Riding to the Rescue?

The Changing Picture in China and the Global Future of Nuclear Power

M. V. Ramana[1]

Abstract

China has the most ambitious targets for nuclear power and some expect that it would shore up the flagging prospects for a large expansion of nuclear power around the world. But in recent years, China's nuclear program has not grown as fast as projected. This chapter explains why there are good reasons to expect nuclear power growth to slow down further. Promises that new reactor designs will be constructed in large numbers in China or exported from China to other countries seem unlikely to materialize. As a result, nuclear power's salience to future global electricity generation will continue to diminish.

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[1] M. V. Ramana, Liu Institute for Global Issues, University of British Columbia, Vancouver, Canada, m.v.ramana@ubc.ca

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1 Introduction

For long, China was expected to be the engine that would propel a large-scale expansion of nuclear power in the 21st century. Starting around 2005, the country embarked on constructing a very large number of nuclear plants (see Figure 1). After a short pause following the 2011 Fukushima Daiichi accidents, China resumed new reactor construction in late 2012 and today has the most number of reactors under construction—18 reactors, nearly a third of the global total (IAEA, 2018).

The dominance of China in nuclear reactor construction testifies not just to China's emergence as an industrial powerhouse but also the decline in nuclear growth elsewhere. Indeed, in recent years, both the United States and Western Europe have seen many reactors shut down well before their license period expire in comparison with new reactor construction. Globally nuclear energy production as a share of all electrical energy generated has declined to around 10.5 percent, nearly 40 percent below the maximum of over 17 percent in 1996 (Schneider and Froggatt, 2017).

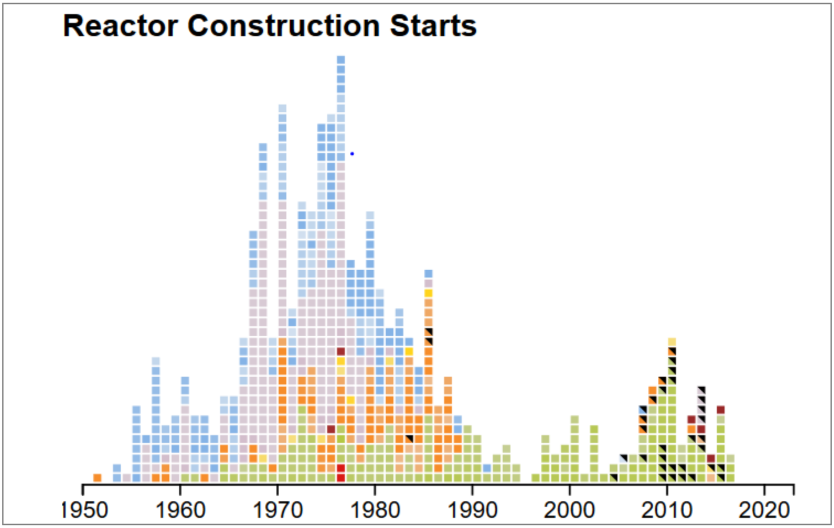

Fig. 1 Annual commencement of nuclear reactor construction

Source: "Global Nuclear Power Database" http://thebulletin.org/global-nuclear-power-database

Targets for nuclear capacity in many countries have also been declining, especially in the aftermath of the disaster that started in 2011 at the Fukushima Daichi nuclear plant (Ramana, 2016). In contrast, China has continued rolling out impressive targets for the future. More recently, the country has also started making determined attempts to export its reactors (Thomas, 2017), for example, by infusing capital into a very expensive nuclear power project in the United Kingdom, as a result of which some were even asking if China might be able to rescue Europe's nuclear energy industry (Brown, 2015; Sputnik, 2015).

Is this a realistic projection of China's role in the future of nuclear power? Will China really be able to compensate for the ongoing decline in nuclear energy? This article tries to answer these questions by examining the targets that have been set and the plans that were announced, and following these by an examination of the actual experience of reactor construction and exports. This is followed by a discussion of some drivers of reductions in nuclear plans and a brief conclusion.

2 Current status

According to the IAEA's Power Reactor Information System, as of January 2019, China had 46 operating reactors with a total net capacity of around 43 GW (gigawatts), and a further 11 reactors with a total capacity nearly 11 GW are under construction (IAEA, 2019). In 2017, nuclear power contributed 247.5 TWh, which constituted 3.9 percent of all electricity generated in China, up from 3.6 percent in 2016. The nuclear fraction has been very gradually increasing since 2010 (see Figure 2). Nevertheless, the small magnitude of that fraction implies that the large buildup of nuclear power was part of a general strategy that called for building up all kinds of electricity generation plants. In particular, China has been ramping up construction of modern renewables. In 2017, wind energy contributed 306 TWh, up by 26 percent from its contribution in 2016, while solar energy contributed 118 TWh, up by 75 percent from 2016 (China Energy Portal, 2018).

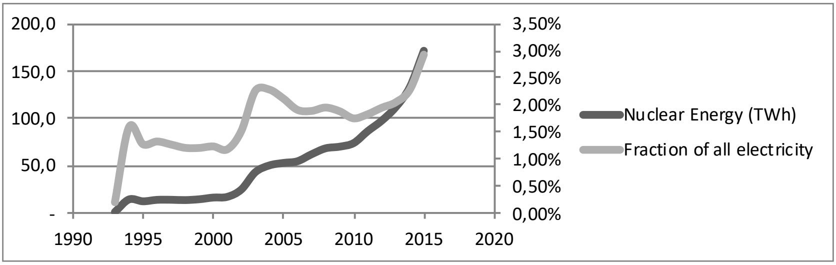

Fig. 2 Nuclear energy supplied to the grid (blue points) and the fraction of all electricity provided by nuclear power

Source: Authors calculations based on figures in BP, 2016, Statistical Review of World Energy 2016: BP, accessed October 18, 2016, at http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

3 Ambitious targets

Although China is a relatively late entrant to nuclear power, with construction of nuclear power plants starting only in the 1980s, three decades after the nuclear weapons program started, it has periodically laid out impressive targets.[2] Some of these are listed in Table 1. Perhaps the highest of these was the figure of 114 GW by 2020, released by the National Development & Reform Commission in 2010 (Power Engineering, 2010). These figures have come down and according to the latest 13th Five-Year Plan, the targets for 2020 were to have 58 GW of nuclear generating capacity in operation and a further 30 GW of capacity under construction (WNN, 2016c). Even this target will likely not be met and Chinese officials admit that it might be only 53 GW by 2020 (Stanway and Chen, 2016). But in the longer term, Chinese nuclear advocates continue to posit impressive targets, up to 150 GW by 2030, nearly thrice what is likely to be the operating capacity in 2020. For example, the China General Nuclear Power Corporation foresees a nuclear capacity of "120-150 GW by 2030" (Stanway, 2016).

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[2] One early projection by Professor Lu Yingzhong who was then Director of the Institute of Nuclear Energy Technology at Tsinghua University envisioned nuclear power contributing 12.7 percent of all energy (including heat and electricity) in China by 2020 with that fraction rising to 19.35 percent by 2030 (Lu, 1984).

Tab. 1 Nuclear Power Targets

Year in which Projection was Made	Year Projected For	Capacity Projected (MW)	Actual Capacity (MW)
1988	2000	6,000	2,168
1996	2010	20,000	10,282
2002	2020	40,000 – 80,000	?
2008	2020	50,000	?
2010	2020	114,000	?
2016	2020	58,000	?

Sources: (Dazhong and Yingyun, 2002; Meyers and others, 1993; Ran and Li, 1998; Sternfeld, 2009; WNN, 2016c)

When it comes to exports, too, Chinese nuclear advocates have been making extravagant claims (Thomas, 2017). This trend has become stronger after the Fukushima accidents that commenced in 2011. That accident set back nuclear programs around the world, leaving China in a comparatively better place. This has been welcomed by Chinese officials; according to Zhang Guobao, a former Administrator at China's National Energy Administration "history has given China an opportunity to overtake the world's nuclear energy and nuclear technology powers" (Stanway, 2013). In 2016, the president of China National Nuclear Corporation (CNNC) announced that "China aims to build 30 nuclear power units… by 2030"; this goal, in turn, was based on the assessment that "more than 70 countries" were "planning or are already developing their own nuclear power projects, and it is estimated 130 more nuclear power units will have been built by 2020" (Xinhua, 2016).

4 Interest in Chinese market

Because of the expectation that China will be building up its nuclear capacity rapidly, reactor vendors and national government representatives have been flocking to the country since the 1980s in the hope of selling their wares (MacDougall, 1984; Lu, 1993; Silver, 1994; Bratt, 1996; Zhou and Zhang, 2010). Foreign government officials, sometimes at very high levels, have been involved in advocating for their reactor designs (Silver, 1994; Silver, 1996b; Silver, 1996a; Zuercher, 1995; Bodgener, 2008; Ria, 2008; Cultice and Feng, 2009).

The nature of the competition is made clear by a 2008 cable from the U.S. embassy in Beijing to Washington and is worth quoting at some length:

> "Effective advocacy for U.S. nuclear suppliers is essential to ensuring access to China's rapidly growing civil nuclear power market. With the exception of the bidding process that resulted in a contract for four Westinghouse AP1000 reactors, all reactor purchases to date have been largely the result of internal high level political decisions absent any open process. Even the Westinghouse decision was arguably a political one, which was quickly followed by subsequent non-competitive purchases of the competing French and Russian plants. China is currently in the process of building as many as 50 to 60 new nuclear plants by 2020; the vast majority will be the CPR-1000, a copy of 60's era Westinghouse technology that can be built cheaply and quickly and with the majority of parts sourced from Chinese manufacturers… Pressing for open and transparent bidding processes for reactor sales (for complete plants or individual major component purchases), as well as advocating for China to pursue advanced reactor technology for future sites so that it's reactor fleet is not so reliant on aging technology through the next half century could be a more effective approach to bolster U.S. interests in China's nuclear market. Regardless of how the United States decides to advocate, it should be done continuously and from a high level in order to keep up with the French and Russians" (U.S. Embassy Beijing, 2008).

Two claims made in this cable are worth noting. First, all nuclear contracts were political decisions. In other words, they may not really be technically or economically justifiable. Neither the Chinese government nor any of the countries seeking to export reactors to the country offered a public cost-benefit analysis in support of the decision to import one or the other reactor type. Further, vendors enticed Chinese policymakers with varying degrees of technology transfer, attractive financing arrangements, and other political benefits (Ramana and Saikawa, 2011).

Second, all countries that seek to sell nuclear reactors have been engaged in high level governmental campaigning, on a continuous basis. As the *New York Times* reported in 2004: "In recent months, a procession of political leaders has pressed China to favor power plant designs and equipment from their home countries. They have included President Jacques Chirac of France; former Prime Minister Jean Chretien of Canada; Viktor Khristenko, who was named fuel and energy minister in Russia on Tuesday; and dozens of less-prominent officials. President Bush even raised the virtues of American nuclear technology with the Chinese prime minister, Wen Jiabao" (Buckley, 2004). The justification for the high level political engagement was the poor state of the nuclear reactor market elsewhere and the promises of growth in China.

5 Recent experience with reactor construction

Partly as a result of such high level intervention, China's nuclear establishment did import a number of reactors. China's entry into nuclear energy began with the construction of a series of indigenously designed reactors at the Qinshan site. However, in the late 1980s, China imported reactors with the M310 design from Framatome in France for the Daya Bay site; the majority of the reactors built in China involve the CPR-1000, a modification of the M310 design. The only exceptions were two VVER1000s and two Candu-600 reactors imported from Russia and Canada, respectively, but there was never any plan to make those the mainstay of the Chinese nuclear fleet. It was only after 2005 and the eleventh 5-year plan that imported reactors came back into consideration, with the specific aim of introducing third-generation reactors from other countries (Xu, 2008).

The relevance of the construction of the reactors was heightened in the aftermath of Fukushima because of the decision made by policy makers that China would build *only* Generation III or III+ reactors. The initial assumption was that this stipulation would lead to the adoption of AP1000 technology, in part because senior nuclear policy makers promoted the idea that this reactor design would have withstood the conditions that led to the events at Fukushima. For example, a general manager in the China Power Investment Corporation pointed out that the "reactors in the Japanese nuclear power plants, which have been affected by the massive quake, are Generation II reactors and have to rely on back-up electricity to power their cooling system in times of emergency", whereas the "AP1000 nuclear power reactors, currently under construction in China's coastal areas and set to be promoted in its vast hinterland, are Generation III reactors and have built in safety features to overcome such a problem" (Reporter, 2011). This was very much the same claim that Westinghouse itself peddled. As the Westinghouse President and Chief Executive Officer Aris Candris put it to ABC News: "Everyone has heard of what happened at the Fukushima Daiichi plant…Had an AP1000 been on that site we would have got no nuclear news post-tsunami" (Sy, 2011).

The other reason to have expected an important role for AP1000s in China's nuclear plans is that a key player in the Chinese nuclear power sector, the State Nuclear Power Technology Corporation (SNPTC), held the sole rights "to sign contracts with foreign parties to receive… 3rd generation nuclear power technology" (SNPTC, 2011). Specifically, the 3rd generation nuclear power technology that SNPTC was to contract for was the Westinghouse AP1000, which it was expecting would become "the dominant technology for China's future nuclear industry development" (Lawrence and Katz, 2007). The Fukushima accidents and the Chinese government's decision that future nuclear construction would be limited to

Generation III reactors gave SNPTC an opportunity to translate their expectation about the AP1000's dominance into reality. By May 2011, SNPTC had convinced officials at Westinghouse Electric Company that the AP1000 was going to dominate the Chinese reactor market from then on (Li and Tranum, 2011). But the actual experience of the projects involving AP1000s proved more problematic.

Before going on to the AP1000 projects, let us first look briefly at the European Pressurized Reactor (EPR) units being built at Taishan. These were originally scheduled to "be commissioned at the end of 2013 and in autumn 2014" respectively, and France's Areva had hoped "to have started work on more reactors" by then (Thibault, 2010). As of February 2017, China General Nuclear Power maintained that the two units will start commercial operations in "the second half of 2017 and the first half of 2018, respectively" (AFP, 2017). Despite the serious concerns set off in April 2015 when the French nuclear safety regulator, Autorité Sûreté Nucléaire (ASN), revealed that the reactor bases and lids Areva had supplied from its Le Creusot plant did not meet safety specifications (Chaffee, 2015), the first EPR was opened for commercial operations in December 2018 (IAEA, 2019). The delays with the EPR were not surprising, at least in retrospect, because by the time construction started in Taishan, the corresponding projects at Olkiluoto in Finland and Flamanville in France had already run into trouble and were expected to be significantly delayed (Kanter, 2009).

In contrast, the AP1000s at the Sanmen and Haiyang sites were the very first constructions of this design anywhere in the world. When construction started at Sanmen, the Shaw Group, one of the partners in the consortium building the reactor, proudly proclaimed, "As with the successful, on-time and on-schedule pour of the first nuclear concrete for the Reactor Building mat earlier this spring, we have again shown that next generation nuclear power plants can be, and are being, built in an efficient and timely manner" and looked forward "to bringing this plant on line as scheduled in 2013" (Shaw Group, 2009). Unfortunately for Westinghouse and Shaw, these promises did not come to pass.

An important source of problems, although not the only one, has been the reactor coolant pumps (RCPs) that were supplied by US manufacturer Curtiss-Wright Corporation. The RCP forces water to circulate through the reactor and transfer the heat generated by the fission reactions in the reactor core. In January 2013, Curtiss-Wright found that a piece of a "blade within the pump had separated from the… casting" and it had to recall the RCPs that had already been shipped off (NIW, 2013). The RCP had to undergo design changes and fixes that took two years to complete. The problem with the RCPs was symptomatic of a larger problem: construction of the Sanmen and Haiyang power plants had began well before the engineering of the plant's design was completed (Spegele, 2016).

Because the design has never been constructed anywhere, new problems keep surfacing.[3] One such problem was observed during tests that were conducted at the first AP1000 unit at Sanmen-1. These tests were conducted without any radioactive material being loaded into the reactor, but at high temperatures. The problem involved neutron shield blocks that are supposed to stop neutrons from the nuclear core from escaping into the rest of the reactor. During these tests, the material that was in the shield blocks had "volumetrically expanded and extruded out of the shield blocks into the nozzle gallery" and there was "internal pressurization of the shield blocks," according to a heavily redacted report on the issue presented by Westinghouse to the U.S. Nuclear Regulatory Commission in February 2017 (Cooke, 2017, p. 5). Westinghouse was forced to admit that it had "not properly considered" the possibility that the shielding material might expand in volume.

Any of these problems could result in serious safety consequences. Chinese nuclear officials have expressed concern in the past about these problems. In 2013, for example, a former vice-president of CNNC complained to *South China Morning Post*: "Our state leaders have put a high priority on [nuclear safety] but companies executing projects do not seem to have the same level of understanding" (Ng, 2013). The result has been a very long series of delays. All four AP1000s went into commercial operation in late 2018 or early 2019 (IAEA, 2019).

Cost estimates have risen too. Early estimates by China's Nuclear Energy Agency put the cost of constructing AP1000 reactors at $2300/kW (NEA, 2010, p. 48). A newspaper article from 2016 claims implicitly that the cost might be $3000/kW (Abe, 2016). In its environmental impact assessment for the Sanmen project, China's National Nuclear Safety Administration "projected a total project pricetag of 52.5 billion yuan ($8.3 billion) — more than double the original budget for the two units of 25 billion yuan"(Yu, 2018).

The problem that this higher cost of construction poses is that of economic competitiveness. In 2016, Steve Kidd, who was formerly with the World Nuclear Association, suggested that a tariff of 0.50 RMB per kWh has been mentioned for AP1000 and EPR nuclear projects, up from 0.43 RMB per kWh for projects that constructed more traditional nuclear reactor designs (Kidd, 2016). But the tariff available to the project developers was significantly lower. In April 2018, Sanmen "cleared the annual power exchange auction in Zhejiang province, making it eli-

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[3] However, it bears remembering that even with the follow on AP1000 constructions in the United States, there have been a number of technical problems with significance for safe operations, which raises fundamental questions about the soundness of that design. These problems were to cause record losses for Toshiba and drive Westinghouse to bankruptcy (Asahi Shimbun, 2017; Cardwell and Soble, 2017; Lewis, 2016).

gible to sell 766 gigawatt hours of output during 2018 at a price of 0.385 yuan per kilowatt hour ($0.061¢/kWh)...roughly 10% less than the standard nuclear tariff of 0.43 yuan/kWh" (NIW, 2018a).

The poor experience at Sanmen and Haiyang has not stopped Westinghouse from making unrealistic claims about the future of the AP1000 in China. In 2016, Jose Gutierrez, interim chief executive of Westinghouse, indulged in wishful thinking: "We expect to see a fleet of AP1000 reactors in China ... We don't know how many China wants to build, but it could be tens" (De Clercq, 2016). This does not appear to have any basis in reality and reflects an attempt to boost its plunging fortunes. Indeed, Westinghouse officials themselves may not believe in this. The Wikileaks cables reveal that nearly a decade ago, at a meeting convened by the DOE China Office, Westinghouse representative in China, Gavin Liu, "noted that because China's technical capacity is increasing, the longer it takes to start the next round of AP1000 reactors, the less scope will be available for Westinghouse" (DOE China Office, 2008).

The outlook for Westinghouse in China is bleak. As Lin Boqiang, director at the China Center for Energy Economics Research at Xiamen University told *Bloomberg News*, "The only way Westinghouse can win contracts in China is to demonstrate they can build reactors quicker and cheaper than anyone else in China's market and win hearts with actions, not words…Westinghouse so far hasn't demonstrated such abilities" (Stapczynski and others, 2015). Li Ning, from Xiamen University, told the *Wall Street Journal* that Chinese officials "are certainly very frustrated" and "they feel Westinghouse oversold the system, oversold the technology, promised more than they could really deliver" (Yap and Spegele, 2015). Of course, ever since Westinghouse filed for bankruptcy in the United States in March 2017 (Cardwell and Soble, 2017), the future of the company itself has been highly uncertain.

6 New reactor designs

China has also been at the center of efforts to rescue nuclear power by adopting new reactor designs in place of the now-standard Light Water Reactor design that has dominated nuclear power around the world. These newer reactor designs, which are mostly paper designs, are held out as solving one or more of the many problems that have plagued nuclear power.

There are at least two reasons offered for the focus on China. The first is the idea that if any country is to be capable of supporting the production of, and offering a market for, a large number of units, it would be China. Growth of nuclear power in other markets is either slow or non-existent (Schneider and Froggatt, 2016). Therefore, the idea goes, if a new reactor design is to be tried out at some scale, it would be possible only in China. As Charles Forsberg, executive director of the MIT Nuclear Fuel Cycle Project, puts it, "There have been studies that indicate that if reactors are mass-produced, they can drive down costs…The Chinese market is large enough to make that potentially possible" (Martin, 2016).

Second, there is the idea that the Chinese nuclear regulatory system might be more open to licensing non-traditional reactor designs (Eaves, 2017). One example of a non-traditional reactor design that some in China are working on, and where U.S. nuclear advocates have been pointing to China as the role model, is the molten salt reactor (Halper, 2015; Martin, 2015; Reischer, 2016). Some of the proponents are Chinese but there are also a number of foreign designers, many from the United States, who seek to have their designs first be commercialized in China.

Two other designs with a connection to China are the High Temperature Gas Cooled Reactor (HTGR) and the Travelling Wave Reactor. In an article in *Issues in Science and Technology*, for example, Richard Lester, another MIT professor, lists several features of the way the U.S. Nuclear Regulatory Commission carries out regulation of new reactor designs and offers the Travelling Wave Reactor design promoted by Bill Gates and Nathan Myhrvold as an example of a technology that was going to be developed in China because of the stricter and more rigid safety regulatory regime in the United States (Lester, 2016).

The saga of the HTGR is also relevant. This reactor design was first proposed in the 1940s and was extensively researched by German technologists, who built two reactors based on this design, but who eventually abandoned the effort to commercialize the technology. In the 1990s, South Africa set up a major program to develop a commercial HTGR called the Pebble Bed Modular Reactor (PBMR). This effort was to collapse a decade later, and the South African government abandoned the project (Thomas, 2011).

In China, work on the HTGR design started in earnest after the country signed a cooperation agreement with Germany in 1984 (MacDougall, 1984). The pilot scale HTR-10 reactor reached its criticality in 2000, achieved full power operation, and began to supply power to the grid in 2003 (Zhou and Zhang, 2010). Soon after the HTR-10 attained criticality, in 2001, the commercial scale design, called the high-temperature gas cooled reactor pebble-bed module (HTR-PM) project, that is capable of generating 250 MW of electricity, was launched (Zhang and others, 2009). The development of this reactor became a high priority under the "Chinese Science and Technology Plan" for the period 2006–2020.

In February 2008, the implementation plan and the budget for the HTR-PM project was approved by the State Council of China. The HTR-PM received final approval from China's cabinet and its national energy bureau around two weeks before the Fukushima accidents (Bradsher, 2011). However, in the aftermath of Fukushima, all nuclear construction was frozen. In December 2012, construction of HTR-PM commenced at Shidaowan in China's eastern Shandong province (IAEA, 2019). The reactor was "expected to start commercial operation in late 2017" (WNN, 2016b).

Chinese HTR proponents have painted an ambitious future for that reactor design. When construction of the plant was starting, there were plans for eventually constructing a further 18 units of the same type at the same site (NucNet, 2013). There are also plans to export these reactors to other countries, and China has entered into exploratory agreements with Saudi Arabia and Indonesia (Can, 2016; WNN, 2016a; WNN, 2016b), but has not completed construction as of January 2019 (IAEA, 2019).

China's construction of the HTR-PM and more generally its pursuit of this reactor design has been much lauded by nuclear advocates around the world, especially by those who seek to promote a focus on HTGRs or other advanced reactors as a way to rescue nuclear power from its declining fortunes. Andrew Kadak, formerly President and CEO of the Yankee Atomic Electric Company (YAEC) that operated the Yankee Atomic Nuclear Power station, said: "The industry has been focused on water-cooled reactors that require complicated safety systems. The Chinese aren't constrained by that history. They're showing that there's another way that's simpler and safer. The big question is whether the economics will pay off" (Reiss, 2009).

Unfortunately, for the proponents, the economics doesn't seem to be working out—even prior to the commencement of operations. According to the trade magazine *Nuclear Intelligence Weekly*, the high cost of generation (60 fen (¢0.9) per kilowatt hour, higher than the average 43 fen/kWh for Gen III reactors) is among the "key challenges" confronting HTGRs in China (Yu, 2016, p. 6). The high cost is no surprise; even HTGR proponents estimate that the capital cost will be about 20% higher than LWRs, although they typically will also claim that this cost will come down as more plants are built (Zhang and Sun, 2007). Another key challenge that the HTGR faces is the fact that there are a host of other small modular reactor technologies under development in China (Ramana and others, 2013; Yu, 2016). Two such designs, the ACPR50 and ACPR100 from CGN and the ACP100 from CNNC, have been in the news recently, as a result of an announcement that China was going to build maritime nuclear power platforms in the South China Sea (NEI, 2016). In part as a result of these challenges, it appears that Chinese policy makers have dropped the plan of building 18 reactors at the Shidaowan site (WNN, 2016b).

The idea of exporting HTGRs also appears to be somewhat wishful thinking. The Indonesia case provides a good illustration. News reports suggest that Wang

Shoujun, chairman of China Nuclear Engineering Group Corporation visited Batan (Badan Tenaga Nuklir Nasional, Indonesia's National Nuclear Energy Agency) in June 2016 in order to better understand the Indonesian market (Can, 2016). Despite such agreements—for example, Batan also has signed an agreement with the Japan Atomic Energy Agency on research and development of HTGRs in 2014 (WNN, 2014)—the odds of Batan being able to construct a commercial scale HTGR in Indonesia in the foreseeable future are essentially nil. Indeed, in December 2015, then Energy and Mineral Resources Minister Sudirman Said announced publicly that the government had concluded that "this is not the time to build up nuclear power capacity. We still have many alternatives and we do not need to raise any controversies" (NEI, 2015).

Other countries that have been targeted by China also have lengthy histories of ambitious announcements followed by little action; for example, over a decade ago, Argentina declared that it was embarking on "an eight year nuclear energy development program with the purpose of increasing the number of atomic plants plus resumption of uranium enrichment production" (Mercosur, 2006). Little was achieved by this program apart from the commissioning of the Atucha-II reactor in 2014, construction of which started in 1981 (IAEA, 2014b). There is little to indicate that Argentina will indeed embark on massive nuclear construction; instead it seems to be heading towards expanding its renewable energy sector (Maxwell, 2016). Indeed, in May 2018, the trade magazine *Nuclear Intelligence Weekly* reported that Argentianian officials have put plans for Chinese supplied reactors on hold (NIW, 2018b).

The pattern that may be discerned is of making tall claims about numerous reactors of one design or the other, raising hopes among nuclear power supporters for a revival of the technology based on this new design. However, these initial announcements are almost always followed by a process of slowing down, and often abandonment, with the latter steps done quietly with little fanfare. This appears to be what has happened to the HTGR design and may well be the fate of the plans to construct floating power plants, unless the real reason for the latter are to raise the stakes on the south China sea disputes. In any case, it seems hard to visualize China as a laboratory for successfully developing a reactor design that solves the problems of nuclear power.

7 Drivers for reduction

In light of all these problems, then, it is not surprising that China's current nuclear target of 58 GW by 2020 is much lower than the earlier high value of 114 GW by 2020. But problems with constructing the current generation of nuclear reactors do not constitute the only reason for this change in the outlook for nuclear power in China. There are at least three additional reasons for a lowering of targets for nuclear deployment (Ramana and King, 2017).

The first is that energy demand in China is not growing at the same fast rate it has in the past. The underlying reason for this is the deliberate shift in the nature of the Chinese economy, from one primarily focused on increasing manufacture, especially by heavy industry, to one that is actively promoting service sector and less energy-intensive sectors (Green and Stern, 2015; Green and Stern, 2016). At the same time, because of ambitious plans in the past, there is a real glut in power capacity. Most power plants, including nuclear reactors, are not being utilized at optimal levels. This trend might result in further reduction in the number of hours that nuclear reactors are operated: in March 2017, the National Energy Administration announced new rules on the priority order for different kinds of generators to supply electricity to the grid; Chinese nuclear companies are already complaining about being forced to reduce how many hours grid operators are willing to absorb the power outputs of reactors (Yu, 2017a).

The second reason is that there are very few coastal sites available for new nuclear plants to be set up. There is a limit to how many reactors can be built on existing sites. There is real and justified resistance to building nuclear power plants in inland sites, next to rivers and large lakes, water from which is already in demand for drinking, agriculture, and other higher priority uses (King and Ramana, 2015).

Finally the government seems to be paying attention local opposition to nuclear facilities; this is, again, entirely justifiable. Opposition to nuclear facilities has been growing in China since the Fukushima accidents (Buckley 2015; Lok-to 2016). One study that explored the Chinese public's willingness to pay to avoid harm found that those surveyed were "particularly concerned about the development of nuclear power in the aftermath of the Fukushima disaster and generally regard nuclear power as unsafe power generation technology" (Sun and others, 2016, p. 692). At least two nuclear facilities that were supposed to be constructed were cancelled after public protests, the most prominent being the decision in 2016 to cancel a 100 billion yuan (US$15 billion) nuclear reprocessing plant that was proposed for a location near the city of Lianyungang, Jiangsu province (Green 2016).

There is independent evidence that even industry insiders within China do expect a decline in nuclear construction going forward. For example, imports of uranium by China from other countries has been declining, from nearly 21,300 tons of uranium concentrate in 2014 down to 19,200 tons in 2015, to under 16,000 tons in 2016 (Chaffee, 2017).

8 Effect on global prospects for nuclear power

What might be the impact of a reduction in China's nuclear targets on the future of nuclear power? One handle on this is provided by critically examining the projections put out by the International Atomic Energy Agency (IAEA). The IAEA's projections have historically been well in excess of what actually materialized (IPFM, 2007, p. 85). Nevertheless, its projections are worthy of examination because they provide an indication of the nuclear industry's own outlook. Each year, the IAEA puts out two sets of projections, a low case and a high case. The first "represents expectations about the future if current market, technology and resource trends continue and there are few additional changes in explicit laws, policies and regulations affecting nuclear power" (IAEA, 2013, p. 6). In contrast, the "high case projections are much more optimistic, but still plausible and technically feasible. The high case assumes that current rates of economic and electricity demand growth*, especially in the Far East*, continue. Changes in country policies toward climate change are also included in the high case" (emphasis added). In other words, the high case projections represent something like a best case scenario for nuclear deployment.

Table 2 below lists the high case estimates for the Far East region and the world as a whole from the last seven years. Since 2010, all of the projections—for nuclear power globally and for the Far East, which is defined as China, Japan, and Republic of Korea—have been declining. Even for the IAEA, the realities of the market cannot be completely ignored. However, barring a few years, although the projected nuclear capacity in the region is declining, the fraction of global capacity constituted by the countries of the Far East has been increasing. The IAEA's low estimates also assume that similarly large fractions (35 to 40%) of the global nuclear capacity will be in the Far East. In other words, if there is to be a big revival of nuclear power, it would have to be fueled by construction in this region.

Tab. 2 Figures from the IAEA's High Case Projections

	High Case Estimate for 2050 for the Far East	High Case Estimate for the World in 2050	Fraction of Global Nuclear Capacity in the Far East	Fraction of electricity generated by nuclear power in 2050 in the Far East	Fraction of electricity generated by nuclear power in 2050 around the world
2010	450	1415	31.80%	21.60%	17.00%
2011	450	1228	36.64%	19.10%	13.50%
2012	417	1137	36.68%	16.90%	12.20%
2013	412	1113	37.02%	16.60%	12.10%
2014	398.7	1091.7	36.52%	15.10%	11.50%
2015	355	964	36.83%	14.40%	10.80%
2016	351	898	39.09%	14.50%	10.00%

Sources: (IAEA, 2010; IAEA, 2011; IAEA, 2012; IAEA, 2013; IAEA, 2014a; IAEA, 2015; IAEA, 2016)

The IAEA does not break up its estimates by country. But the much larger size of China as compared to the other two countries in the region implies that it is likely to be the dominant contributor to the IAEA's projections for the Far East. In its latest projections, the high case involves 351 GW of nuclear capacity in this region, much of which has to be in China. Even with this massive buildup, nuclear power loses market share; nuclear power contributes a slightly smaller fraction to all electricity generated in 2050 than now.

9 Conclusions

Nuclear power in China has grown dramatically in the last decade or more, in large part because of high level political decisions to promote the technology even if it was not really technically or economically justified. This rapid expansion and the ambitious targets announced by the Chinese nuclear establishment have led to the expectation that China might give the nuclear industry a new lease on life. But, as the IAEA's projections show, even if this trend is to change, and China does restart another phase of rapid expansion, nuclear power will become a smaller contributor to global electricity production than today.

This chapter has argued that because of the kinds of shifts seen in recent years, China will likely never build up the kind of nuclear power capacity that was foreseen for it even just a decade or less ago. The country is not on track to meet its current target of 58 GW of nuclear power capacity in 2020. And unless there is a substantial shift in various policies, for example, a deliberate effort to build up nuclear capacity even if it is uneconomical or otherwise undesirable, it is quite likely that the targets set in future years will, if they are to be realistic, reflect a much slower pattern of growth. There are many reasons to expect that such a policy reversal, namely for Beijing to actively promote the rapid construction of nuclear plants around the country, will not occur. In particular, there are shifts in the pattern of energy demand growth and growing public concerns about nuclear facilities that impacts the siting of reactors negatively.

The export market is not growing fast either. Despite much talk, Pakistan remains the only country to which China has exported nuclear power plants. With the rapid reductions in the costs of renewable energy technologies, especially solar photovoltaic panels, and the continued pattern of high costs and lengthy construction periods of nuclear reactors, the demand for nuclear plants is likely to decline.

One way by which nuclear enthusiasts have held on to their hope for a major revival of nuclear power is to postulate that alternate reactor designs will be introduced and constructed in large numbers. In this scenario too, China is presumed to be the main actor because of two factors: its presumed large market for nuclear reactors and the expectation that its regulatory process will approve new reactor designs more easily. But these scenarios of new reactor designs coming in to save nuclear power ignore the lengthy history of failed experiments with alternate designs and the multiple challenges faced by nuclear power, which pose conflicting priorities on reactor designers (Ramana and Mian, 2014).

Put together, these trends suggest that China is unlikely to rescue the global nuclear industry from its ongoing gradual decline.

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