said had neither such feature — to "a car without airbags and safety belts."[37]

Korean authorities acknowledge that the APR1400 would not meet US or European requirements particularly on aircraft crash protection and, for Europe, a core-catcher.[38] [39] If the UAE price was realistic, it is not clear how much of the price advantage over Areva NP's EPR would be lost if these features were included. However, Korea has signalled its intention to try to compete in the US and UK markets. In 2010, it announced it would submit its design to the NRC for regulatory review in 2012.[40] However, when it finally submitted the design in September 2013, the NRC found it contained insufficient information.[41] Korea plans to resubmit the application in December 2014. Its plans for UK are still at an early stage.

Since the success with the UAE tender, Korea has shown interest in a number of nuclear markets but appears to have no strong prospects for further sales. In Turkey, Korea withdrew from bidding because of KEPCO's insistence that the agreement to buy the power should be guaranteed by the Turkish government.[42] It may be that this marks a reluctance to repeat the sort of risks it is incurring with the UAE deal.

Korea's image as a high quality nuclear operator building plants quickly and operating them reliably was seriously damaged by revelations of faked quality control documents. In November 2012, it emerged that quality control certificates for thousands of pieces had possibly been forged. Two reactors were closed (Yongwang 5 and 6) and five others already off-line remained closed.[43] The two Yongwang reactors were allowed back on-line in January 2013 but it was only after it was found that more than 2,000 parts (fuses, switches, cooling fans) had been given forged certificates and had to be replaced. Six other reactors were found to have significant numbers (100 to 300) of forged documents.[44] Three more reactors were closed for seven months from May 2013 when it was found that tests for control cables had been fabricated.[45] Nearly 130 employees at KHNP and its suppliers were indicted, and hundreds of others reprimanded internally as a result of this scandal. How far this event has damaged Korea's nuclear industry's reputation remains to be seen.[46]

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[37] Nucleonics Week 'ENEC says it considered designs with core catchers for new reactors' Jan 28, 2010
[38] A core-catcher is designed to prevent the contents of the reactor core burning down into the environment in the event of a reactor meltdown
[39] Nucleonics Week 'No **core catcher,** double containment for UAE reactors, South Koreans say' April 22, 2010
[40] Inside NRC 'Kepco to submit **APR1400** design for NRC review in 2012' April 26, 2010
[41] Nuclear Engineering International '**NRC** rejects APR-1400 certification.' February 2014
[42] www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Turkey/
[43] Business Recorder, "South Korea widens nuclear lapses probe; KEPCO chief resigns", November 2010.
[44] Inside NRC, "Korean regulator NSSC approves restart of Yonggwang reactors", 14 January 2013.
[45] Nucleonics Week, "South Korea units shut in parts probe restarting", 9 January 2014.
[46] Korea Times, "Endless scandals hit nuclear power supplier", 1 September 2013, see www.koreatimes.co.kr/www/news/biz/2013/09/335_142036.html, accessed 25 May 2014.

3.5 Russia AES-2006

After the Chernobyl disaster of 1986 and the subsequent break-up of the Soviet Union, Russia largely withdrew from the home and international reactor market leaving a large number of part-built plants mostly in the Former Soviet Union and Eastern Europe. Work on some of these resumed, for example, in Ukraine and Russia, some are still under construction, for example in the Slovak Republic, and some were simply abandoned. Two export orders were won both for two reactors, one order for India (Kudankulam) using the AES-92 design and one for China (Tianwan) using the similar AES-91 design. Construction at Kudankulam started in 2002 but there were numerous delays and the first unit only went critical in 2014. Tianwan started construction in 1999 and the reactors were built in 7-8 years, much longer than the typical five years for China. These two designs are of about 1000MW and are sometimes discussed for markets requiring smaller reactors (e.g. Jordan) but they were not built in Russia. In 2008, Russia began building reactors of its new design, AES-2006 for its home market with two starts in 2008 and one each in 2009 and 2010. A further order for the enclave of Kaliningrad was started in 2012, but construction was suspended a year later and it is not clear if or when it will restart.

Since 2010, Russia's efforts seem to have focused more on export markets, reportedly winning orders in Belarus, Vietnam, Turkey and Bangladesh and competing hard in Finland, Jordan, Lithuania and other East European countries especially Hungary. However, only one of the orders is actually under construction (one reactor in Belarus) and the others are either delayed or still some time from being able to proceed. It has won follow-up orders for China and is negotiating with India. It has signalled its intent to try to get GDA in the UK but it is some way from being able to start this process and the unrest in Ukraine may mean that Russian nuclear vendors will not be welcome in the UK for several years.

A key market will be Finland because it is a Western country with significant nuclear experience, unlike most of the other prospects, albeit Finland's reputation has been badly damaged by the Olkiluoto debacle. Rosatom, the Russian nuclear vendor, has taken a 34% stake in the project to build a reactor at the Hanhikivi site. If political hurdles are overcome, construction will not start until 2015 or later with completion expected around 2024.[47] Rather surprisingly, when the head, Jukka Laaksonen, of the Finnish safety regulatory body (STUK) retired in February 2012, he moved directly to a position as a Vice President with a Rosatom company. How far this has influenced the decision is not clear.

In Turkey, Russia was reported to have won an order to supply four reactors for the Akkuyu site in 2010.[48] This was a unique deal under which power from two of the units was reported to be guaranteed an offtake price of 12.35 euro-cents/kWh over 15 years after commissioning. Other reports said the deal could correspond to a price guarantee for 70% of the first two reactors' output and for 30% of the second pair's sales. Ownership would be in the hands of a Russian consortium with the possibility of Turkish interests later taking a minority stake. Construction was expected to start in 2011. This deal followed a number of previous failed attempts by Turkey to order nuclear power plants and the deal of 2010 followed on from an earlier bid by Russia involving a sale price of 21 euro-cents/kWh. By 2014, construction start was not expected before 2016 and Turkish investors were not forthcoming.[49] The construction cost was claimed by the company set up to own the plant to be $20bn, about $4200/kW, but given that the companies involved are all Russian, it is not clear how reliable this figure is.

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47 Power in Europe '**Rosatom** confirms stake in **Fennovoima' March 31, 2014**

48 Nucleonics Week 'Akkuyu plant construction to begin in 2011, says Turkish energy ministry' May 27, 2010

49 Nucleonics Week 'Turkey's Akkuyu faces further delays: project company' June 5, 2014

Most of Russia's markets do not provide reliable figures on expected costs, but in June 2014, it was reported the expected construction cost of the Hanhikivi reactor would be about €7.68bn for a 1200MW reactor, which puts its costs on par with the Hinkley deal.[50] If these figures are correct, the common assumption that Russian reactors would be cheap would appear to be wrong.

In terms of safety reviews, Russian reactors do have core-catchers and have protection against aircraft impacts, but the design has not been tested by an experienced, open Western regulatory body.

The strength of the Russian industry in export markets appears to be the willingness to provide a comprehensive package including fuel, fuel cycle services, finance, training and even taking an equity stake in the plants as in Finland and Turkey. Whilst most of the projects remain at an early stage, Russia's ability to deliver components, finance etc. remains untested and its ability to provide finance for markets that are seen as highly risky must be in doubt.

3.6 The ABWR

The ABWR is a rather different case to the other reactor designs having some operating experience, albeit with a much earlier version of the design and only in Japan. It dates back to 1980 and was jointly developed by GE (USA) and Hitachi and Toshiba (Japan) and the design pre-dates Chernobyl. Construction on the first unit of this design was started in 1992 coming on line in 1996 with other reactors being completed in 1997, 2005 and 2006. Two more reactors are reportedly under construction in Japan but whether the sites are active post-Fukushima is hard to know. Two more ABWRs were ordered for Taiwan and construction started on these in 1997, but after continual delays, they are no longer under active construction and are unlikely to be completed.

This first design was updated and submitted to the US safety authorities receiving approval in 1997, which expired in 2012. This design was never ordered. In 2006, when Toshiba took over GE's main historic rival in the nuclear field, Westinghouse, there was a split and Toshiba now promotes its own ABWR technology, while Hitachi formed a new joint venture with GE for global markets, Hitachi-GE with 80% of the shares with Hitachi. Both vendors have applied to renew US regulatory approval but the extent of the upgrades required is not clear although enhanced aircraft protection will certainly be one element.[51] Given that neither company has any realistic immediate prospect of an order in the USA, it is not clear how hard the companies are pursuing approval. The NRC has not given an estimate of when it will complete the process.

In 2013, Hitachi-GE took a controlling stake in one of the consortia (Horizon) attempting to build nuclear in the UK and announced it would seek GDA for its version of the ABWR. The process started in 2014.[52] How far the design presented to the UK regulator will differ from that presented to the US regulator is unclear.

In terms of cost, there is no evidence the ABWR will be cheaper than, say the EPR or AP1000, especially for the upgraded versions now being reviewed by the US and UK regulators. Its bid for the UAE was reportedly higher than that for the EPR and the estimates of the US utilities that were interested in the ABWR were no lower than those for other reactor technologies.

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50 www.talouselama.fi/uutiset/fennovoima+paljastaa+lopulta+voimalansa+kokonaishinnan++siirto+olisi+kohtalokas/a2254008

51 www.nrc.gov/reactors/new-reactors/design-cert/renewal-abwr-toshiba.html#appreview and www.nrc.gov/reactors/new-reactors/design-cert/renewal-abwr-ge-hitachi.html

52 www.onr.org.uk/new-reactors/uk-abwr/index.htm

Like the AP1000, the extent to which Hitachi and Toshiba can count on the support of the Japanese government is unknown. Before Fukushima, a key element in export bids was the presence of Tokyo Electric (TEPCO), the largest Japanese utility and owner of Fukushima, providing its expertise and perhaps an equity stake. However, the Fukushima disaster shattered the credibility of TEPCO and the Japanese vendors have been left without a utility partner. TEPCO has also had to withdraw from bids for Vietnam and Texas.

4. Conclusions

None of the Generation III+ options has any operating experience yet and it will be 2015 before there is operating experience in China and even later before there is operating experience in a Western country.

The apparent assumption that the failure of the 2008 tender in South Africa was because the wrong options had been chosen has been proved wrong, especially once the option of going for obsolescent technologies was ruled out. The two competitors in 2008, the EPR and AP1000 remain competitors albeit their expected cost has gone up real terms by about 25%.

Of the other options, the designs offered by Korea and China are effectively untested even in their home markets. The Korean design will need significant upgrades to meet Western standards and the design has not been reviewed by a strong independent Western regulatory body. China's technologies are still under development and are not ready for construction unless the customer is prepared to start without a full design, much less regulatory approval. The costs of the Chinese options are not known and until safety upgrades for the Korean design are included and priced, the cost of the Korean option will not be known.

The Russian design appears to tick the right regulatory boxes but until it is reviewed by a strong Western regulatory body, doubts about whether the design really meets the standards required will remain. In terms of cost, there is very little evidence but what there is suggests it will not be cheaper than, say, the EPR. Unlike China, Russia is not known as a place of high quality low-cost manufacturing so there is no *a priori* reason to expect prices to be low.

The ABWR is more to evaluate. It has construction and operating experience but this is with a design that dates back more than 30 years. The current designs have no orders, much less construction and operating experience.

Overall, a renewed call for tenders (or perhaps bilateral negotiations with a preferred bidder) is likely to produce the same result as 2008: a very high price for an unproven technology that will only be financeable if the South African public, either in the form of electricity consumers or as taxpayers, is prepared to give open ended guarantees.