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| **Construction delays at Generation III+ Nuclear Power Plants**  Professor Steve Thomas  July 2015  The Public Services International Research Unit (PSIRU) investigates the impact of privatisation and liberalisation on public services, with a specific focus on water, energy, waste management, health and social care sectors. Other research topics include the function and structure of public services, the strategies of multinational companies and influence of international finance institutions on public services. PSIRU is based in the Business Faculty, University of Greenwich, London, UK. Researchers:  Prof. Steve Thomas, Jane Lethbridge (Director), Emanuele Lobina, David Hall, Dr. Jeff Powell, Sandra Van Niekerk, Dr. Yuliya Yurchenko |

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# Introduction

Generation III+ designs were meant to drive the ‘Nuclear Renaissance’ that was forecast by the nuclear industry from the late 1990s onwards The central claim for the new technologies was that they would build on existing technology but the design, especially the safety systems, would be rationalized. This would mean that the plants would be safer than their predecessors, but simpler, therefore cheaper and less prone to construction delays. There would be a reliance on ‘passive’ safety, fabrication of large parts of the plant in factory-made modules and standardisation of designs. This report examines experience of constructing Generation III+ identifying the major problems met and thereby testing the claim that Generation III+ designs would be more buildable. We do not examine the claim of greater safety here, although we do note the differing approaches to improving safety.

There has been considerable analysis of cost escalation, so we do not examine these in detail. Early claims that these new designs could be built for around US$1,000/kW[[1]](#endnote-1) of capacity have proved over-optimistic and, in 2013 (in 2012 money), the proposed Hinkley Point C reactor was expected to cost about US$8,000/kW, and this is seen to represent the current benchmark.[[2]](#endnote-2) However, the claim of reduced complexity, which we examine here, has not been reviewed so fully.

The construction delays that the nuclear industry was increasingly prone to in the decades up to 2000 were attributed to the complexity that meeting the safety lessons that the Three Mile Island and Chernobyl accidents had resulted in. A common claim for the new designs was the use of greater ‘passive safety’ features under which, in accident conditions, the reactor would be kept in a safe state by natural processes such as convection, rather than relying on the operation of engineered systems. This was exemplified by the Westinghouse AP1000 for which ‘AP’ represented Advanced Passive and the GE-Hitachi Economic Simplified Boiling Water Reactor (ESBWR). Westinghouse claimed: ‘The **AP1000** PWR is the safest and most economical nuclear power plant available in the worldwide commercial marketplace.’[[3]](#endnote-3) GE-Hitachi claimed: ‘ESBWR is the world’s safest reactor. It has the lowest core damage frequency (industry standard measure of safety) of any Generation III or III+ reactor and can safely cool itself with no AC electrical power or human action for more than 7 days.’[[4]](#endnote-4)

There was also a perception that delays were in part down to the large proportion of the construction work that had to take place on site. Site-work is often portrayed as more difficult to manage than work in a manufacturing facility. So, many of the designs were expected to use greater modularization under which components were fabricated and assembled in factories leaving much less work at the site. Westinghouse claims for its AP1000 design: ‘Factory-built modules can be installed at the site in a planned construction schedule of three years - from first concrete pour to fuel load.’[[5]](#endnote-5) GE-Hitachi claims the ESBWR would offer: ‘Optimized construction schedule from standardized and modularized design.’[[6]](#endnote-6) However, not all the designs claimed to be Generation III+ have been designed around passive safety or modularization (see below).

Clearly, there is a relationship between construction cost and construction time and, if nothing else, a delay in construction will inevitably increase the interest during construction and, intuitively, it might be expected that construction delays would arise from causes such as construction errors that would also raise costs. However, the relationship seems far from linear. By early 2015, the Finnish Olkiluoto EPR reactor was running more than nine years behind schedule and the expected construction cost had nearly tripled since construction start. However, this latest estimate of the construction cost was still less than the expected construction cost for each of the UK’s proposed Hinkley Point C’s EPR reactors long before any construction had started and before any construction problems had had a chance to arise. In this report we examine only delays and cost increases that occur in the construction phase. There can be huge expected cost increases before construction starts. For example, in 2003, the French Industry Ministry estimated that construction costs for an EPR would be just over €1bn per reactor. The price tag had tripled by the time the contract was signed in December 2003 for the first EPR to be built in Finland (see also World Nuclear Industry Status Report 2013, Table 2[[7]](#endnote-7)). Similarly, in 2008, the UK Department of Energy & Climate Change estimated that an EPR could be built in UK for an overnight cost of only £2bn per reactor and would be on-line by late 2017. In 2013, when preliminary agreement was reached with EDF to build the plant, the expected overnight cost per reactor was £8bn and completion was not before 2023.

While the primary objective of this report will be to examine these claims of ease of construction, the analysis also brings evidence on three other important areas:

* Standardization. For more than 40 years, the nuclear industry has claimed that standardization would solve many of the problems of high costs and construction over-runs that have plagued the nuclear industry throughout its history;
* Generic design reviews. Construction delays are often seen as the result of design issues emerging during construction. It has been claimed that ‘generic’ design assessments by national regulators would resolve all design issues prior to construction start and would be valid for a given technology at any site in that country;
* The future of light water reactor technology.[[8]](#endnote-8) If Generation III+ designs are not a commercial success, what future is there for reactors cooled and moderated by ordinary (‘light’) water?

# Reactor designs examined

## 2.1 The definition of Design Generations[[9]](#endnote-9)

Nuclear power plants are sometimes categorized according to their design generation, with four generations identified. There are no clear definitions of what defines a particular design generation. For Generation III and III+, there are two approaches, not mutually exclusive, one based on the period when the design was conceived (or underwent significant revisions) and the other is based on its technical features.

Generation I is the prototype and early nuclear orders, for example, the UK’s ‘Magnox’ gas-cooled reactors and US reactors such as Shippingport, Dresden 1 and Indian Point 1. The last operating reactor of this generation, one of the Magnox reactors at the Wylfa plant is due to close at the end of 2015. Generation II includes the vast majority of operating reactors ordered from the mid-60s to about 1990. The majority of these reactors are light water cooled and moderated reactors, either Pressurised Water Reactors (PWR) or Boiling Water Reactors (BWRs). However, there are some heavy water cooled and moderated plants all except one of which is of the Canadian Candu design and some gas-cooled plants (using carbon dioxide as coolant and graphite as moderator) of the UK’s Advanced Gas-cooled Reactor (AGR) design.

Generation III designs started to become available from the mid-80s onwards, learning from the Three Mile Island accident. Generation III is often subdivided in Generation III and III+. While a number of Generation III designs were developed few orders were placed. Nearly all designs ordered were light water reactors. Two designs usually categorized as Generation III are particularly relevant to the Generation III+ category. The Westinghouse AP600 was a more radical departure from previous practice than the others, being much smaller than its predecessors and relying on ‘passive safety’. It received generic design approval from the US safety authorities in 1999 but was never offered for sale. However, it was scaled up to about 1150MW to form the AP1000. The ABWR (Advanced BWR) was developed jointly by GE, and its Japanese partners Toshiba and Hitachi and four reactors of this design were completed in Japan from 1996 onwards with a further two under construction in Japan and two in Taiwan. The reactors in Taiwan have been under construction since 1998 and may not be completed while those in Japan have been delayed by the Fukushima disaster.

Generation III+ reactors (see Appendix 2 for more details of the different designs) were developed or significantly modified after the Chernobyl disaster. They also now include the added requirements of being able to stand up to aircraft impact resulting from the terrorist attack of September 11 2001 (the 9/11 attack). Three designs (AP1000, EPR and AES-2006) have received orders, whilst another four (GE-Hitachi[[10]](#endnote-10) ESBWR, Hitachi-GE and Toshiba updated versions of the ABWR and the Mitsubishi APWR) are undergoing generic review by the U.S and/or the UK safety authorities.

Generation III+ designs were seen as transitional technologies until Generation IV designs became available. The Generation IV International Forum (GIF)[[11]](#endnote-11) claims: ‘Generation-IV designs will use fuel more efficiently, reduce waste production, be economically competitive, and meet stringent standards of safety and proliferation resistance.’ However, despite 15 years of effort, none of the six designs identified by GIF as promising seems close to commercial deployment and Generation IV designs are not considered further in this report. So for probably a decade or more, the designs that will be commercially available can only be the Generation III+ designs noted above.

In terms of their technological characteristics, the World Nuclear Association (WNA) claims that: ‘Newer advanced reactors [Generation III+] now being built have simpler designs which reduce capital cost. They are more fuel efficient and are inherently safer.’[[12]](#endnote-12) In more detail, it lists some of the design characteristics:

* a standardised design for each type to expedite licensing, reduce capital cost and reduce construction time,
* a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets,
* higher availability and longer operating life – typically 60 years,
* further reduced possibility of core melt accidents,
* substantial grace period, so that following shutdown the plant requires no active intervention for (typically) 72 hours,
* resistance to serious damage that would allow radiological release from an aircraft impact,
* higher burn-up to use fuel more fully and efficiently and reduce the amount of waste,
* greater use of burnable absorbers ("poisons") to extend fuel life.

The first two characteristics, standardisation and simplification, are of particular relevance to this analysis. The WNA then goes on to list some additional possible characteristics including: ‘The greatest departure from most designs now in operation is that many incorporate passive or inherent safety features which require no active controls or operational intervention to avoid accidents in the event of malfunction, and may rely on gravity, natural convection or resistance to high temperatures.’ And ‘A feature of some new designs is modular construction. The means that many small components are assembled in a factory environment (offsite or onsite) into structural modules weighing up to 1000 tonnes, and these can be hoisted into place. Construction is speeded up.’

These possible design characteristics do reveal the diversity of the reactors claimed to be design Generation III+. The six most developed designs (those with orders and those undergoing generic review) broadly fall into two categories. The first, including EPR, ABWR and APWR, are essentially updated versions of existing commercially sold (or offered in the case of APWR) designs. For the second category, the AP1000 and the ESBWR, the use of passive safety and modularisation is much more central. The AP1000 was developed from the AP600 design dating back to about 1990 whilst the ESBWR substantially post-dates the 9/11 attack. AES-2006 seems to sit somewhere between the two categories.

## 2.2 Commercial experience with Generation III+

By January 2015, there were 18 reactors under construction claimed to meet Generation III+ criteria all of which were Pressurized Water Reactors (see Table 1). Eight of these were of the Toshiba/Westinghouse[[13]](#endnote-13) AP1000 design, four in China and four in the USA. Four were of the French AREVA EPR design, two in China and one each in Finland and France. The other six were of the Russian AES-2006 design, four under construction in Russia and two in Belarus.[[14]](#endnote-14) There is little information available on the Belarus plants, which only started construction in November 2013. In February 2015, the Belarus authorities claimed the plant was still on schedule to meet the dates for completion forecast when construction started just over a year before.[[15]](#endnote-15) However, in March 2015, Atomstroyexport admitted the plant would cost 1,433.7bn Rubles compared to the forecast from 2014 of 840bn Rubles.[[16]](#endnote-16) At exchange rates of March 2015, when the Ruble was valued at about half the level of 2014, this equates to an original cost estimate of US$13bn, increasing by 71 per cent to US$22.9bn.[[17]](#endnote-17) The contract is denominated in US dollars and the collapse of the Ruble has also meant that Atomstroyexport has had to ask Belarus for support despite the contract being reported to be a ‘turnkey’ or fixed price one[[18]](#endnote-18), although the Belarus energy ministry has expressed satisfaction with work of the Russian contractor.[[19]](#endnote-19)

## 2.3 The suppliers of Generation III+ plants

Both AREVA and Westinghouse have seen significant changes in their ownership since 2000. AREVA was created in 2001 from the merger of the reactor vendor Framatome (then renamed AREVA NP), COGEMA (renamed AREVA NC) and Technicatome (renamed AREVA TA). Ownership of the AREVA group is dominated by the French state, which in 2015, held about 87 per cent of the shares. Siemens merged its reactor business into AREVA taking a 34 per cent stake in AREVA NP (for simplicity, subsequently referred to as AREVA). In 2009, Siemens announced it was exiting AREVA paying AREVA €648m in compensation.[[20]](#endnote-20) In November 2014, its credit rating was reduced to ‘junk’ by Standard & Poors (BB+ for long-term and B for short-term).[[21]](#endnote-21) In March 2015, it posted annual losses of €4.8bn including an additional €720m for Olkiluoto making the total losses for Olkiluoto it had acknowledged €4.5bn[[22]](#endnote-22) and Standard & Poors lowered its long-term credit rating two further notches to BB-.[[23]](#endnote-23) By June 2015, the French government was trying to engineer a rescue package which would involve separation of the AREVA NP business expected to be controlled by the French utility Électricité de France (EDF), also largely state-owned (about 85 per cent).

In October 2006, Toshiba of Japan completed the purchase of a majority stake of the reactor business of the US based Westinghouse from the UK nationally-owned company BNFL. BNFL had acquired the Westinghouse nuclear business in 1997, but BNFL went bankrupt in 2002 and its component parts, including Westinghouse, were individually sold off. The Shaw Group, an engineering, construction, maintenance, technology and fabrication company covering many sectors, took a 20 per cent stake. Shaw was expected to be a major supplier of modules for the AP1000 through its Lake Charles facility in Louisiana. In September 2011, Shaw announced its intention to sell its stake in Westinghouse. There was speculation that this would allow it to diversify its reactor interests away from AP1000 towards the Advanced Boiling Water Reactor (ABWR) and other PWRs.[[24]](#endnote-24) However, in July 2012, Chicago Bridge & Iron Company (CB&I), a company based in USA but with headquarters in The Hague, bought Shaw for US$3.04bn.[[25]](#endnote-25) In January 2013, Shaw exercised its right to sell its 20 per cent stake in Westinghouse to Toshiba for US$1.4bn, raising Toshiba’s stake in Westinghouse to 87 per cent.[[26]](#endnote-26) There was speculation at that time that CB&I would buy a stake in Westinghouse but this did not happen. The contract to build Vogtle and Summer was with a consortium of Westinghouse and the Shaw Group, now owned by CB&I. Another contractor for Vogtle and Summer, Stone & Webster, historically one of the main US nuclear architect engineering companies, was part of the Shaw Group until 2012, when it was acquired by Technip, a French oil and gas services group for €225m as part of the deal for CB&I to acquire the Shaw Group.[[27]](#endnote-27)

The Russian vendor structure is complex with the state-owned Rosatom group, which has more than 400 subsidiaries, at the centre of things. It is fully integrated across all civil nuclear activities including reactor design, reactor ownership and operation, reactor supply and fuel supply. Key subsidiaries include: two competing design companies Saint-Petersburg Atomenergoproekt and Moscow Atomenergoproekt; Atomenergoprom, an integrated company covering all aspects of the nuclear business including uranium production, nuclear power plant construction and energy generation; Rosenergoprom, which owns Russia’s nuclear facilities; OKB Gidropress, which designs and produces VVER plants; and Rusatom, which supports Rosatom subsidiaries in foreign markets.[[28]](#endnote-28)

## ****2.4 EPR****

**The EPR**[[29]](#endnote-29) **was the product of a collaboration started in 1989 between the reactor sales interests of Siemens (Germany) and Framatome (France) aimed at producing a design that was licensable in both France and Germany, and thus internationally. Its roots were claimed to be the Siemens ‘Konvoi’ design for its instrumentation and control systems and the Framatome N4 design for the containment. Three Konvoi plants were built, all in Germany. They averaged six years from start of construction to commercial operation (in 1988-89) and their life-time load factor to end 2014 over their 75 reactor-years of operation was an outstanding 93 per cent. By contrast, the N4 reactors were highly problematic. They averaged 12 years from start of construction to first criticality then a further 3.5 years from criticality to commercial operation which happened in 2000-02 (this latter phase only took on average 3 months for the Konvoi plants). The average load factor over the 52 reactor-years of operation they had completed by end 2014 was only 76 per cent.**

**While the guiding principle for the EPR was said to be ‘simplifying system design’, it seems clear they were unable to do this. This was confirmed in the Roussely report, a** 2010 inquiry into the problems facing the EPR commissioned by the French government and chaired by the Honorary President of EDF, François Roussely. This found **that:**

“The resulting complexity of the EPR, arising from the choice of design, specifically the level of power, the containment, the core catcher and the redundancy of the security systems is certainly a handicap for its construction and therefore its cost. These factors explain, in part, the difficulties encountered in Finland or in Flamanville.”[[30]](#endnote-30)

**Also in 2010, Anne Lauvergeon, then CEO of AREVA told its shareholders: “**Safety has a cost, 15 per cent for EPR compared with generation 2.”[[31]](#endnote-31) **While AREVA does claim on its web-site use of passive features in the EPR**[[32]](#endnote-32)**, elsewhere it said it had chosen “**an evolutionary path with an emphasis on active safety features”.[[33]](#endnote-33)

## ****2.5 AP1000****

**In contrast to the EPR, its predecessor AP600 and AP1000 were a radical departure from the reactors Westinghouse had previously offered. Its roots were the AP600 design that emerged around 1990.** Westinghouse claimed that they had looked for the scale economies of building ever bigger reactors and found they were not there and therefore proposed a reactor of about 600 MW, about half the output size of its predecessors**.**[[34]](#endnote-34) **This was submitted to the US Nuclear Regulatory Commission (NRC) and received approval in 1999.**[[35]](#endnote-35) **However, by then, it was clear the plant design was not economic, so it was never ordered. It was scaled up to about 1,150 MW and submitted to the NRC in 2002. Westinghouse argued that** 80 per cent of the work done on AP600 could be transferred to the AP1000 design.[[36]](#endnote-36) Despite this, i**nitial approval was not given until 2006 and the process was quickly re-opened following submission by Westinghouse of design changes that delayed final approval until 2011.**[[37]](#endnote-37)

Westinghouse set out its claims for the AP1000 design in 2003.[[38]](#endnote-38) The design philosophy centred on passive safety measures, which, it claimed was already ‘mature’. It claimed the scale increase would ‘reduce cost’ and suggested the cost would be competitive due to: simplification, economics of scale, short project schedules, standardization and modularization. On simplification, Westinghouse claimed 50 per cent fewer valves, 35 per cent fewer pumps, 80 per cent less pipe, 80 per cent fewer heating, ventilating and cooling units, 45 per cent less seismic building volume and 70 per cent less cable than on its predecessor designs.[[39]](#endnote-39) It claimed modularization would “allow many repetitive construction activities to be performed in a more controlled environment; capture experience and lessons learned more easily; provide multi-path parallel construction with large reduction in field labor”.

Despite the claims of 2003 that the design was mature, a flow of design changes has continued, delaying final approval by the NRC by five years till 2011. Since 2011, the flow has not abated with about 30 design changes per year being submitted to the US NRC. In the UK, the Office of Nuclear Regulation (ONR) issued an interim design acceptance certificate in 2011[[40]](#endnote-40) but in December 2014 after Westinghouse re-opened the process, **ONR reported: “**Westinghouse informed the Regulators that the AP1000 design has undergone substantial change since 2011.”[[41]](#endnote-41)

## 2.6 AES-2006

The Russian vendor, Rosatom, was not so prominent in the hyperbole that surrounded the talk of the Nuclear Renaissance, but they claim their current technology, AES-2006, meets all the requirements of the West, for example, it has a ‘core-catcher’ and it is designed to withstand impact from a large civil airliner.[[42]](#endnote-42)

Its antecedents are said, by Rosatom[[43]](#endnote-43), to be the VVER-1000 reactors ordered in the 1970s and 1980s of which 31 units are in service and one is under construction. This was succeeded by the AES-91 and AES-92, said to have been evolved from the VVER-1000 of which two units of each were supplied to China and India respectively. The AES-2006 was said to have been evolved from these two designs.

In fact, since the early days of the Russian reactor industry, the basic designs have had a number of variants with four different versions of the VVER-1000 (see Table 2). The explanation for this proliferation of designs is partly the existence of two separate design companies within Rosatom, The Saint-Petersburg Atomenergoproekt design company was responsible for the AES-91 and the AES-392M, while the Moscow Atomenergoproekt was responsible for the AES-92 and the AES-491.

The AES-91 and AES-92 marked a significant departure from their predecessors being the first reactor design in the world to include a ‘core-catcher’ and also both including a ‘passive heat removal system’ which it claimed will remove core heat without any mechanical systems for many hours. Both designs are still being offered with the AES-92 being considered for Vietnam, India and Jordan, while construction started on two further AES-91 reactors in China.

**Table 2 Russian VVER designs**

|  |  |  |
| --- | --- | --- |
| **Basic design** | **Variant** | **Number built/under construction** |
| VVER-1000 | V-187 | 1 |
|  | V-302 | 1 |
|  | V-338 | 3 |
|  | V-320 | 26/1 |
| AES-91 | V-428 | 2/2 |
| AES-92 | V-412 | 1/1 |
| V-466 |  | 1 |
| AES-2006 | V-491 | 0/4 |
|  | V-392M | 0/2 |

Source: <http://www.rosatom.ru/en/resources/b6724a80447c36958cfface920d36ab1/brochure_the_vver_today.pdf> (Accessed May 6, 2015)

Notes

1. The V-466 was a one-off and was based on a VVER-1000 reactor built inside a Siemens reactor building. Siemens built the reactor building for the Bushehr plant from 1975 to 1979 before it abandoned work. Rosatom completed the plant.
2. Two more V-491 design units began construction at the Baltic site but construction work was suspended in 2013.

The Saint-Petersburg version of the AES-2006 (V-491) and the Moscow version (V-392M) have different passive safety systems.[[44]](#endnote-44)

The design has not been reviewed in detail outside Russia so it is not clear whether it would be licensable without significant modification by an experienced, open and transparent nuclear regulatory body. The vendor does claim: “availability of passive safety systems, excluding influence of personnel’s errors”, “construction during 4 years and series manufacturing of equipment”; “modular principle of construction”; “standardization of designs that simplifies licensing, decreases costs and dates of NPP construction”.[[45]](#endnote-45)

In 2010, it was announced that this design was being superseded by a new once, VVER-TOI, with some extravagant claims on cost and buildability, including building costs reduced by 20 per cent, and the construction timeframe limited to 40 months. The design, designated V-510, is being developed by Moscow Atomenergoproekt. However, this design had not been ordered by March 2015, three years after it had been expected to be available, when it was announced in 2010.[[46]](#endnote-46) The first unit of this new design was expected in the Nizhny Novgorod site in Russia, but by March 2015, there was no immediate prospect of this order being placed.[[47]](#endnote-47) The VVER-TOI design was expected to be used for the Smolensk site but in May 2015, first structural concrete for this plant was put back five years to 2023.[[48]](#endnote-48)

The VVER-TOI design was expected to form the basis of any attempt to export Russian reactors to the UK, but the political situation in Russia in 2015 suggests this is no more than a distant prospect. There are reports the VVER-TOI design would be used for the Akkuyu project for four reactors in Turkey, when and if this goes ahead. However, Jukka Laaksonen, formerly director general of STUK but from 2012, Vice President of Rusatom Overseas, said in July 2013 that Akkuyu would be close to the VVER-TOI, but would probably use the Novovoronezh-2 design, which is an AES-2006, as reference.[[49]](#endnote-49) As discussed below, there is strong evidence that the AES-2006 is little more than a broad design concept, not two standardized designs.

# Causes of construction delays

## 3.1 Complexity

The reactor vendors all made great play of reduced complexity in their promotional material. Westinghouse claimed their AP1000 design had 50 per cent fewer valves, 35 per cent fewer pumps, 80 per cent less pipe, 80 per cent fewer heating, ventilating and cooling units, 45 per cent less seismic building volume and 70 per cent less cable than its predecessors.[[50]](#endnote-50) AREVA claimed that a ‘guiding design principle’ for its EPR design was ‘simplifying system design’.[[51]](#endnote-51) Similar claims for GE’s Economic Simplified Boiling Water Reactor were implicit in its name. However, in 2010, an inquiry into the problems facing the EPR commissioned by the French government and chaired by the Honorary President of EDF, François Roussely, found that a major factor behind the problems experienced in Finland and France was complexity:[[52]](#endnote-52)

In 2010, in the wake of the Roussely Report, AREVA began a review of the EPR design to make it easier and less costly to build. AREVA claimed in 2012, it was learning a lesson per day from experience building the EPR in Finland, France and China with 1,600 lessons learnt by then. Of these, AREVA estimated 44 per cent concerned design, 18 per cent construction, 11 per cent procurement and 27 per cent project management and organization.[[53]](#endnote-53) It said these lessons would allow EPRs to be built in 3-5 years. By 2014, AREVA claimed it was only halfway through the process with any new design not available to be built before 2020, after construction of the proposed Hinkley Point C reactors had started.[[54]](#endnote-54)

In July 2013, the US NRC, which was carrying out a generic review of the EPR design, judged “the digital instrumentation & control design of the US-EPR reactor does not meet regulatory requirements, saying unneeded complexity in the system is preventing the company from showing it complies with agency regulations.”[[55]](#endnote-55)

It is hard to see how AREVA’s attempt started in 2010 to reduce complexity and reduce construction times can be more successful this time given that simplifying system design was a guiding design principle for its EPR and that, as with the instrumentation and control system, attempts to meet safety requirements seem to increase complexity.

## 3.2 Other causes of delay

In practice, when delays occur, they are seldom attributed directly to complexity although often, it seems likely that complexity is one of the root causes. The most commonly cited causes of delay are: design issues; shortage of skilled labour; quality control issues; supply chain issues; poor planning either by the utility or equipment suppliers; shortage of finance; and public opposition. Even with these more specific causes of delay, it is not realistic to expect to be able to apportion the delays that have occurred nevertheless, an analysis of the reported issues will give a good sense of what the main factors have been. Poor quality control may result from shortage of skilled labour, supply chain issues and poor planning.

The role of public opposition in delaying construction is frequently over-stated and there is no evidence that construction of any of the 18 Generation III+ plants being built has been delayed by public opposition. While obtaining finance is clearly now one of the major hurdles to building new nuclear plants, this is much more likely to occur before construction starts. If it does occur after construction starts, this might be due to cost over-runs leading to a need for more finance than was anticipated. Again, there is no evidence that shortage of finance has delayed construction apart from the plants under construction in Russia.

The Fukushima disaster did delay ordering in some markets, for example China, but there is no evidence that any of the delays at the Generation III+ plants under construction resulted directly from lessons drawn of the catastrophe in Japan.

### 3.2.1 Design issues

A frequent problem, and not only with this generation of designs, is that detailed engineering is only worked out by the vendor during construction. If producing the final detailed design proves difficult, for example, if the regulator is not satisfied with the detailed design, this can delay construction. Notable examples of this were the Instrumentation & Control (I&C) System for the EPR (see Appendix 1) and the Reactor Coolant Pump for the AP1000. In 2009, the safety regulatory authorities for Finland, France and UK issued a joint statement expressing concern about the adequacy of the safety systems (those used to maintain control of the plant if it goes outside normal conditions), and their independence from the control systems.[[56]](#endnote-56) This was eventually resolved in all three countries but with a different solution for each and only after up to five years of effort to produce designs that would satisfy the national regulator.

Continued failure of the pumps for the AP1000s being built in China to pass commissioning tests led to a design change that will be implemented for the AP1000s being built in the USA.[[57]](#endnote-57)

### 3.2.2 Shortage of skilled labour, loss of expertise

The low ordering rate for new nuclear power plants over the past 30 years (apart from in China) has meant that there has been little demand for skilled construction workers, so the workforce has aged and its skills have not been utilized. For Finland, construction on the most recent order before the Olkiluoto order was placed was in 1975, while for France, work on the predecessor to Flamanville started in 1991. In Russia, no new construction work started between 1986 and 2008. In China, reactor ordering continued at a rate of only about one reactor a year until 2007 when ordering suddenly accelerated to more than five per year. How far this extremely rapid increase in required skills has over-stretched Chinese resources is difficult to tell.

Re-building a skilled workforce cannot be done quickly, requiring basic education as well as experience. Until the flow of orders is more established and the job prospects secure, the incentives for workers to undergo such training will be weak. A particular issue at the Olkiluoto site seems to be a shortage of local skilled labour and it has been widely reported that the site work force had to be drawn from about 55 different nationalities[[58]](#endnote-58) causing significant problems of communications.[[59]](#endnote-59)

For both the first orders for EPRs, the first major construction activity, the pouring of the concrete base-mat had to be re-done because of errors in doing this. Particularly for France, where EDF, the owner and site engineer had already built 58 PWRs and might be expected to be well-versed in this process, it seems reasonable to assume this was due to loss of expertise.

### 3.2.3 Supply chain issues

Here we are dealing with poor quality of equipment or delays in delivery rather than unavailability of equipment, which is dealt with under ‘poor planning’. An often quoted example of supply chain problems is the supply of the pressure vessels for the largest reactors. This market is dominated by Japan Steel Works and it was expected that anyone wanting to build a large reactor had to get into the queue for this component well in advance if construction was not to be delayed.[[60]](#endnote-60) However, whilst supply of major components might, in theory, delay construction start, in practice, ordering rates have been so low that this does not seem to have happened. Indeed, ordering has been so slow it now appears that Japan Steel Works is suffering from over-capacity.[[61]](#endnote-61)

The dearth of orders over the past 30 years has meant that many component suppliers have exited the sector and most dedicated production line facilities for major specialized components have been closed with components now individually fabricated. A more significant problem seems to be delays caused by poor quality equipment, misconceived designs or failure by suppliers to deliver on time. A particular example of supply chain problems has been the reactor coolant pumps (RCPs) for the AP1000 to be supplied by Curtiss-Wright. Curtiss-Wright acknowledged: “It failed to meet deadlines for shipping RCPs from the US to AP1000 plant sites in China and that it had to ship pumps back from the Sanmen and Haiyang sites in China for modification.”[[62]](#endnote-62) The errors by Areva in the fabrication of the pressure vessels for Flamanville and the two reactors for Taishan in China are another significant failure (see section 7.2 and 7.3)

### 3.2.4 Poor planning

The dearth of orders has also led to a loss of project planning expertise in utilities, project engineers and regulatory bodies. The history of construction at the Olkiluoto 3 site has been littered with accusations of failures of planning by the utility, the vendor and the regulatory authority (see below).

### 3.2.5 First of a kind problems

There is frequent mention of first-of-a-kind (FOAK) issues and, intuitively, it might be expected that the first time a design is built problems will arise that will not affect subsequent units. For this analysis, these problems generally fall into one of the other categories, such as poor planning, supply chain issues or loss of skills. For example, if construction is delayed because new procedures have to be approved by the regulator, this must be counted as poor planning.

# The future of light water reactors

At the time the Renaissance, nuclear ordering had collapsed with no new orders in prospect in Europe, the USA and Russia, while China and India were providing only a trickle of orders. The problems of high nuclear costs, low gas costs, the impact of electricity liberalization, which exposed utilities to the economic risks of nuclear power plants and the fresh memory of the Chernobyl disaster meant there was little interest in nuclear power. The cost claims appear to have been based on what it would take for nuclear to be competitive with power from natural gas. Two of the most important target markets were the USA and the UK because of their long history in nuclear power and because of the perception that they had rejected nuclear power so winning these countries back would be a major fillip for the nuclear industry. The first to be convinced was the US Bush administration in 2002, which offered subsidies for a small number of demonstration plants after which it was expected that nuclear would have proved itself cheap enough for ordering to be self-sustaining without subsidy. As a measure of the optimism at that time, the Bush programme, Nuclear 2010, was so-called because it was expected the first reactors would be in operation by 2010.[[63]](#endnote-63)

In 2002, the UK nuclear industry was in chaos with its two nuclear companies, the nationally-owned fuel cycle company, BNFL, and the privatised nuclear generation company, British Energy, both bankrupt and requiring massive state intervention to clear up the mess. Re-launching nuclear power at that time was clearly politically difficult. It was not until 2005, when British Energy had been rescued and BNFL broken up and sold off, that Prime Minister Blair was able to claim that nuclear power was back “with a vengeance”.[[64]](#endnote-64) What made the policy to re-launch nuclear power politically acceptable was a claim that nuclear power was cheap enough to survive in the market with no public subsidy.

The basis for the attempted revivals in the USA and the UK, that nuclear power was cost competitive with natural gas, has been proven wrong. Heightened concerns about climate change has lowered the economic bar nuclear power must clear by making the relevant comparator the cost of renewables and energy efficiency but it is far from clear that nuclear is competitive with these options.

If it is not, it is hard to see how light water reactors would be given another chance. Whether that would mean the end for nuclear power or a more determined attempt to commercialize Generation IV designs or other radical new designs such as Small Modular Reactors or Thorium fuel cycle reactors is a moot point.

# Standardisation

For more than 40 years, there has been a strong belief in the nuclear industry that failure to standardise designs has been a factor raising costs. In the early 1970s a number of US utilities cooperated to produce a standardised design (Standardized Nuclear Power Plant System or SNUPPS) that could be replicated on any site with minimal modifications with six units planned. Only two of these were actually built.

The intuitive advantages of standardization are clear:

* Reduced design costs because the design would be replicated;
* Reduced regulatory costs, because approval at one site would be a strong precedent for subsequent orders;
* Reduced component costs because components of a given design would be manufactured in larger numbers;
* Increased ‘learning’ making construction work and servicing more efficient.

However, there are disadvantages to the freezing of the design that rigorous standardization requires:

* Experience from operating reactors and those under construction cannot be embodied in the standardized design;
* The design must meet all possible requirements, for example, on resistance to earthquakes raising costs at sites where such rigorous standards are not needed.

There is also the existence of national regulatory requirements. While there is some consensus amongst regulators about the overall standards that should be achieved, as has been clearly illustrated by the problems of getting regulatory approval for the instrumentation & control system for the EPR (see Appendix 1), there is no consensus about the specific design details needed to meet those requirements. There are also specific conditions in a country, for example, the AP1000 design approved by NRC would be unlikely to meet the earthquake resistance requirements needed for China. Designs can, at most, be standardised for a given country.

In practice the Generation III+ designs are all diverging markedly from site to site. A useful insight on this was provided by Vaclav Bartuska, who oversaw the attempt, eventually abandoned, by the Czech government from 2010-14 to order new nuclear power plants for its Temelin site.[[65]](#endnote-65) The three technologies discussed here, EPR, AP1000 and VVER-2006 were all candidates that were examined in depth so he acquired a detailed knowledge of the implementation of these designs.

For AES-2006, Bartuska said that the design offered to the Czech Republic ‘de facto did not exist,’ and that it was ‘a brand, nothing more.’ The two Russian projects, Leningrad 2 and Novovoronezh 2, were supplied by different companies and have ‘different designs for the primary circuit and the safety concept, that is, in the amount of active and passive elements.’ For the EPR, he claimed that all three projects—Olkiluoto, Flamanville and Taishan—varied significantly and he had been told by AREVA only about 50 per cent of their respective nuclear islands are the same. For AP1000, he was critical of failures in the supply chain claiming “the disintegration of supply structures also hit Westinghouse—manifested most strongly in loss of control over their sub-contractors and their other suppliers”.

In 2010, Atomenergoproekt OJSC announced it was developing a new version of the VVER-2006, VVER-TOI expected to be ready for ordering in 2012, ‘TOI’ denoting standardized, optimized, computerized and the output would be increased to about 1300 MW.[[66]](#endnote-66)

# Generic design reviews

The rationale for the generic approval process applying in the USA since 1992 and in the UK since 2008 was that a nuclear design could be fully standardized. Detailed review of the standardized design would resolve all major issues and approval for the design would be valid wherever it was built within the regulator’s jurisdiction. This would save design and regulatory costs and reduce scope for disruption to construction that would occur if a detailed design issue emerged in mid-construction.

The issue of incomplete detailed designs was recognized as a problem in the USA and the UK and from 1992, the US safety authority, the NRC, has undertaken a full detailed review of design that should resolve all design issues other than site specific features that must be completed before the design can be built. This generic approval is valid for 15 years. Five designs have now received generic approval: the GE ABWR in 1997 after ten years of review; the Combustion Engineering System 80+ in 1997 (after seven years), the Westinghouse AP600 in 1999 (after ten years), the Westinghouse AP1000 in 2011 after nine years and the GE-Hitachi ESBWR in 2014 after nine years. The approval for the first three has expired, although both GE-Hitachi and Toshiba, independently, have applied to renew the approval for the ABWR. A number of other designs have started the review process and are still under review, e.g. the Korean APR1400 (developed from System 80+) or have been withdrawn, e.g. the South African PBMR or the process suspended, e.g. the Mitsubishi APWR.

In the UK, only one design has completed the process, the AREVA EPR after five years. Two more designs, the Hitachi-GE ABWR and the Westinghouse AP1000 are under review.

It is a clearly a lengthy process. For example, the Westinghouse AP1000, which was portrayed as just a scaled up version of the AP600, a design that received NRC approval in 1999, was submitted to the process in 2002. It completed the review in 2006, but the process was almost immediately re-opened, when Westinghouse submitted a series of design changes that were not finally approved until 2011. The flow of design changes has continued since then.[[67]](#endnote-67)

The timescales for completing an NRC review seem to be escalating. The AREVA EPR and the Mitsubishi APWR both started their reviews in 2007 and were some way from completion when the vendors withdrew from the process in 2015. GE-Hitachi and Toshiba applied to renew the approval for the ABWR in 2010 but by 2015, there was no forecast completion date.[[68]](#endnote-68)

If this process works as anticipated, delays caused by problems with detailed design features should not arise in the USA (and the UK if it builds new nuclear plants). France and Finland have chosen not to go through a detailed ‘generic’ design review process. The regulator determines whether, in principle, the design could be licensable before construction starts but resolves detailed issues as they arise in the construction process.

For China, NNSA does not carry out a generic design approval process.[[69]](#endnote-69) It has a four stage process starting with a Project Approval Set-up which looks at site-specific safety and environmental impact. There is then a construction permit, First Fuel Loading Permit (FFLP) and finally an operation license.[[70]](#endnote-70) The extraordinary workload the NNSA was facing in 2015 is important to understand. It was having to oversee construction of 25 reactors, with three of the designs being built, EPR, AP1000 and the Pebble Bed Reactor being built at Shidao Bay, being the first of a kind. It has four further reactor designs, SNPTC’s CAP1400, CGN’s ACPR1000, CNNC’s ACP1000, and CGN’s and CNNC’s versions of the Hualong One[[71]](#endnote-71), which are expected to be ordered, where it will be the first regulatory body to review the designs (see Appendix 2 for more details).

Details of how the Russian authorities review new designs and whether they require a generic design review are sparse, but there is no evidence Russia does carry out a comprehensive design review before construction starts. Jukka Laaksonen, formerly director general of STUK but from 2012, Vice President of Rusatom Overseas said in 2013, safety assessment in licensing of nuclear facilities in Russia “was coordinated by Technical Support Organization of the regulatory body SEC-NRS, which contracts most of the assessment work to certified experts representing a large number of organizations, including those within a Rosatom consortium.” The official licensing document “is a short piece of paper, since the memos are, in the regulator’s view, the property of whoever has paid for that work and in Russia that is Rosenergoatom, Rosatom’s nuclear power plant operator subsidiary”. For exports, he said Rostechnadzor’s, the Federal safety regulatory body[[72]](#endnote-72) requires experts to write “a bunch of separate memoranda, which are not really compiled as a single document”.[[73]](#endnote-73)

# 7. Experience at Generation III+ reactor construction sites

## 7.1 Olkiluoto

**Olkiluoto-3 was the first order placed for a Generation III+ design. In January 2004,** Teollisuuden Voima Oy (**TVO) applied for a construction license and, on the advice of the Finnish Radiation and Nuclear Safety Body (STUK), the Finnish government granted a construction license for Olkiluoto-3 in February 2005.**[[74]](#endnote-74) **The contract was signed with a consortium of AREVA NP (then 66 per cent owned by AREVA and 34 per cent by Siemens) and Siemens, which would supply in particular the turbine generator and the control & instrumentation platform. In 2009, Siemens exited the AREVA group but it remains a supplier for Olkiluoto-3.**

**First structural concrete was poured in August 2005 with an estimated construction time of four years and a cost, including interest during construction, of about €3bn**[[75]](#endnote-75)**. Confidence was high that, being the showcase for a new generation of technologies and given Finland’s high reputation as an efficient operator of nuclear power plants, construction would go smoothly. AREVA was so confident it offered ‘turnkey’ (fixed price terms for the whole plant) despite the record of such offers leading to heavy losses with reactor suppliers. This was seen as possible because AREVA would not only supply the equipment, but would also carry out the architect engineering, so it should have had full managerial control over construction. However, this was a role that it had not undertaken before, with EDF fulfilling it for previous orders including the 58 light water reactors built in France.**

**The history of the use of turnkey orders in the nuclear sector goes back to 1964 in the USA.**[[76]](#endnote-76) **Until then, US utilities had been reluctant to buy nuclear power plants because they perceived them as expensive and financially risky and orders up to then had only been possible with federal government subsidies. However, GE offered a ‘turnkey’ (the utility simply had to turn the key when the plant was complete and start operating it) deal for the Oyster Creek BWR order. There followed eleven turnkey orders distributed amongst all four US vendors (GE, Westinghouse, Babcock & Wilcox and Combustion Engineering). For these contracts to be possible, the vendors, as did AREVA at Olkiluoto, had to take on the architect engineering role, a job they had not done before, so that overall management of the project was under their control.**

**It was soon clear these deals would lose the vendors very large amounts of money and no further turnkey contracts were offered in the USA. While these orders caused the vendors serious financial problems, they did achieve their goal of convincing utilities that they could order a nuclear power plant with the same confidence as for a coal-fired plant and nuclear ordering in the USA took off rapidly from then on. Since then, there have been very few genuine turnkey orders. In some cases, for contracts reported as being turnkey, the fixed price terms apply just to a particular component, not the whole plant, and in other cases, turnkey simply means that one company has overall responsibility for the whole contract with no guarantee on prices.**

**In 2008, after AREVA refused to honour the turnkey contract, TVO and the AREVA-Siemens consortium filed counter-claims for compensation to be heard by the Stockholm Court of Arbitration, the AREVA-Siemens consortium claiming €1bn and TVO claiming €1.4bn.**[[77]](#endnote-77) **In 2012, a small part of the claim, €125m, was settled in favour of the AREVA-Siemens consortium.**[[78]](#endnote-78) **In October 2013, AREVA-Siemens again increased their claim from €1.9bn to €2.6bn and increased it again in October 2014 to €3.5bn.**[[79]](#endnote-79) **TVO again increased its claim from €1.8bn to €2.3bn**[[80]](#endnote-80) **and said in June 2015, it might increase its claim further.**[[81]](#endnote-81)

**Table 3 shows that the project encountered serious problems from the beginning covering a wide range of issues. There has been no let-up in the flow of difficulties. There have been continual accusations by the parties to the project—the vendor, the utility and the regulator—of failure to complete tasks properly or on time. The instrumentation and control design issue seems to have been a continual problem and source of delay since 2009 (see Appendix 1). The poor quality welding and concrete pouring as well as the huge number of nationalities that were brought in also suggests that shortage of labour and loss of expertise have been important. The supply chain does not seem to have caused many of the major problems nor has shortage of finance despite the huge cost over-runs.**

**The problem with the pressure vessels for the Flamanville and Taishan plants (see below) that was uncovered in April 2015 should not affect Olkiluoto because the components concerned were supplied by Mitsubishi**[[82]](#endnote-82)**, although the Finnish regulator has asked for new tests to confirm their quality.**[[83]](#endnote-83)

## 7.2 Flamanville

EDF had for several years, going back to before the Olkiluoto order, been forecasting the order of its first EPR, but it was not till May 2006, it decided formally to proceed with Flamanville-3, by which time things were already going wrong at Olkiluoto. Site work commenced in July 2006 with a target construction time of 54 months and a cost of €3.3bn (excluding fuel and finance charges). The Nuclear Steam Supply System was ordered from AREVA in January 2007, a construction license was issued by the French government in April 2007 on advice from the safety regulator Autorité de Sûreté Nucléaire (ASN) and first concrete was poured in December 2007.

The common perception was that the problems with Olkiluoto-3 were due to: first-of-a-kind problems that would not be repeated; lack of skills in Finland, a problem not likely to occur in France given EDF’s unmatched experience; and the use of AREVA as the architect engineer rather than EDF. In the event, as with Olkiluoto, problems arose from the start with errors in the pouring of the concrete. Arguably, the Flamanville project has gone no better than the Olkiluoto project.

Table 4 shows there were a series of issues of poor quality, for example in welds and concrete and the issue of the instrumentation and control system caused concern although apparently not on the scale of those in Finland. A more comprehensive list of the problems incurred at Flamanville between start of construction and 2012 was published by Makhijani and Marignac[[84]](#endnote-84). Increasingly, supply chain issues seem to be arising with delays to the delivery of equipment.

The most serious defect to date was acknowledged in April 2015 when it was admitted that the top and bottom sections of the pressure vessel had suffered serious manufacturing errors. This affected components for six reactors manufactured from 2006 onwards including the two EPRs under construction in China at Taishan, the two vessels expected to be supplied for the Hinkley Point C project in the UK and a vessel expected to be used at the now abandoned Calvert Cliffs project in the USA. For Taishan and Flamanville, the problem is particularly serious because the faulty components are no longer easily accessible. By May 2015, it was not clear if the faults would be deemed acceptable by the French and Chinese regulators and if they were not whether repair was feasible or if the plants would have to be abandoned. In evidence to the French Senate, the President of ASN, Pierre-Franck Chevet, confirmed the faults were ‘very serious’ and that a decision on whether they were tolerable might not be made before early 2016.[[85]](#endnote-85) In June 2015, a leaked document written by the advisory body to the ASN, the Institut de Radioprotection et Surêêté Nucléaire (IRSN) identified serious deficiencies with the safety relief valves are situated on the pressuriser.[[86]](#endnote-86) [[87]](#endnote-87) By June 2015, it was not known whether a similar issue applied at the Taishan and Olkiluoto plants.

## 7.3 Taishan

In November 2007, China Guangdong Nuclear (CGN)[[88]](#endnote-88) and AREVA signed a deal reported to be for €8bn to supply two EPRs to be built at the Taishan site in Southern China. It is not clear what was covered by this contract but it is apparent it was not for the whole project. The plant would be owned by a special vehicle, Taishan Nuclear Power Company (TNPC), in which EDF holds a 30 per cent stake with CGN holding the rest.[[89]](#endnote-89) The two units were then expected to go into operation between 2013 and 2015. After a delay of two months caused by a tropical storm, structural concrete for the first unit was poured in October 2009 for the first unit with a construction time of 52 months forecast so completion would be in early 2014.[[90]](#endnote-90) Concrete was poured at the second unit in April 2010, so expected completion at that time was August 2014.[[91]](#endnote-91)

Table 5 shows that by early 2015, both units appeared to be about two years late. There were few authoritative reports of problems until early 2014 when a Chinese official acknowledged that all the plants under construction in China prior to the Fukushima disaster, even those using the old well-proven design, were running late with the Taishan units a year late.[[92]](#endnote-92) Since then, more details have been publicised, particularly concerns from the regulator that the delays at the Olkiluoto and Flamanville had meant that China was having to carry out first-of-a-kind operations, for example on testing that it had anticipated would have been proved either at Olkiluoto or Flamanville.[[93]](#endnote-93)

What is conspicuously different to experience at Olkiluoto and Flamanville is that there have been no reported examples of the poor quality work, such as poor welding and problems with concrete, that have been a frequent feature at Olkiluoto and Flamanville. How far this is because the quality of Chinese workmanship is so much better than that of Finland and France and how far it is down to lower standards of quality control and regulatory oversight is hard to determine. In 2015, referring to the prospects for Chinese nuclear power plant exports, a senior expert at China's State Nuclear Power Technology Corp (SNPTC) said: “Our fatal weakness is our management standards are not high enough. There is a big gap with international standards.”[[94]](#endnote-94)

The problem of the instrumentation and control system, which has been a major concern for regulators in Finland, France, UK and USA (see Appendix 1) does not seem to have been a major concern for China’s National Nuclear Safety Administration (NNSA). There is no information in the public domain about what back-up system has been approved.

Stephane Pailler, head of international relations at France's ASN, said: “We don't have a regular relationship with the Chinese on EPR control like we have with the Finnish.” Philippe Jamet, one of the French regulator's five governing commissioners, testified before French Parliament in February 2014: “Unfortunately, collaboration [with China] isn't at a level we would wish it to be. One of the explanations for the difficulties in our relations is that the Chinese safety authorities lack means. They are overwhelmed.” In March 2014, EDF's internal safety inspector Jean Tandonnet published his annual report to the utility's chief executive that detailed a mid-2013 visit to the Taishan building site. He wrote that “the state of conservation” of large components like pumps and steam generators at Taishan “was not at an adequate level” and was “far” from the standards of the two other EPR plants in Finland and France.[[95]](#endnote-95)

Potentially the most serious problem to date has been the issue uncovered at the Flamanville site with the top and bottom of the reactor pressure vessel (see above). As with Flamanville, by May 2015, it was not clear whether the problem would need repair and if it did, whether repair was feasible.

## 7.4 Haiyang and Sanmen

In December 2006, China became the first country to order the Westinghouse AP1000, selecting it over the AREVA EPR and Russian technology for four initial orders with technology transfer and an expectation that there would be further orders with an increasing Chinese supply content.[[96]](#endnote-96) The announcement was delayed until ownership of the Westinghouse nuclear business had been transferred from British Nuclear Fuels Limited to Toshiba. In March 2007, the sites, Sanmen and Haiyang, were selected and construction was expected to begin in 2009, with the first plant becoming operational at Sanmen in late 2013 and the remaining three plants expected to come online in 2014 and 2015. In October 2007, the Chinese partner for the AP1000, State Nuclear Power Technology Corporation (SNPTC), announced its intention to uprate the design to 1400MW, the CAP1400.[[97]](#endnote-97) The choice of the AP1000 as the expected base for future nuclear orders in China also led to the shelving of work on a design, CNP1000, one of AREVA’s partners, China National Nuclear Corporation (CNNC) had been working on for more than a decade.[[98]](#endnote-98) This would have been seen as an old design generation and this decision signalled China’s intention to move to Generation III+ standards. First structural concrete was poured for Sanmen-1 in April 2009, for unit 2 in December 2009 and Haiyang unit 1 in September 2009 and for unit 2 in June 2010.

Table 6 shows that, as with the Taishan project, there was little sign of any problems for some years with confident predictions of completion to time and cost. It was not till 2014, when a Chinese official revealed the scale of delays. The first hint of significant trouble was in 2011 when design issues with the novel reactor coolant pumps came to light, Westinghouse claimed damages against the reactor coolant pump supplier and the Chinese regulator revealed a number of areas requiring repairs and upgrades. The Chinese regulator also revealed concerns about the lack of testing procedures.

## 7.5 Vogtle[[99]](#endnote-99) [[100]](#endnote-100)

In 2010, the US Department of Energy shortlisted five nuclear new-build projects for Federal loan guarantees. Of these, only two are going ahead, the Vogtle project and the VC Summer project, both for two AP1000s.[[101]](#endnote-101) Both are in states, Georgia and South Carolina respectively, where the electricity market is still regulated and these projects were seen as feasible because of the passing of state laws requiring regulators to allow whatever costs were incurred to be passed through to consumers. The major shareholder and the project manager for the Vogtle project is Georgia Power, a subsidiary of the Southern Company with 46 per cent. The other stakes are split between Oglethorpe Power Corp., the Municipal Electric Authority of Georgia and the city of Dalton. These minority shareholders are publicly-owned and not regulated by the state utility regulatory authority and are therefore able to pass on extra costs without regulatory approval. Vogtle has generally been seen as somewhat ahead of the Summer project although the ‘lead’ has changed at various times and most of the problems incurred are common to both sites.

Georgia Power claimed that the assurance that their shareholders would not be liable for cost over-runs was sufficient that Federal loan guarantees were not essential. The other three shareholders are all publicly owned companies and not subject to economic regulation by the state regulators. Loan guarantees of US$6.5bn for the Vogtle plant were not finalized until February 2014, a year after construction started, with the possibility of a further US$1.8bn being allocated.[[102]](#endnote-102) Normally, a fee is charged for loan guarantees reflecting the risk of default. The fee should reflect the default risk so that the fees collected from all projects receiving loan guarantees should be sufficient to cover the cost to taxpayers for the projects which do default and which do require public money to be used to repay the banks. Official documents show that the Department of Energy did not charge the owner of Vogtle, the Southern Company, any fee for the loan guarantees.[[103]](#endnote-103)

The AP1000 design was finally given regulatory approval by the NRC in December 2011 and, with the project already shortlisted for loan guarantees, it was expected the project would quickly proceed. However, even before construction started, there were supply chain problems.[[104]](#endnote-104) A Shaw Group facility that builds modules for the Westinghouse AP1000 reactor, said to be critical for meeting construction schedules, failed to meet NRC quality assurance requirements.[[105]](#endnote-105) Both Westinghouse and Shaw issued large numbers of license amendment requests (about 20 per year) as soon as construction started to reflect the fact that the AP1000 design had had to be frozen to complete the generic review.[[106]](#endnote-106)

The NRC provides a useful record of problems with construction with its ‘Part 21’ reports. The NRC states: ‘The US Nuclear Regulatory Commission (NRC) receives reports from its licensees under Part 21 of Title 10 of the Code of Federal Regulations. This regulation specifies the conditions under which information must be submitted when a licensed facility, activity, or basic component fails to comply with the Atomic Energy Act of 1954, as amended or other NRC regulations.’[[107]](#endnote-107)

Table 7 shows the number of Part 21 filings relating to the Summer and Vogtle projects from 2013 to end of April 2015. In 2014 and 2015, nearly 30 per cent of all filings for all US plants related to the CB&I facilities with, by comparison few problems at the sites and no other suppliers named. Whether, as construction advances, other suppliers will be cited and whether more on-site problems emerge remains to be seen

**Table 7 NRC Part 21 filings relating to the Summer and Vogtle projects**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year** | **Total reports for all US plants** | **CB&I** | **Summer** | **Vogtle** |
| 2013 | 123 | 10 | 4 | 2 |
| 2014 | 160 | 44 | 2 | 1 |
| 2015 (to May 1) | 37 | 11 | 1 | 2 |

Source: <http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/2013/> (Accessed May 1, 2015)

Supply chain problems were common for both the Vogtle and Summer projects (see Tables 8 and 9) and were apparent at least two years before construction started especially at the Chicago Bridge & Iron (CB&I) facility at Lake Louise. A senior executive with Chicago Bridge & Iron, one of the main equipment suppliers said: “The suppliers really struggled understanding the exact nature of what we wanted, how to stand up [nuclear quality assurance] programs. Getting suppliers up the learning curve on what was expected in terms of quality and how that process had to work was quite difficult”.[[108]](#endnote-108)

In February 2012, the NRC issued Combined Construction-permit Operating Licenses (COLs) for the Vogtle units, the first construction licenses it had issued since 1978.[[109]](#endnote-109) Construction start was expected to follow in the same year with completion of the first unit due in 2016 and the second a year later after a construction period of about 50 months. First structural concrete was not poured at the first unit till March 2013 when completion was expected in fourth-quarter 2017, with the second unit to follow about a year later. In November 2013, first structural concrete was poured at the second unit. The reactor coolant pump problems that disrupted the two Chinese projects occurred early enough for the same problem to be avoided at Vogtle and Summer with a different manufacturing process used for the impellers.[[110]](#endnote-110) In May 2015, the two reactors were about 20 per cent over budget and 2-3 years late.

By June 2015, strong parallels were emerging between the Olkiluoto project and the Vogtle project with utility and vendor blaming each other. As discussed above, the Olkiluoto project was a true turnkey contract with the price fixed at the time the contract was signed. While the Vogtle project is not turnkey, the construction contract limits the extra construction charges that Georgia Power and other owners must pay as a result of delay.[[111]](#endnote-111) There were, by then, legal proceedings with Georgia Power suing the contractors, including Westinghouse, CB&I and Stone and Webster, with the contractors countersuing Georgia Power with US$900 million at stake.[[112]](#endnote-112)

## 7.6 Summer[[113]](#endnote-113)

The Summer project is owned by South Carolina Electric & Gas Company (SCE&G, a subsidiary of SCANA) with 60 per cent and South Carolina Public Service Authority (Santee Cooper) with 40 per cent.[[114]](#endnote-114) Santee Cooper is state-owned and not regulated by the state utility regulatory authority and are therefore able to pass on extra costs without regulatory approval. The COLs for the two Summer units were issued in March 2012[[115]](#endnote-115) with construction expected to follow in the same year and first structural concrete in the summer of 2012. Completion of the first unit was expected in 2017 and the second in 2018 with a construction period of 60 months.[[116]](#endnote-116) First structural concrete was not poured at the first unit till March 2013 when completion was expected in March 2017 with the second unit in May 2018. In November 2013, first structural concrete was poured at the second unit. As with the Vogtle project, the owners claimed that loan guarantees were not required to obtain finance and, despite being short-listed, the owners seem likely not to accept the loan guarantees. South Carolina Electricity & Gas’s chief operating officer said it was easier to raise money commercially. He said: ‘Everything we offer is oversubscribed’. Getting a government loan guarantee requires extensive financial disclosures to the federal government, and paying fees. ‘I'm not sure why I'd want to’.[[117]](#endnote-117)

The problems that have affected the Summer site have been very similar to those suffered at the Vogtle site (see above and Table 9).[[118]](#endnote-118) By May 2015, like Vogtle, both Summer units were about 20 per cent over budget and 2-3 years late.

## 7.7 Leningrad-2 and Novovoronezh-2

**In February 2007, Rosatom claimed that a new design, AES-2006 would be ready in June of that year. The first plants would be pairs of units at the Novovoronezh and Leningrad (also known as Sosnovy Bor) sites. The expected construction cost was quoted as US$1,200/kW and the plants would come on-line in 2012-13. The plan was to build two units a year from 2007 onwards till at least 2030.**[[119]](#endnote-119) **By April 2007, the plans had become more ambitious, envisaging** start-up of one nuclear unit a year beginning in 2009, accelerating to two units a year from 2012, three a year from 2015, and four a year from 2016.[[120]](#endnote-120) The financial crisis slowed electricity demand growth and the plans were scaled back again in 2009. Since 2009, construction has only started on two more large reactors, one of which appears to have been abandoned. The Novovoronezh-2 plant was supplied by Moscow-based Atomenergoproekt using the V-392M design while Leningrad-2 using the V-491 design was supplied by Saint-Petersburg Atomenergoproekt.

First concrete was not poured at Novovoronezh-2-1 until June 2008 and for Leningrad-2-1 in October 2008 with start-up expected in 2012 and 2013 respectively.[[121]](#endnote-121) First concrete was poured for Novovoronezh-2-2 in July 2009 and for Leningrad-2-2 in April 2010 with first power in 2013 and 2014 respectively. In February 2012, first concrete was poured at the first of two units to be built in the Kaliningrad enclave.[[122]](#endnote-122) However, work was stopped in favour of building a medium-size reactor, but given that there does not exist a medium-size Russian reactor design, this does not appear plausible and it seems likely the plant will be abandoned.[[123]](#endnote-123)

Few details have been made public about construction at these sites and the regulatory procedures are not clear (see Table 10). Expected completion dates have been slipping for several years and all four units were 3-4 years late by April 2015. However, explanations were not forthcoming until Russia’s Audit Chamber seemed to put the blame squarely on shortage of funds in a report from January 2015.[[124]](#endnote-124) In December 2014, there were reports of further budget cuts for domestic nuclear projects so more delays are likely. There were even reports that there had been discussions with the Chinese company, CNNC, aimed at them taking part in new-build projects in Russia and third countries.[[125]](#endnote-125) A report by a senior Czech official who had been centrally involved in the attempted procurement of new units for the Temelin site revealed the lack of standardization in the VVER-2006 with different suppliers for different projects (see above).[[126]](#endnote-126)

Without more details of the factors behind the delays it is hard to draw conclusions on the buildability of the AES-2006, although the new design, VVER-TOI does claim to be cheaper and easier to build than AES-2006 suggesting there have been problems. There have been some reports of poor quality materials, corruption and poor quality work, mostly related to the Leningrad project. It is difficult to tell whether this represents a real difference in experience between Leningrad and Novovoronezh or whether Leningrad’s closer proximity to Western Europe means problems are more likely to be made public. The lack of any serious attempt to standardize the design, with each project apparently being designed specifically does mean it is less likely that learning will be an effective way to reduce construction times.

# Comparison of the AP1000 and the EPR

## 8.1 Regulatory reviews

### 8.1.1 EPR

The designs for the EPRs under construction in Finland, France and China have not undergone a comprehensive generic review of the type carried out in the USA and the UK. The EPR was submitted to the UK’s Generic Design Acceptance (GDA) process in 2007 and given a Design Acceptance Certificate in December 2012.[[127]](#endnote-127) The EPR was also submitted to the US NRC in 2007 but in March 2015, AREVA asked the NRC to suspend the review.[[128]](#endnote-128) Press reports then suggested that the earliest approval could be given was 2017.[[129]](#endnote-129) As there were no realistic prospective customers for the EPR in the USA – its best prospect was the Calvert Cliffs project, which collapsed in 2010 - and given its very poor financial condition, AREVA could not justify the resources needed to proceed.

### 8.1.2 AP1000

**The AP1000 received regulatory approval in the USA in December 2011. It was submitted to the UK safety authorities, then Nuclear Installations Inspectorate (NII), now ONR, in 2008. In December 2011, the NII issued an Interim Design Acceptance Certificate, but with 51 issues to be resolved.**[[130]](#endnote-130) **Westinghouse announced it wanted to re-open the process in 2014 but progress has been slow.** Completion of this review is not expected before about 2017.[[131]](#endnote-131)

## 8.2 Cost

**A comparison of the cost of the two designs is difficult because no plant of either design had been completed at time of writing and further cost increases at the sites are highly likely. Outside China, the earliest any Generation III+ reactor is forecast to be complete is 2017. Reliable cost information is hard to come by from China and Russia. Elsewhere, although bid prices are not usually released by the parties to the tender, reasonably reliable reports of them are usually published. In 2007, AP1000 was chosen ahead of EPR for China reportedly because of its “**lower construction cost and greater technology transfer agreed by Westinghouse”.[[132]](#endnote-132)

The next competition between EPR and AP1000 was for South Africa, launched in January 2008 and calling for 3,200 MW to 3,600 MW of new capacity from AREVA and Toshiba-Westinghouse. It was reported that the bids were in the order US$6,000/kW[[133]](#endnote-133) and in November 2008, it was reported that AREVA had won the contest.[[134]](#endnote-134) However, in December 2008, Eskom cancelled the tender citing “the magnitude of the investment”.[[135]](#endnote-135)

In February 2009, EPR and AP1000 (and a Canadian design) bid for two reactors to be constructed in Ontario.[[136]](#endnote-136) In June 2009, the Ontario government suspended the tender citing concerns about pricing. It was reported that AREVA’s bid for one EPR was US$21bn (US$13,000/kW). This was denied by AREVA but they did not reveal the actual figure, nor was the AP1000 bid reported.[[137]](#endnote-137)

In February 2009, the United Arab Emirates (UAE) began the assessment of bids for 5,000 MW of new nuclear capacity including bids for EPR, AP1000, GE-Hitachi’s ABWR and Korea’s APR1400. In July 2009, three bids were selected for assessment including bids for EPR, ABWR and APR1400, but not AP1000. In December 2009, it was announced that the tender had been awarded to the Korean consortium for four APR-1400 units at a price of US$20bn ($3,600/kW). According to Korean media reports, the Korean bid was almost 30 per cent lower per kW than the EPR bid (about US$5,000/kW), while the GE Hitachi offer was said to be higher than the French bid.

It is difficult to conclude much from this history other than that on bid price, EPR may have bid lower than AP1000 (and ABWR) in most cases. In terms of out-turn prices, the lack of reliable cost information and the difficulties of comparing relatively new construction work for the AP1000s in the USA (only two years of construction by March 2015) with long-running construction efforts of 8-10 years in Finland and France mean little can reliably be concluded yet.

## 8.3 Buildability

With 16 out of 18 Generation III+ r**eactors under construction at least a year late the claims that these designs would be less prone to construction delays appear to be in tatters. If we look at the reported factors behind the delays, the picture for EPR and AP1000 is rather different.**

### ****8.3.1 EPR****

**For the EPR at both Olkiluoto and Flamanville, the dominant and persistent issues appear to have been quality problems for on-site work, especially concrete, welds and for Flamanville there have been concerns about accidents at the site, including fatalities. There have also been some quality control problems at component factories, most conspicuously the reactor vessel and the pressuriser valves for Flamanville. The quality problems were initially attributed to lack of skills in Finland, but with the Flamanville site apparently no less problematic, this explanation does not appear credible. From 2009 onwards, the problems of satisfying the regulators with the instrumentation and control design seem to have become a major issue, especially for the Olkiluoto site. There have been some problems with supply chain, for example, delays in delivering equipment at both sites. The Finnish regulator has acknowledged that it should have reviewed the design in much more detail before it allowed construction to start and has continually been critical of both TVO and AREVA for failure to supply information promptly and of the standard required.**

**By contrast, there are no similar problems reported for the Taishan plant with the delay blamed heavily on Taishan having overtaken the Olkiluoto and Flamanville projects and having to carry out a significant number of** first-of-a-kind **activities it did not anticipate. The Chinese regulator did criticize AREVA’s slowness in providing procedures for commissioning that it had to review. EDF is involved in the construction although it is not clear who the architect engineer is, although it is not AREVA.**

**The effective bankruptcy of Areva**[[138]](#endnote-138) **and the possibility of a takeover of the reactor division of AREVA by EDF**[[139]](#endnote-139)**, and the discovery of serious issues with the reactor pressure vessel and the pressuriser safety valves has put the future of the EPR in even greater doubt than before.**

### ****8.3.2 AP1000****

**The US AP1000s started construction 6-8 years after the EPRs in Finland and France. Whether the AP1000s are closer to completion than the EPRs is far from clear. So far, the problems appear to be dominated by supply chain issues, for example reactor coolant pumps and squib valves and NRC has continually had to cite suppliers for their inadequacies. The high level of modularization of equipment was meant to deal with the difficulties of assuring high-quality work on a construction site. However, so far, it seems simply to have shifted the problems from the construction site to suppliers’ facilities.**

**For China, the main problem seems to have also been supply chain, with reactor coolant pumps, squib valves and use of unqualified contractors. As with Taishan, there is criticism by the Chinese regulator of the vendor for not meeting the regulator’s requirement, most recently for late delivery of commissioning procedures. How far the inability to stabilize the design has caused problems is difficult to determine.**

# ****Conclusions****

**The conclusions fall into three categories: Is the claim that Generation III+ designs are more buildable borne out? Are standardization and generic design reviews feasible and useful in reducing construction delays? Is there a future for light water reactors?**

## ****9.1 Are Generation III+ designs more buildable?****

**The claim that Generation III+ designs would be less prone to construction delays than their predecessors does not appear to be borne out. This claim was based on the belief that design complexity was behind a high proportion of the delays that nuclear construction had suffered and that these new designs could, at the same time, be made safer, simpler and cheaper. A second factor believed to cause construction delays, the problems of managing construction sites was to be tackled in some designs by modularization with modules being factory produced, so that site work was minimized. Improved safety was expected to be achieved by greater use of ‘passive’ safety systems that relied only on natural processes rather than the intervention of engineered safety systems.**

**Whether the new designs will be safer has yet to be determined but it has long been clear that the claims of lower cost were unfounded. The target cost of US$1,000/kW has proved grotesquely inaccurate and by 2015, the expected cost was of the order US$8,000/kW. The latest design generation seems more liable to construction delays than its predecessors. There is no evidence that delays due to public opposition or due to the Fukushima disaster or, outside Russia, shortage of finance have played any significant part in the problems experienced.**

**Only three of the many Generation III+ designs announced, the AREVA EPR, the Westinghouse AP1000 and the Russian AES-2006, actually have construction experience, although none of these are on-line yet. Of these designs, there is too little information about the cause of delays with the Russian AES-2006 design to draw strong conclusions about its buildability.**

**While the EPR and the AP1000 are both claimed to be Generation III+, their design and construction philosophy is very different. The AP1000 is a scaled up version of a new design, AP600 that received regulatory approval from the US authorities in 1999 but was never ordered. The design philosophy was based on passive safety measures and large reductions in the number of components needed were made, for example, 80 per cent less pipework than its predecessors. There was extensive use of modularization so that site-work was characterized as simply “onsite module assembly”.**[[140]](#endnote-140)

**The EPR was evolved from two designs, the Siemens Konvoi and the Framatome N4 dating from the 1980s. While AREVA has talked about use of passive safety features, AREVA does acknowledge that there was “**an emphasis on active safety features”. AREVA also claimed **“simplifying system design” was a guiding principle but there is little evidence that there was much if any success in meeting this objective. An official French governmental inquiry into the problems being experienced** found **that: “**The resulting complexity of the EPR… is certainly a handicap for its construction and therefore its cost.”[[141]](#endnote-141) By 2015, AREVA was in the middle of a review, taking 10 years that it was hoped would make the EPR easier and less costly to build, but it is hard to see how this can be achieved given that the existing design was said to have a guiding principle of simplification.

**This difference in design philosophy seems to be reflected in a different profile of construction problems. At the EPR sites there have been a large number of quality control problems, particularly on welding and concrete quality. This may also reflect the loss of skills that the scarcity of nuclear orders in Europe in the last 30 years has resulted in. The problem revealed in April 2015 that there had been a significant error in the fabrication of parts of the reactor pressure vessel for Flamanville and Taishan was by far the most serious manufacturing quality control problem to date.**

**By contrast, the problems with the AP1000 have been more often concerned with quality problems with the factory production of the modules with particular difficulties at the factory of the main module supplier, CB&I. Whether, as construction advances, problems of site-work quality will also arise remains to be seen.**

**For both models, there have been significant design issues. For the EPR, the problem has been convincing the various safety regulators concerned of the adequacy of the back-up system for the instrumentation and control system. For the AP1000, the problem has been that elements of the design, particularly the reactor coolant pump and the squib valves, are not fit for purpose and the pumps shipped to China have had to undergo repeated modification.**

## 9.2 Are standardization and generic design reviews useful?

**Experience also sheds light on two other important issues, standardization and the use of generic safety reviews. These must be considered together as without a standardized ‘frozen’ design, an in-depth review of the design by a regulator would not be possible.**

**For 40 years, the nuclear industry has claimed that standardization would allow cheaper more predictable construction and again, there were claims made that Generation III+ designs would be highly standardized. These claims have not been borne out and nine years after receiving approval from the US NRC the flow of design changes with the AP1000 shows no sign of subsiding.**

**For the EPR, the projects in Finland, China and France will end up with very different instrumentation and control system designs and an authoritative Czech source claimed AREVA had said, “**Only about 50 per cent of their respective nuclear islands are the same”.[[142]](#endnote-142) For the AES-2006, the same source said the design “de facto did not exist”, and that it was “a brand, nothing more”. A new design VVER-TOI has been said to be ready to use since 2012 but has not been ordered.

Part of the problem might be that the technology is not mature enough yet to standardize. The flow of operating information requiring design modifications may be too fast to allow standardization. Another element of the problem may be the very long time-scales involved in commercializing new designs and the very low order rate. It was about 15 years from start of the design process to first order for both the EPR and the AP1000. In that period, neither Westinghouse nor AREVA had won any orders. If we assume the life-span of a reactor design once it is ready to order is, perhaps ten years, if no more than a handful of orders are placed in that period, any benefits from standardization will be heavily diluted.

The issue of generic reviews is related to standardization. Intuitively, if design issues can be sorted out before construction starts, there should be less scope for delays in construction. Given that the only construction sites in a country with generic design reviews, the USA, have seen no more than two years of construction, it is too early draw firm conclusions on whether the use of generic reviews has reduced construction delays. The Finnish regulator acknowledges it should have reviewed the EPR design in much more detail before it allowed work to start on Olkiluoto.

However, a rigorous design review is a lengthy process taking about ten years in the USA and at least five years in the UK. The first orders for both the EPR and the AP1000 were placed in countries that do not require generic detailed design reviews prior to construction. The first orders for AP1000 in the USA would not have been possible until about 15 years after the design process started, while the first orders for the EPR in the UK would not have been possible until about 20 years after the design process started. So regulatory review will add to the already long period from start of design to first commercial orders and will inevitably lead to design changes during the process as new design requirements (for example, protection of the reactor against aircraft impacts) emerge and technical change throws up new design options. The existence of significantly differing national regulatory requirements further limits the scope for standardization.

While the USA has had a requirement for more than 20 years for a generic design review process, it remains largely untested. Four out of five designs that have completed the process were not ordered in the USA while the four reactor orders that have been placed for a certified design are all in the early stages of construction and construction started soon after regulatory approval was given. Over longer periods, would the process still be credible. For example, would an order for an ABWR placed in 2011, a year after Fukushima and a decade after 9/11 have been seen as defensible?

## 9.3 Is there a future for light water reactors?

The sub-text to the Nuclear Renaissance was that it was the last chance for light water reactors. The previous design generations were seen to have become so weighed down with complexity resulting from safety systems that they had become prohibitively expensive, very difficult to build and did not provide the level of safety required. The intuitively plausible idea that the safety systems could be rationalised and simplified was behind the claims for Generation III+ and held out the hope that light water technology could be viable, at least until Generation IV technology became available.

It may be that the problems with Generation III+ designs can be overcome. The EPR, which has little of the passive safety and modularization seen as central to Generation III+ may be a poor design that will have to be abandoned. The difficulties with AP1000 may turn out to be teething problems that will be overcome as the design errors are sorted out and equipment suppliers regain their skills. However, the high cost of AP1000 may mean that even if this does happen, it will be uneconomic.

The world nuclear industry seems to be becoming increasingly dependent on China and Russia to provide markets and to export at affordable prices to emerging markets. Russia claims to have orders or is close to receiving orders for about 20 reactors in markets such as Iran, Turkey, Bangladesh, Vietnam, Hungary, Jordan and Egypt. In several cases, these are markets that other vendors have proved unwilling to bid into. However, Russian designs are unproven and subject to continual design changes. There are also doubts about Russia’s capacity to supply the equipment, the project finance and operate in countries outside its sphere of influence needed to fulfil all these orders. The common assumption is that Russian reactors would be cheaper than reactors supplied by Japanese or European vendors, but that assumption remains untested.

For China, there are ambitious efforts to develop new independent designs but China’s ability to innovate in nuclear design as opposed to essentially copying existing designs remains unproven. There are also concerns about the rigour of its regulatory processes and its quality control and, like Russia, it remains unproven in foreign markets.

It may be too early to write off Generation III+ designs yet but unless projects begin to emerge that do not suffer long construction delays and cost over-runs and until there is some sign of an end to real cost escalation, there must be increasing doubts about these designs.

# Appendix 1 The EPR Instrumentation & Control System

The instrumentation & control system for the EPR has been one of the most problematic design areas and illustrates clearly problems such as achieving standardization and getting generic design approval.

The problem was first publicized in November 2009 when the safety regulatory authorities for Finland, France and UK issued a joint statement expressing concern about the adequacy of the safety systems (those used to maintain control of the plant if it goes outside normal conditions), and their independence from the control systems.[[143]](#endnote-143) The main issue seems to be that AREVA was proposing a back-up digital system to the digital main system and there was a fear that a common fault could knock out both systems. The problem is often portrayed as a requirement, especially by the Finnish and US regulators, for an analogue back-up system although it is probably more accurate to say the need is a for a ‘diverse’ back-up system.

The statement claimed: ‘as designs are similar, it is likely that the solution will be similar, although not necessarily identical, taking into account individual licensees' requirements and national regulatory requirements or practices.’ It also claimed: ‘This is a good example of how independent regulators working closely together can promote a shared understanding and application of existing international standards, and promote the harmonization of regulatory standards and the build of reactor designs with the highest levels of safety.’ There is no information in the public domain about how far the instrumentation & control design has been a problem in China and how the problem has been tackled. The Chinese safety authorities and the US NRC were not signatories to the November 2009 letter to AREVA.

## Finland

The Olkiluoto project was then the most advanced EPR, on the original schedule, it should already have been in service by then, and so a resolution of the problem appeared most urgent there. The issue had already surfaced in Finland, but in May 2009, STUK had expressed confidence that the architecture of the system would be approved in June of that year. The head of STUK, Jukka Laaksonen, had expressed some dissatisfaction with AREVA claiming that AREVA personnel sent to Finland ‘appeared not to know enough about the subject.’[[144]](#endnote-144)

In June 2010, it was reported that STUK had repeatedly asked for additional testing and documentation on the system and has been concerned about how various components would interact with one another. This was cited as one of the reasons behind an expected further delay in completion of the plant from mid-2012 to mid-2013.[[145]](#endnote-145) In October 2011, STUK said it was waiting for more documentation of Olkiluoto-3's digital instrumentation & control architecture, and testing of the instrumentation & control could not go ahead until it was received.[[146]](#endnote-146) In April 2012, STUK claimed the main issues with the instrumentation & control system would be resolved by June of that year.[[147]](#endnote-147) In September 2013, STUK said it expected to finish its final review of the digital instrumentation and control architecture for Olkiluoto-3 in about a month.[[148]](#endnote-148) In April 2014, STUK said April 10 it had approved the architecture for Olkiluoto-3's digital instrumentation and control system but that some modifications should be done to make the system more robust against failure.[[149]](#endnote-149)

## France

The French regulator has generally been seen as less difficult to satisfy than the other regulators in respect to the instrumentation & control system despite them signing up to the November 2009 letter. Nevertheless, in August 2010, ASN, the French regulator asked EDF to modify the architecture of the non-safety instrumentation and control system on the Flamanville-3 EPR ‘in order to improve the robustness’ of the system, although the changes were described as minor.[[150]](#endnote-150) In April 2012, ASN said that changes EDF has made to the instrumentation and control architecture of the Flamanville-3 nuclear reactor unit were ‘satisfactory’ and allowed it to lift the hold ASN had placed in October 2009 on use of the system.[[151]](#endnote-151)

## UK

After the letter of November 2009, there were few reports on the UK’s review of the EPR instrumentation & control until December 2011 when the NII issued an Interim Design Acceptance Certificate with 31 issues still to be resolved including six related to the instrumentation & control system. In its quarterly review, the NII used a traffic light system to show the status of the efforts to resolve these issues. Grey represented issues already resolved while red signals signified ‘closure of the GDA Issue is in serious doubt with major risks apparent.’ By the end of June, four of the six instrumentation & control issues were in the red category and the other two were amber (‘closure of the GDA Issue appears feasible but significant risks exist requiring prompt attention’).[[152]](#endnote-152) Despite this, by December, all the issues had been resolved and NII issued a final Design Acceptance Certificate.

## USA

In April 2010, the NRC extended its forecast completion of its generic review of the EPR by four months to June 2012 with instrumentation & control as one of eight areas that would not be complete on time.[[153]](#endnote-153) In July 2010, AREVA announced it was modifying its US-EPR reactor design to respond to NRC staff concerns that the digital instrumentation and control system was too complex and interconnected to meet US regulations.[[154]](#endnote-154) In December 2011, it was reported that the NRC approved the design for the instrumentation & control.[[155]](#endnote-155) However, in July 2013, the NRC told AREVA instrumentation & control design did not meet regulatory requirements, saying unneeded complexity in the system was preventing the company from showing it complies with agency regulations. The forecast completion date for the review of December 2014 was withdrawn and since then, AREVA has decided not to pursue NRC approval.[[156]](#endnote-156)

# Appendix 2 Other Generation III+ designs

There are a large number of designs that might be categorized as Generation III+, but here we only consider those that either have immediate sales prospects or which are undergoing detailed design review by an open and experienced regulatory body.

## ABWR

The Advanced Boiling Water Reactor (ABWR) is often quoted as a Generation III+ design. However, the design that has been built or is under construction is one that predates the Chernobyl disaster and is more accurately seen as Generation III. An upgraded design did get generic approval from the NRC in 1997 but that upgraded design was never ordered. This approval expired in 2012 and the two companies offering the design, GE-Hitachi and Toshiba have submitted updated designs to the NRC. However, approval has yet to be given and in March 2015, the NRC had no forecast date for completion either of the reviews. There is no early prospect for US orders for either vendor’s version of the ABWR. An updated design, targeted at European markets has also been submitted to the UK safety authorities but this is still at least 3 years away from approval and no orders have been placed. Nevertheless, the ABWR is being actively considered in a number of markets worldwide.

## ESBWR

The Economic Simplified Boiling Water Reactor (ESBWR) developed by GE-Hitachi was one of the first of the new designs to be proposed. It was portrayed as being a radical new design.[[157]](#endnote-157) Publicity material for it claimed it: ‘can safely cool itself with no AC power or operator action for more than seven days’ and ‘using natural circulation, it uses 25 per cent fewer pumps and mechanical drives than existing acting safety plants.’ The design has only seen significant buyer interest in the USA and none of the potential US buyers seems likely to go ahead with its high cost seen as one of the major barriers. The two remaining customers are DTE Electric to build a plant in Michigan (Fermi) and Dominion to build a plant in Virginia (North Anna) but by March 2015, neither was close to making a decision whether to proceed. Nevertheless, in October 2014, the NRC did complete its review and gave it final approval in November 2014.[[158]](#endnote-158) The UK ONR did begin a generic review of the ESBWR in 2008, but GE-Hitachi withdrew the design from the process within a year.

## APWR

The Mitsubishi Advanced Pressurized Water Reactor (APWR), like the ABWR has its origins in Japan in the early 1980s but despite continual forecasts of orders a year or two ahead, it has never been ordered for the Japanese market. It was submitted to the US NRC but its only potential customer is highly unlikely to proceed and in March 2014, at Mitsubishi’s request, work was suspended.[[159]](#endnote-159)

## APR1400

This design is offered by Korea Electric Power Company (KEPCO) and is based on a design, System 80+ offered by Combustion Engineering (now part of Toshiba-Westinghouse) which received NRC approval in 1997. It was never seriously marketed in the USA and Toshiba-Westinghouse is not going to market the design. Four reactors of this design are under construction in Korea and three are under construction in the UAE with a fourth expected to start construction in 2015. Anne Lauvergeon, then CEO of AREVA was highly critical of the design following its adoption for UAE ahead of AREVA’s EPR describing it as like buying ‘a car without air bags and safety belts.’[[160]](#endnote-160) KEPCO acknowledges the design needs to be upgraded to meet European and US standards.[[161]](#endnote-161)

In September 2013, KEPCO submitted an application to NRC for a review of their upgraded design, but in December 2013 NRC told KEPCO ‘it would not accept the APR1400 design for review because more information is needed from the applicant on a variety of issues.’[[162]](#endnote-162) A revised submission was made in December 2014 and in March 2015, this was accepted allowing the review process to start. No schedule was then published.[[163]](#endnote-163) Despite this, APR1400 has no immediate sales prospects in Europe or USA.

## Chinese designs

It soon became clear to the Chinese builders after the placing of orders for imported Generation III+ that building EPRs and AP1000s in China at an affordable cost might not be possible. The Chinese government had made a firm policy decision to move to reactor designs meeting Generation III+ standards so the three Chinese reactor vendors began to develop their own Generation III+ designs for their home market but also for export markets like Pakistan, South Africa and the UK.

The State Nuclear Power Technology Corporation (SNPTC), partner to Toshiba-Westinghouse for the Chinese AP1000s is developing the CAP1400, a scaled up AP1000. China was predicting first orders for this design will be placed for China in 2015 for the Shandong site but these may be delayed[[164]](#endnote-164) and it is being offered for export to South Africa[[165]](#endnote-165) and Turkey[[166]](#endnote-166). It is claimed the design has been approved by the NNSA, but it is not clear how in-depth this review was. In November 2014, there were reports the CAP1400 would be built at the Shidao Bay site, although this might be delayed by regulatory concerns about the reactor coolant pump.[[167]](#endnote-167) China General Nuclear (CGN, previously China Guangdong Nuclear) is a long-time partner to AREVA and participated in the Daya Bay project to build two PWRs supplied by Framatome (AREVA’s predecessor) in the 1980s. Its advanced design, ACPR1000 has been proposed for some sites in China and in March 2015, construction of Hongyanhe-5 started, using the ACPR1000 design.[[168]](#endnote-168) China National Nuclear Corporation (CNNC) has also collaborated with AREVA and has its own Generation III+ design, ACP1000. It has reportedly been ordered for export to Pakistan but by March 2015, no construction work had started and it was expected the CNNC version of Hualong One would be used.[[169]](#endnote-169) In October 2014, a court order barred Pakistan Atomic Energy Commission (PAEC) from continuing work on the two proposed new nuclear reactors.[[170]](#endnote-170) As with ACPR1000, it has been proposed for sites in China but it is not clear how many of these will go ahead.

The Chinese government has been trying to force greater cooperation between CNNC and CGN given the close similarities between their designs, including the possibility of a merger. The Chinese government is requiring the two companies to ‘merge’ their advanced designs and the ‘Hualong One’ design is the result, although there is now speculation that CNNC and CGN will offer their own versions of this design.[[171]](#endnote-171) In May 2015, first structural concrete was poured for Fuqing 5[[172]](#endnote-172) which will house the first CNNC Hualong One design.[[173]](#endnote-173) In November 2014, the CGN version of Hualong One was expected to be built for Fangchanggang 3 and 4.[[174]](#endnote-174)

Both CNNC and CGN are projected to be investors in the consortium to build the UK Hinkley Point C plant taking 40 per cent of the consortium.[[175]](#endnote-175) They are reported to see this participation as a prelude to selling Chinese designed reactors in the UK.[[176]](#endnote-176) Nevertheless, this must still be seen as no more than a long-term prospect given that China is still in the early stages of proving it is a credible reactor exporter.[[177]](#endnote-177)

**Table 1 Summary of status of Generation III+ construction projects**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Plant** | **Country** | **Technology** | **Construction start[[178]](#endnote-178)** | **Construction completion at construction start** | **Forecast construction completion at 3/15** | **Forecast cost at construction start** | **Latest forecast cost** |
| Olkiluoto 3 | Finland | EPR | 5/05 | 5/09 | Late 2018[[179]](#endnote-179) | €3-3.2bn[[180]](#endnote-180) | €8.5bn |
| Flamanville 3 | France | EPR | 12/07 | 5/12 | 2017[[181]](#endnote-181) | €3.2bn | €8.5bn |
| Taishan 1 | China | EPR | 11/09 | 2/14 | 12/15 | €4bn[[182]](#endnote-182) |  |
| Taishan 2 | China | EPR | 4/10 | 8/14 | 2016 | €4bn |  |
| Sanmen 1 | China | AP1000 | 4/09 | 8/13 | Mid 2016 | $1940/kW[[183]](#endnote-183) | 20 per cent over budget |
| Sanmen 2 | China | AP1000 | 12/09 | 8/14 | 6/16 | $1940/kW | 20 per cent over budget |
| Haiyang 1 | China | AP1000 | 9/09 | 5/14 | 3/16 | $1940/kW | 20 per cent over budget |
| Haiyang 2 | China | AP1000 | 6/10 | 2/15 | 9/16 | $1940/kW | 20 per cent over budget |
| Summer 2 | USA | AP1000 | 3/13 | 3/16 | 6/19[[184]](#endnote-184) | $5.2bn | $6.2bn[[185]](#endnote-185) |
| Summer 3 | USA | AP1000 | 11/13 | 11/18 | 6/20 | $5.2bn | $6.2bn |
| Vogtle 3 | USA | AP1000 | 3/13 | 4/16 | 2nd q 2019[[186]](#endnote-186) | $6.65bn | $8.15bn[[187]](#endnote-187) |
| Vogtle 4 | USA | AP1000 | 11/13 | 1/18 | 2nd q 2020[[188]](#endnote-188) | $6.65bn | $8.15bn |
| Leningrad 2-1 | Russia | AES-2006 | 10/08 | 2013 | 2016[[189]](#endnote-189) |  |  |
| Leningrad 2-2 | Russia | AES-2006 | 4/10 | 2015 | 2018[[190]](#endnote-190) |  |  |
| Novovoronezh 2-1 | Russia | AES-2006 | 6/08 | 2013 | 2016[[191]](#endnote-191) |  |  |
| Novovoronezh 2-2 | Russia | AES-2006 | 7/09 | 2014 | 2018[[192]](#endnote-192) |  |  |
| Belarusian 1 | Belarus | AES-2006 | 11/13 | 2018[[193]](#endnote-193) | 2018[[194]](#endnote-194) | $6.5bn | $11.45bn[[195]](#endnote-195) |
| Belarusian 2 | Belarus | AES-2006 | 4/14 | 2020 | 2020[[196]](#endnote-196) | $6.5bn | $11.45bn |

Source: See endnotes

**Table 3 Timetable of problems at Olkiluoto 3**

|  |  |
| --- | --- |
| **Date** | **Event** |
| 4/04 | STUK: ‘We are getting the documents late. They (AREVA) aren’t reserving enough time for our review and they don’t have all the information required by our guides.’[[197]](#endnote-197) |
| 10/05 | Pouring of base slab delayed by concerns about strength of concrete. Manufacturing of reactor pressure vessel and steam generators “a few weeks” behind the original schedule[[198]](#endnote-198) |
| 2/06 | Problems with qualifying pressure vessel welds and delays in detailed engineering design put construction more than six months behind schedule[[199]](#endnote-199) |
| 3/06 | STUK opened an investigation into manufacturing and construction problems[[200]](#endnote-200) |
| 5/06 | Despite measures including two shifts on site and three shifts at AREVA’s component manufacturing plant, work is eight to nine months behind schedule.[[201]](#endnote-201) |
| 7/06 | TVO acknowledges delay now 1 year. STUK investigation: An extremely tight budget and timetable, supplier inexperience, poor subcontractor control and regulators’ difficulty in assessing information have caused confusion and quality control problems that have delayed the Olkiluoto-3 project[[202]](#endnote-202) |
| 10/06 | AREVA takes provision of ca €300m for Olkiluoto project[[203]](#endnote-203) 3 out of 4 ‘hot legs’ not made to specification. [[204]](#endnote-204) Project manager replaced [[205]](#endnote-205) |
| 12/06 | Delay estimated at 18 months[[206]](#endnote-206) |
| 1/07 | AREVA: AREVA-Siemens cannot accept 100 per cent compensation responsibility, because the project is one of vast co-operation. The building site is joint so we absolutely deny 100 per cent compensation principle’ TVO: ‘I don’t believe that AREVA says this. The site is in the contractor’s hands at the moment. Of course, in the end, TVO is responsible of what happens at the site. But the organization of the project is AREVA’s responsibility’[[207]](#endnote-207) |
| 5/07 | TVO and AREVA agree design not complete enough when contract signed. STUK: ‘a complete design would be the ideal. But I don’t think there’s a vendor in the world who would do that before knowing they would get a contract. That’s real life.[[208]](#endnote-208) |
| 8/07 | Problems meeting requirements to withstand an airplane crash mean delay 2 years[[209]](#endnote-209) |
| 9/07 | Steel containment liner repaired in 12 places to fix deformations and weld problems[[210]](#endnote-210) AREVA acknowledges further financial provisions for losses but does not quantify them. Independent estimate €500-700m[[211]](#endnote-211) |
| 6/08 | TVO site manager replaced[[212]](#endnote-212) |
| 10/08 | Delay now estimated at 3 years[[213]](#endnote-213) Manufacturer of containment liner failed to obey an order to stop welding after a STUK-TVO inspection discovered that an incorrect welding procedure was being used[[214]](#endnote-214) AREVA initiates arbitration proceedings in Arbitration Institute of the Stockholm Chamber of Commerce over ‘a technical issue’[[215]](#endnote-215) |
| 12/08 | AREVA announces further loss provisions. Independent estimates €1.3bn[[216]](#endnote-216) |
| 12/08 | Letter from STUK Director General top CEO AREVA: ‘I cannot see real progress being made in the design of the control and protection systems.’ ‘This would mean that the construction will come to a halt and it is not possible to start commissioning tests.’ ‘the attitude or lack of professional knowledge of some persons who speak in the expert meetings on behalf of that organization prevent to make progress in resolving the concerns’[[217]](#endnote-217) |
| 1/09 | Delay acknowledged to be 3.5 years.[[218]](#endnote-218) Siemens announces withdrawal from AREVA.[[219]](#endnote-219) AREVA-Siemens file a second arbitration proceeding against TVO.[[220]](#endnote-220) AREVA asking for €1bn in compensation. TVO counterclaiming for €2.4bn for ‘gross negligence’[[221]](#endnote-221) TVO expects arbitration to take several years[[222]](#endnote-222) |
| 3/09 | AREVA admits cost over-run now €1.7bn[[223]](#endnote-223) |
| 06/10 | TVO reports further delay till 2013 to completion of the plant.[[224]](#endnote-224) Delay confirmed by AREVA[[225]](#endnote-225) |
| 07/10 | AREVA booked €367m in new charges on expected losses with Olkiluoto.[[226]](#endnote-226) |
| 11/10 | TVO reports operation would be delayed till 2nd half 2013 but this was denied by AREVA[[227]](#endnote-227) |
| 10/11 | TVO reports the completion would be delayed to 2014[[228]](#endnote-228) |
| 10/11 | Finnish nuclear regulators waiting for more documentation of Olkiluoto-3’s digital instrumentation and control architecture. Testing of the I&C cannot go ahead until it is received[[229]](#endnote-229) |
| 3/12 | AREVA announces fresh provision of €220m for losses due to cancellation of a contract with a “large subcontractor” responsible for pipework and transfer of that work to the “main contractor.” “Some difficulties with components” for the plant also acknowledged[[230]](#endnote-230) |
| 5/12 | STUK forecasts that the issue of design of I&C systems would be resolved in June 2012. It acknowledged STUK ‘should have focused on the I&C more intently and earlier and that “we shifted too much [of the design review] to the construction phase.”’[[231]](#endnote-231) |
| 7/12 | TVO revises the expected completion date to 2015. TVO based this on information from the AREVA/Siemens consortium that ‘factory testing of the [instrumentation and control] system is not going to happen according to the previous schedule.’ AREVA said TVO was responsible for delays in supporting “specific I&C tasks to be performed together in order to optimize this sensitive and crucial milestone of the project,” as part of a “shared process to consolidate the OL3 schedule” on which the parties agreed in December 2011. STUK confirmed “The [I&C] design is not approved yet,” “We haven’t yet seen final documentation about the diversity of different [I&C] platforms.”[[232]](#endnote-232) |
| 2/13 | TVO announces a delay of completion till 2016, although AREVA claimed completion was still due in 2014[[233]](#endnote-233) |
| 9/13 | STUK announced it expected to complete the review of the I&C system in about a month (Oct 2013)[[234]](#endnote-234) |
| 2/14 | AREVA denies it is closing the Olkiluoto site but it is ‘adjusting the workforce’ as it focuses ‘its engineering resources on  the critical project milestones’[[235]](#endnote-235) |
| 4/14 | STUK said that they have approved the architecture for Olkiluoto-3’s digital instrumentation and control system but that some modifications should be done to make the system more robust against failure.[[236]](#endnote-236) |
| 9/14 | AREVA puts back scheduled completion till 2018. TVO claims the plant could be completed earlier but no longer has a start-up schedule. The delay was blamed on the I&C system and on a commissioning phase expected to take 2 years[[237]](#endnote-237) |
| 4/15 | STUK asks TVO to carry out new tests on the Reactor Pressure Vessel even though, unlike Flamanville, it was not supplied by AREVA[[238]](#endnote-238) |

Source: See endnotes

**Table 4 Timetable of problems at Flamanville 3**

|  |  |
| --- | --- |
| **Date** | **Event** |
| 12/07 | First concrete poured[[239]](#endnote-239) |
| 3/08 | ASN asks EDF to improve work in several areas involving in particular quality control and organization[[240]](#endnote-240). Inspection had revealed several problems in the civil construction work carried out by Bouygues, including errors in installation of steel reinforcing bar in the concrete and “inconsistency” between rebar blueprints and the concrete pouring plan. Cracks in concrete repaired using resin. Organization for preparing concrete pouring was “insufficient,”[[241]](#endnote-241) |
| 5/08 | ASN requires EDF to stop concrete pouring on May 26 (ban lifted June 17). Problems ‘show insufficient discipline on the part of the licensee and insufficient project organization’. Welding anomalies found in one of the four bottom pieces of the steel liner of the containment building [[242]](#endnote-242) |
| 10/08 | ASN told AREVA to improve its oversight of forgings after procedures used by Italian subcontractor Societe della Fucine were found not to conform to standards.[[243]](#endnote-243) |
| 12/08 | EDF acknowledges cost had increased to €4bn due mainly to inflation, and technical & regulatory changes.[[244]](#endnote-244) Construction schedule claimed still to be achievable |
| 2/09 | ASN found problems with reactor’s concrete shell, e.g., steel reinforcement bars that should have been on either side of a penetration in the shell were not in place[[245]](#endnote-245) |
| 01/10 | Unions claim construction is at least 2 years behind schedule and completion would be 2014.[[246]](#endnote-246) |
| 07/10 | EDF confirms delay and announces expected costs are €1.7bn over budget.[[247]](#endnote-247) |
| 08/10 | ASN asks EDF to modify the architecture of the non-safety instrumentation and control system.[[248]](#endnote-248) |
| 09/10 | Bouygues, the main civil contractor claims EPR has ‘complex ergonomics and an ‘extremely difficult implementation’[[249]](#endnote-249) |
| 4/11 | ASN confirms investigation into under-reporting of accidents at the Flamanville 3 construction site with allegations of 1 in 4 accidents not being reported[[250]](#endnote-250) |
| 7/11 | ASN reported “weaknesses” in EDF’s measures for ensuring quality control of studies and manufacturing related to the Flamanville-3[[251]](#endnote-251) |
| 7/11 | EDF announces further 2 year delay to completion till 2016 with estimated cost increased to €6bn. It stated it had underestimated the amount of the work still to be done, particularly in civil engineering. It added that two serious accidents resulting in two deaths had stopped civil works for weeks early this year[[252]](#endnote-252) |
| 9/11 | ASN requires EDF to improve the quality of concrete work after defects in the pouring of concrete panels for the reactor pit and other safety-related structures were found[[253]](#endnote-253) |
| 11/11 | ASN required welding of 105 new adapter nozzles to the reactor vessel closure head to be redone because of multiple defects[[254]](#endnote-254) |
| 4/12 | ASN approved changes EDF has made to the I&C architecture allowing it to lift the hold ASN had placed in October 2009 on use of the system[[255]](#endnote-255) |
| 6/12 | EDF acknowledges delay in lifting reactor head from summer 2012 to 2013[[256]](#endnote-256) |
| 12/12 | EDF announces cost estimate increased to €8.5bn. It cites first-of-a-kind effects, changes in reactor design, supplementary engineering studies, integration of new regulatory requirements, and lessons from the Fukushima accident in Japan. It also includes additional expenditures associated with problems encountered in the construction project, such as the need to replace 45 consoles that support the circular polar crane in the reactor building. Pouring of concrete on the nuclear island was suspended pending resolution of the problem. Reactor dome lifting scheduled for Jan/Feb 2013[[257]](#endnote-257) |
| 7/13 | Reactor dome installed, a year late[[258]](#endnote-258) |
| 12/13 | EDF forced to halt planned installation of major reactor components, including the reactor pressure vessel. ASN and the Labour Ministry asked EDF to halt further installations until it had addressed safety concerns about a crane setup that will be used to lower Flamanville-3’s reactor vessel into place[[259]](#endnote-259) |
| 11/14 | Completion put back to 2017 due to delays to the delivery of equipment, including the lid and other internal structures for the reactor vessel, as well as delays encountered assembling specialized high-pressure equipment. New cost estimates expected in a few months. AREVA notified EDF of welding issues on the steam generators and gave updates on testing carried out on pressurizer valves as well as material testing on the reactor lid[[260]](#endnote-260) |
| 3/15 | Bouygues fined by a French court for using illegal workers at the work site[[261]](#endnote-261) |
| 4/15 | ASN announces defects had been found in the reactor pressure vessel. Further tests were required to determine whether construction could proceed, or repairs would be required or construction would have to be abandoned.[[262]](#endnote-262) |
| 6/15 | A leaked IRSN document identifies issues with the pressuriser safety valves. Test revealed ‘unexpected behavior, including a failure to open at the expected pressure.’[[263]](#endnote-263) |
| 6/15 | New weld defects reportedly detected in the primary circuit[[264]](#endnote-264) |

Source: See endnotes

**Table 5 Timetable of problems at Taishan**

|  |  |
| --- | --- |
| **Date** | **Event** |
| 10/09 | First structural concrete for unit 1 poured in October 2009[[265]](#endnote-265) |
| 4/10 | First structural concrete for unit 2 poured in April 2010[[266]](#endnote-266) |
| 7/10 | Delay to start of building work for second phase reported, but no reason specified[[267]](#endnote-267) |
| 6/11 | TNPC claims Taishan 1 is on course for commercial operation in December 2013[[268]](#endnote-268) |
| 6/11 | Reactor dome installed two years before Flamanville[[269]](#endnote-269) |
| 1/14 | Chinese official acknowledges Taishan units are 15 months (unit 1) and 13 months late (unit 2) in presentation to IAEA but no explanation for delays[[270]](#endnote-270) |
| 1/14 | Fuel loading at unit 1 with connection to grid end 2015, a further delay of about 9 months[[271]](#endnote-271) |
| 3/14 | Representative of National Nuclear Safety Administration (Li Jijen) said AP1000 units expected to begin commissioning process at the end of this year [2014] or in early 2015, while “there are only a small amount of commissioning test procedures” developed, and no acceptance criteria submitted for review. Reviewing test data in connection with the acceptance criteria can take six months, he said. The same issue affects the Chinese project at Taishan to build two AREVA EPR reactors, Li said.[[272]](#endnote-272) |
| 3/14 | Speculation that factors behind delay are mainly to do with Taishan now being the most further forward EPR project; testing first of a kind equipment; supply chain conflicts; extra regulatory workload; start-up procedures not tested elsewhere[[273]](#endnote-273) |
| 4/15 | Chinese Environment Ministry states fuel will not be loaded into Taishan until safety issues about the reactor pressure vessels had been resolved.[[274]](#endnote-274) |

Source: See endnotes

**Table 6 Timetable of problems at Haiyang and Sanmen**

|  |  |
| --- | --- |
| **Date** | **Event** |
| 4/09 | First structural concrete at Sanmen 1 |
| 9/09 | First structural concrete at Haiyang 1 |
| 12/09 | First structural concrete at Sanmen 2 |
| 6/10 | First structural concrete at Haiyang 2 |
| 12/10 | Westinghouse official acknowledges delays but claims they had been recovered and no cost overrun. These were due to design changes, and some due to delays in equipment manufacturing. “We started behind schedule [in installing major equipment], and we were six months behind at one point,” But as of late November, Sanmen-1 had “basically recovered the six-month delay in setting the containment vessel bottom head.[[275]](#endnote-275) |
| 9/11 | Delivery of canned reactor coolant pumps, first of a kind equipment, delayed by problems of overheating in long-term endurance test. No delay to the schedule expected[[276]](#endnote-276) |
| 1/12 | SNPTC admits delays of 6-12 months blaming Westinghouse’s design adjustments even during construction[[277]](#endnote-277) |
| 3/12 | SNPTC claims construction back on schedule after earlier delays[[278]](#endnote-278) |
| 4/12 | Curtiss-Wright announces completion of testing of reactor coolant pumps with delivery expected in 2nd quarter 2012[[279]](#endnote-279) |
| 8/13 | Reactor coolant pumps shipped to Sanmen from US to China following replacement of the impeller[[280]](#endnote-280) |
| 1/14 | Chinese official acknowledges Sanmen 24 months late and Haiyang 18-22 months late citing: engineering completion behind schedule; Westinghouse not familiar with China regulations; on shore design team with insufficient authority to handle basic design changes; insufficient support for regulatory review from off shore team. Particular problems: reactor coolant pump impeller: irregularities welded without documentation; squib valve: supplier uses components & sub-contractor without nuclear equipment qualification[[281]](#endnote-281) |
| 2/14 | Westinghouse seeks damages of US$25m from Curtiss-Wright after defective parts forced pumps already shipped to China to be returned to the US for re-manufacturing. To be reshipped in 2-4 quarter 2014[[282]](#endnote-282) |
| 3/14 | NNSA says late design changes and component failures have delayed completion Delays now 30 months. Pressurizer support columns require repair and upgrade required for lateral supports of the steam generators. Only a small amount of commissioning test procedures developed, and no acceptance criteria submitted for review.[[283]](#endnote-283) |
| 6/14 | Further delays acknowledged at Sanmen due to reactor coolant pump problems[[284]](#endnote-284) |
| 9/14 | Intergovernment talks involving US National Security Council (NSC) and China’s National Energy Administration (NEA) in progress over several months to push Westinghouse to address quality assurance issues, e.g. for reactor coolant pumps and squib valves, described by a Chinese official as occurring at an “alarming rate”[[285]](#endnote-285) |
| 11/14 | Curtiss-Wright admits pumps will not be shipped back before 2015[[286]](#endnote-286) |
| 2/15 | Testing of modified pumps still ongoing. Shipment expected June 2015[[287]](#endnote-287) |

Source: See endnotes

**Table 8 Timetable of problems at Vogtle**

|  |  |
| --- | --- |
| **Date** | **Event** |
| 6/12 | Independent construction monitor for Georgia PSC says original completion dates for no longer achievable. First unit delayed from Apr 2016 to Nov 2016 and second unit from Apr 2017 to Nov 2017. But dates do not consider delays in pouring concrete and additional problems fabricating parts[[288]](#endnote-288) |
| 8/12 | Westinghouse/Shaw sue plant owners for US$29m over added costs of backfilling the excavation sites for the two reactors’ nuclear islands[[289]](#endnote-289) |
| 11/12 | NRC cites Enertech, part of Curtiss-Wright Corp., for violation and non-conformances with regulations for check valves used in the passive cooling system[[290]](#endnote-290) |
| 11/12 | Litigation between co-owners and Westinghouse and CB&I on who should bear financial responsibility for design changes to the shield building and modular concept required by the Nuclear Regulatory Commission, and delays in installing reinforcing steel[[291]](#endnote-291) |
| 12/12 | Georgia PSC’s independent construction monitor warns of 2-4 year delay criticizing contractors for managing the project on a six-month basis[[292]](#endnote-292) |
| 12/12 | 880-ton railcar carrying a 330-ton reactor pressure vessel to Vogtle site malfunctioned less than a mile from the port of Savannah, Georgia, where the RPV had been unloaded after shipment from Korea[[293]](#endnote-293) |
| 12/12 | Target to pour first concrete missed due to delays delivering modules[[294]](#endnote-294) |
| 2/13 | NRC has expanded its review of the squib valves supplied by SPX following a failure of a test sample to fire an explosive charge used to actuate the valves[[295]](#endnote-295) |
| 3/13 | First structural concrete at unit 1[[296]](#endnote-296) |
| 4/13 | Shaw Group forced to turn over documents related to an investigation of possible falsification of documents at its modular fabrication business to NRC[[297]](#endnote-297) |
| 4/13 | NRC ordered CB&I to submit plan in 30 days to improve safety-conscious work environment, investigate why management did not respond more forcefully to resolve issues[[298]](#endnote-298) |
| 11/13 | First structural concrete at unit 2[[299]](#endnote-299) |
| 11/13 | NRC cited Newport News International fabricator of steel-concrete modules for the shield buildings non-conformance with quality assurance regulations[[300]](#endnote-300) |
| 11/14 | Georgia Public Service Commission says Vogtle faces scheduling delays and cost escalation due to failure to meet target dates in May 2014 Integrated Project Schedule[[301]](#endnote-301) |
| 1/15 | Southern Co. reported an 18 month delay US Securities and Exchange Commission with additional US$700m costs[[302]](#endnote-302) |
| 3/15 | US appeals court rules in favour of hearing Georgia Power’s case over Westinghouse over US$900m breach of contract on who should bear responsibility for additional work including design changes to the shield building and modular concept required by the NRC and delays in installing reinforcing steel, or rebar[[303]](#endnote-303) |
| 5/15 | Georgia Public Service Commission expects additional delays due to site erection problems[[304]](#endnote-304) |

Source: See endnotes

**Table 9 Timetable of problems at Summer**

|  |  |
| --- | --- |
| **Date** | **Event** |
| 11/12 | NRC cites Enertech, part of Curtiss-Wright Corp., for violation and non-conformances with regulations for check valves used in the passive cooling system[[305]](#endnote-305) |
| 2/13 | NRC has expanded its review of the squib valves supplied by SPX following a failure of a test sample to fire an explosive charge used to actuate the valves[[306]](#endnote-306) |
| 3/13 | First structural concrete at unit 1[[307]](#endnote-307) |
| 4/13 | Shaw Group forced to turn over documents related to an investigation of possible falsification of documents at its modular fabrication business to NRC[[308]](#endnote-308) |
| 4/13 | NRC ordered CB&I to submit a plan within 30 days to improve the safety-conscious work environment of the facility and an investigation of why management did not respond more forcefully to resolve the issues[[309]](#endnote-309) |
| 6/13 | Delays of about 6 months announced due to problems at CB&I’s Lake Charles manufacturing facility[[310]](#endnote-310) |
| 8/13 | Construction reported to be 7 months behind schedule, mainly due to schedule changes attributable to contractors Westinghouse and CB&I[[311]](#endnote-311) |
| 11/13 | First structural concrete at unit 2[[312]](#endnote-312) |
| 11/13 | NRC cited Newport News International fabricator of steel-concrete modules for the shield buildings non-conformance with quality assurance regulations[[313]](#endnote-313) |
| 8/14 | Westinghouse admits unit 1 not likely to be complete before late 2018 or early 2019 with unit 2 a year later. South Carolina Electric & Gas did not accept the delay. Blame for delays placed on CB&I module fabrication facility[[314]](#endnote-314) |
| 2/15 | Inadvertent damage to the containment vessel at the first unit.[[315]](#endnote-315) NRC opens a special inspection CBI workers ‘cut some safety-related rebar and damaged the containment vessel bottom head while drilling into concrete’[[316]](#endnote-316) |
| 3/15 | Cost estimate increased to US$6.2bn per reactor and completion delayed by more than 2 years. Due to delays in production and delivery of structural sub-modules at the CB&I facility in Lake Charles and shield building panels at the Newport News Industries facilities.[[317]](#endnote-317) |
| 4/15 | NRC propose fine of $11,200 for CB&I after its management tried to cover up the dropping of a prefabricated building section in March 2013.[[318]](#endnote-318) |

Source: See endnotes

**Table 10 Timetable of problems at Novovoronezh-2 and Leningrad-2**

|  |  |
| --- | --- |
| **Date** | **Event** |
| 6/08 | First structural concrete at Novovoronezh 2-1 |
| 10/08 | First structural concrete at Leningrad 2-1 |
| 7/09 | First structural concrete at Novovoronezh 2-2 |
| 4/10 | First structural concrete at Leningrad 2-2 |
| 1/11 | Local court orders 40 day halt to construction at Leningrad due to fire safety and sanitary violations[[319]](#endnote-319) |
| 7/11 | Steel structures for containment building collapse requiring 1200 tonnes of reinforcing steelwork to be dismantled to rebuild the destroyed wall of the containment building at Leningrad[[320]](#endnote-320) |
| 10/11 | Construction license renewed for Leningrad following 1 month suspension[[321]](#endnote-321) |
| 2/12 | Rosatom subsidiary, ZiO Podolsk, supplier to Leningrad 2 and Novovoronezh 2 accused by Federal Prosecutor ‘buying low quality raw materials on the cheap and pocketing the difference’[[322]](#endnote-322) |
| 2/13 | Dry shielding installed at Novovoronezh 2-1. Expected completion 2014 for unit 1 and 2015 for unit 2[[323]](#endnote-323) |
| 6/14 | Reactor pressure vessel positioned at Leningrad 2-1. Expected completion 2016 for unit 1 and 2018 for unit 2[[324]](#endnote-324) |
| 1/15 | Russia’s Audit Chamber reveals delays of 12-38 months due partly to shortage of funds[[325]](#endnote-325) |
| 4/15 | Management of construction, start-up and operation of Leningrad-2 transferred to Leningrad Nuclear Power Plant to improve efficiency[[326]](#endnote-326) |
| 4/15 | Rosatom official confirms start-up of Leningrad-2 units delayed to 2016 and 2018 and for Novovoronezh also to 2016 and 2018.[[327]](#endnote-327) |

Source: See endnotes

1. These figures are the overnight (excluding interest during construction) construction costs, meaning that for a typical 1500MW reactor, the construction cost would be $1.5bn. [↑](#endnote-ref-1)
2. <https://www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley> (accessed February 13, 2015) [↑](#endnote-ref-2)
3. <http://www.westinghousenuclear.com/New-Plants/AP1000-PWR> (Accessed April 24, 2015) [↑](#endnote-ref-3)
4. <https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/esbwr.html> (Accessed April 24, 2015) [↑](#endnote-ref-4)
5. <http://www.westinghousenuclear.com/New-Plants/AP1000-PWR> (Accessed April 24, 2015) [↑](#endnote-ref-5)
6. <https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/esbwr.html> (Accessed April 24, 2015) [↑](#endnote-ref-6)
7. <http://www.worldnuclearreport.org/World-Nuclear-Report-2013.html#olkiluoto_and_flamanville> (Accessed April 24, 2015) [↑](#endnote-ref-7)
8. Most of the reactors in service around the world use water as coolant and moderator and are either Pressurised Water Reactors (PWRs) or Boiling Water Reactors (BWRs. [↑](#endnote-ref-8)
9. For a discussion of design generations see S Goldberg & R Rosner (2011) ‘Nuclear Reactors: Generation to Generation’ American Academy of Arts and Sciences. <https://www.amacad.org/pdfs/nuclearReactors.pdf> (Accessed April 21, 2015) [↑](#endnote-ref-9)
10. In 2006, Toshiba ended its partnership with GE and Hitachi and began to market its own version of the ABWR in competition with Hitachi and GE. Hitachi and GE formed two joint ventures, GE-Hitachi with 80 per cent GE for the USA and Hitachi-GE (80 per cent Hitachi) for non-US markets. Only GE-Hitachi markets the ESBWR. [↑](#endnote-ref-10)
11. The Generation IV International Forum is an international organisation set up in 2000 and funded by 13 countries. <https://www.gen-4.org/gif/jcms/c_9260/Public> (Accessed April 24, 2015) [↑](#endnote-ref-11)
12. <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Advanced-Nuclear-Power-Reactors/> (Accessed April 21, 2015) [↑](#endnote-ref-12)
13. The Westinghouse reactor vendor business is physically based in the USA but is wholly owned by the Japanese Toshiba company [↑](#endnote-ref-13)
14. Another plant, started construction in the Kaliningrad enclave, Baltic 1, but construction appears to have been abandoned. Bellona ‘Baltic NPP debacle: Construction reported halted, possibly mothballed’ May 30, 2013. <http://bellona.org/news/nuclear-issues/nuclear-russia/2013-05-baltic-npp-debacle-construction-reported-halted-possibly-mothballed> (Accessed February 27, 2015) [↑](#endnote-ref-14)
15. <http://www.atom.belta.by/en/belaes_en/view/construction-of-first-second-units-of-belarusian-nuclear-station-on-schedule-5056/> (Accessed February 27, 2015) [↑](#endnote-ref-15)
16. There is confusion in Atomstroyexport’s press release about the decimal point. It claims the original cost estimate was 8.4bn Rubles and the new estimate is 14337bn Rubles. These would equate to US$0.13bn and US$227bn respectively, neither of which is credible. [↑](#endnote-ref-16)
17. <http://www.atomstroyexport.ru/wps/wcm/connect/ase/eng/journalists/press/9e84aa00478814e2b1d9f36578d50f5d> (Accessed March 16, 2015) [↑](#endnote-ref-17)
18. <http://www.world-nuclear-news.org/WR-Belarus-adopts-radwaste-strategy-09061501.html> (Accessed June 15, 2015) [↑](#endnote-ref-18)
19. Russia & CIS Business and Financial Newswire ‘Russian contractor having problems, asks Belarus to maintain nuclear plant contract, part 2’ March 12, 2015 [↑](#endnote-ref-19)
20. Financial Times ‘Siemens to pay Areva €648m for breaking pact’ May 20, 2011 <http://www.ft.com/cms/s/0/6ed60084-82bd-11e0-b97c-00144feabdc0.html#axzz3TQmcrd9b> (Accessed March 4, 2015) [↑](#endnote-ref-20)
21. Nuclear Fuels ‘Areva's credit rating drops to junk status on financial woes’ November 24, 2014 [↑](#endnote-ref-21)
22. Areva ‘Management report from the Board of Directors’. Available at <http://www.areva.com/finance/liblocal/docs/2014/Résultats%20Financiers/RA%202014/Management%20report%202014%20AREVA.pdf> (Accessed March 6, 2015) [↑](#endnote-ref-22)
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24. Nuclear Intelligence Weekly ‘Examining Shaw’s Westinghouse Withdrawal’ September 12, 2011 [↑](#endnote-ref-24)
25. Domain-b ‘CB&I to buy engineering firm Shaw Group for $3.04 billion’ July 30, 2012 [↑](#endnote-ref-25)
26. M&A Navigator ‘Toshiba buys Shaw Group's stake in Westinghouse Electric’ January 7, 2013 [↑](#endnote-ref-26)
27. M&A Navigator ‘Technip closes buy of Stone & Webster process technologies business’ September 3, 2012 [↑](#endnote-ref-27)
28. <http://www.rosatom.ru/en/> (Accessed March 6, 2015) [↑](#endnote-ref-28)
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30. F Roussely (2010) ‘Future of the French civilian nuclear industry’ Translated by the Institute for Energy and Environmental Research, Takoma Park, Maryland. <http://www.psr.org/nuclear-bailout/resources/roussely-report-france-nuclear-epr.pdf> (accessed February 13, 2015 [↑](#endnote-ref-30)
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32. <http://www.areva.com/EN/global-offer-419/epr-reactor-one-of-the-most-powerful-in-the-world.html> (Accessed March 6 2015) [↑](#endnote-ref-32)
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39. R Matzie (2003) ‘The AP1000 Reactor Nuclear Renaissance Option’ Presentation to Tulane Engineering Forum, September 26, 2003. [http://www2.lakelandcc.edu/nora/events/iuser/faculty/images/members/AP1000, per cent202.pdf](http://www2.lakelandcc.edu/nora/events/iuser/faculty/images/members/AP1000,%202.pdf) (accessed February 13, 2015). [↑](#endnote-ref-39)
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41. <http://www.onr.org.uk/new-reactors/reports/gda-quarterly-report-oct-dec-14.pdf> (Accessed February 24, 2015) [↑](#endnote-ref-41)
42. <http://www.rosatom.ru/en/resources/b6724a80447c36958cfface920d36ab1/brochure_the_veer_today.pdf> (Accessed March 11, 2015) [↑](#endnote-ref-42)
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47. Nuclear Intelligence Weekly ‘Newbuild Slows but Only Slightly’ October 24, 2011 [↑](#endnote-ref-47)
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60. <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Heavy-Manufacturing-of-Power-Plants/> (accessed February 13, 2015) [↑](#endnote-ref-60)
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62. Nucleonics Week ‘AP1000 reactor pump issue brings plant design change: Westinghouse’ November 6, 2014 [↑](#endnote-ref-62)
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74. <http://www.stuk.fi/ydinturvallisuus/ydinvoimalaitosten-toiminta/ydinvoimalaitosluvat/viides/en_GB/rakentamislupa/> (Accessed February 18, 2015) [↑](#endnote-ref-74)
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82. <http://www.areva.com/EN/operations-2389/finland-olkiluoto-3.html#tab=tab5> (Accessed May 12, 2015) [↑](#endnote-ref-82)
83. <http://yle.fi/uutiset/nuclear_watchdog_seeks_re-check_of_olkiluoto_3_reactor/7937448> (Accessed April 24, 2015) [↑](#endnote-ref-83)
84. A Makhijani & Y Marignac (2012) ‘Sûreté nucléaire en France post-Fukushima: Analyse critique des Évaluations complémentaires de sûreté (ECS) menées sur les installations nucléaires françaises après Fukushima’ IEER & WISE. <http://www.greenpeace.org/france/PageFiles/300718/120217RapportECS-IEER-WISE-Paris.pdf> [↑](#endnote-ref-84)
85. Power in Europe ‘Flamanville-3 flaws ‘very serious’’ June 8, 2015, p 1 [↑](#endnote-ref-85)
86. The Telegraph ‘Faulty valves in new-generation EPR nuclear reactor pose meltdown risk, inspectors warn’ June 9, 2015 <http://www.telegraph.co.uk/news/worldnews/europe/france/11662889/Faulty-valves-in-new-generation-EPR-nuclear-reactor-pose-meltdown-risk-inspectors-warn.html> (Accessed June 15, 2015) [↑](#endnote-ref-86)
87. <http://www.irsn.fr/EN/newsroom/News/Pages/20150906_Information-note-technical-instruction-EPR-nuclear-reactor-Flamanville.aspx> (Accessed June 15, 2015) [↑](#endnote-ref-87)
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89. Nucleonics Week ‘Areva hits jackpot with contract for islands, fuel for Taishan EPRs’ November 29, 2007 [↑](#endnote-ref-89)
90. Nucleonics Week ‘First nuclear island concrete poured for Taishan-1 EPR’ November 26, 2009 [↑](#endnote-ref-90)
91. Nucleonics Week ‘First nuclear island concrete poured at second Taishan EPR’ April 29, 2010 [↑](#endnote-ref-91)
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93. Nuclear Intelligence Weekly ‘Taishan’s Delays Hinder Further Areva EPR Sales’ March 21, 2014 [↑](#endnote-ref-93)
94. <http://www.firstpost.com/fwire/made-in-china-nuclear-reactors-a-tough-sell-in-global-market-2140127.html> (Accessed March 6, 2015) [↑](#endnote-ref-94)
95. Energy Monitor Worldwide ‘China regulators 'overwhelmed' as reactor building steams ahead’ June 21, 2014 [↑](#endnote-ref-95)
96. Nucleonics Week ‘Westinghouse wins China contract; Chinese look at next expansion’ December 21, 2006 [↑](#endnote-ref-96)
97. Nucleonics Week ‘China nuclear companies want to uprate AP1000 to 1,400 MW’ October 18, 2007 [↑](#endnote-ref-97)
98. Nucleonics Week ‘China's Gen III push shelves CNNC's 1,000-MW PWR design at least to 2011’ May 3, 2007 [↑](#endnote-ref-98)
99. A Semi-Annual Construction Monitoring Report is published by the Georgia Public Service Commission. <http://www.psc.state.ga.us/factsv2/Docket.aspx?docketNumber=29849> (Accessed March 1 2015) [↑](#endnote-ref-99)
100. A detailed record of all incidents at US reactor sites, is published by the NRC in its ‘Part 21’ reports at <http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/2015/> (Accessed May 12, 2015) [↑](#endnote-ref-100)
101. There were already two operating reactors at the Vogtle site so the new reactors are designated by the utility as no 3 and no 4, but for this report we refer to no 3 as unit 1 and no 4 as unit 2. Similarly there was an operating reactor at the Summer site so the new reactors are designated by the utility as no 2 and no 3, but for this report we refer to no 2 as unit 1 and no 3 as unit 2 [↑](#endnote-ref-101)
102. Nucleonics Week ‘Two Vogtle partners get DOE loan guarantees’ February 20, 2014 [↑](#endnote-ref-102)
103. <http://www.eenews.net/stories/1059998194> (accessed June 1, 2015) [↑](#endnote-ref-103)
104. For an overview of the construction problems at Vogtle, see <http://enformable.com/2015/03/new-nuclear-construction-projects-in-the-us-face-many-issues/> (Accessed March 12, 2015) [↑](#endnote-ref-104)
105. Nucleonics Week ‘NRC finds quality problems at Shaw facility for AP1000 modules’ January 12, 2012 [↑](#endnote-ref-105)
106. Inside NRC ‘Southern Nuclear will request 60-90 amendments for Vogtle COLs’ July 15, 2013 [↑](#endnote-ref-106)
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108. Nucleonics Week ‘US experiences nuclear construction challenges, progress: industry’ August 29, 2013 [↑](#endnote-ref-108)
109. Electric Power Daily ‘Southern Company gets OK to build nuclear plants; first since 1978’ February 10, 2012 [↑](#endnote-ref-109)
110. Nucleonics Week ‘AP1000 pumps spark dispute for Westinghouse, Curtiss-Wright’ February 27, 2014 [↑](#endnote-ref-110)
111. <http://www.timesfreepress.com/news/business/aroundregion/story/2015/jun/02/southern-co-casts-blame-builders-nuclear-plant-delay/307557/> (accessed June 4 2015) [↑](#endnote-ref-111)
112. Pittsburgh Post-Gazette ‘Nuclear conundrum; As construction and design delays continue at Westinghouse project, parties battle over who pays’ February 10, 2015. [↑](#endnote-ref-112)
113. A quarterly construction progress report is published by the South Carolina Public Service Commission. www.psc.sc.gov/ [↑](#endnote-ref-113)
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115. Business Wire ‘Shaw Congratulates South Carolina Electric & Gas on Combined License for New Nuclear Units at V.C. Summer Nuclear Station’ March 30, 2012 [↑](#endnote-ref-115)
116. Inside NRC ‘NRC issues COLs for Summer AP1000s’ April 9, 2012 [↑](#endnote-ref-116)
117. New York Times ‘Loan Program for Reactors Is Fizzling’ February 19, 2014 [↑](#endnote-ref-117)
118. For an overview of the construction problems at Summer, see <http://enformable.com/2015/03/new-nuclear-construction-projects-in-the-us-face-many-issues/> (Accessed March 12, 2015) and <http://www.thestate.com/news/business/article13893275.html> (Accessed May 31, 2015) [↑](#endnote-ref-118)
119. Nucleonics Week ‘Rosatom expects construction of new design to start this year’ February 8, 2007 [↑](#endnote-ref-119)
120. Nucleonics Week ‘Russian government approves plan for constructing new reactors’ April 26, 2007 [↑](#endnote-ref-120)
121. Nucleonics Week ‘First nuclear island concrete poured for Leningrad-II-1’ October 30, 2008 [↑](#endnote-ref-121)
122. Energy in Eastern Europe ‘First Baltic NPP concrete poured’ March 9, 2012 [↑](#endnote-ref-122)
123. Nuclear Intelligence Weekly ‘Kremlin Searches for Alternatives to Kaliningrad NPP’ April 18, 2014 [↑](#endnote-ref-123)
124. Nuclear Intelligence Weekly ‘Auditor Report Illuminates Rosatom’s Financial Challenges’ January 23, 2015 [↑](#endnote-ref-124)
125. Nuclear Intelligence Weekly ‘Russia Poised to Cut Financing for Domestic Newbuilds’ December 5, 2014 [↑](#endnote-ref-125)
126. Nuclear Intelligence Weekly ‘Bartuska’s Critique of Newbuild Vendors’ January 23, 2015 [↑](#endnote-ref-126)
127. <http://www.onr.org.uk/new-reactors/reports/gda-progress-report-1212-0813.pdf> (Accessed February 24, 2015) [↑](#endnote-ref-127)
128. Nucleonics Week ‘Areva suspends effort to get **NRC** approval of US-**EPR** reactor design [↑](#endnote-ref-128)
129. Nuclear News ‘US EPR open items may close by 3Q2016’ May 2014 [↑](#endnote-ref-129)
130. <http://www.onr.org.uk/new-reactors/ap1000/index.htm> (Accessed February 24, 2015) [↑](#endnote-ref-130)
131. <http://www.onr.org.uk/new-reactors/ap1000/gda-issues-res-plan.htm> (Accessed March 13, 2015) [↑](#endnote-ref-131)
132. South China Morning Post ‘ Mainland enters new nuclear energy era; State Nuclear Power leads acquisition of US 3G technology’ May 28, 2007 [↑](#endnote-ref-132)
133. Nucleonics Week ‘Big cost hikes make vendors wary of releasing reactor cost estimates’ Sept 14, 2008 [↑](#endnote-ref-133)
134. Nucleonics Week ‘Eskom to build initial reactors, but long-term plan to be curtailed’ Nov 20, 2008. [↑](#endnote-ref-134)
135. Nucleonics Week ‘Eskom cancels tender for initial reactors’ Dec 11, 2008, p 1 [↑](#endnote-ref-135)
136. Nucleonics Week ‘AECL, Areva, Westinghouse submit bids for new reactors at Darlington’ Mar 5, 2009, p 3. [↑](#endnote-ref-136)
137. Nucleonics Week ‘Areva disputes EPR cost figure as Canadians grapple with risk issue’ Jul 23, 2009, p 1. [↑](#endnote-ref-137)
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