Just days after the March 2011 Fukushima accident, China’s State Council suspended approvals of new nuclear power plants and created a range of rigorous measures aimed at improving the country’s nuclear-safety provisions. It was not until October 2012 that the council cautiously lifted the ban on new construction. Then-Premier Wen Jiabao announced that all newly approved reactors would need to meet third-generation criteria, meaning that they should have certain advanced inbuilt safety features lacking in most conventional second-generation reactors. China’s actions demonstrate a new resolve among its leadership to give greater consideration to the safety, rather than the economic benefits, of nuclear power. Fukushima caused concern that a similar accident in China would put the government’s nuclear programme, which is the fastest growing in the world, at serious risk. Of even greater concern was the possibility that an accident could strengthen opposition to the rule of the Communist Party.

Far-reaching changes in China’s nuclear-energy policy have been made, but the country has not moved away from its longstanding commitment to developing a plutonium-based nuclear fuel cycle, with spent-fuel reprocessing and fast-neutron reactors. The security and proliferation risks of conventional, uranium-fuelled light-water reactors (LWRs) are considered manageable. But nuclear reprocessing and fast reactors operating with plutonium-based fuel would create considerable proliferation challenges.
for China. This is because the plutonium could, in principle, be used in nuclear weapons.

One concern is that this kind of nuclear-energy fuel cycle could support China’s strategic-weapons programme. A related worry is that the subsequent export of reprocessing and fast-reactor technologies by China, running counter to international non-proliferation goals, would increase access to know-how and materials connected with nuclear weapons. Additionally, having a larger amount of weapons-usable fissile material in circulation would increase the challenge of protecting it from terrorists and other malicious actors.

Post-Fukushima safety measures
Nuclear power is a logical choice for China. Years of high economic growth have boosted electricity demand and helped cover the cost of expansion. The country has a strategic interest in increasing energy security by diversifying energy sources and decreasing its dependency on fossil fuels. A 2007 report by the World Bank and China’s State Environmental Protection Administration (SEPA) estimates that pollution costs the state around 5.8% of GDP, much of which comes from the coal-powered plants that produce the bulk of its electricity. China operates 17 power plants and is constructing a further 28. Its generating capacity will reach around 60 gigawatts (electrical) by 2020. By 2030, China will have surpassed the United States’ current installed capacity of 102GW(e). In comparison, the United Kingdom’s current capacity is 10GW(e).

Although China’s nuclear-energy programme has had no major safety incidents, there is still room for improvement in key aspects of its current nuclear-safety provisions. As well as ceasing to approve new projects, following Fukushima the state council swiftly halted construction at 26 nuclear sites. It also ordered the National Nuclear Safety Agency (NNSA), China’s nuclear watchdog, to conduct inspections of all nuclear facilities and to draft a new nuclear-safety plan. Both the inspection report and the safety plan were eventually accepted in May 2012. The plan envisages the redesign of proposed reactors to incorporate new safety features, although power plants currently under construction are spared expensive alterations. However,
the fact that 22 second-generation reactors are under construction in China, many more than in any other country, means that the majority of the states’ nuclear facilities will not meet the highest safety criteria for several decades.

Other safety deficiencies that need to be addressed relate especially to the undersized cadre of safety experts at the NNSA and the inadequate regulatory system. It is estimated that by 2020 the ratio of staff to installed capacity will be much lower than in Western countries – although Beijing promised to address this after Fukushima.³ China can drive forward and realise ambitious construction projects at impressive speed, but it is no secret that build quality sometimes falls short of the required standard. A shortage of experienced nuclear engineers is therefore a threat to nuclear safety. Similarly, China’s provisions for responding to a nuclear accident or a terrorist attack are considered inadequate due to a shortage of well-trained, experienced staff.⁴

On a structural level, China does not have an independent and sufficiently authoritative regulatory body that ensures new nuclear technology is ready for deployment and verifies the safe operation of nuclear facilities. The NNSA is supervised by the Ministry of Environmental Protection, SEPA’s replacement. In comparison, even the country’s three state-owned operators have a closer connection to the state council.⁵ At an IISS workshop on nuclear security in June 2012, a Chinese participant noted that the accident in Japan has not led to an increase of the NNSA’s independence or authority.⁶ Its Japanese counterpart’s lack of independence was found to be a key permissive cause of Fukushima.

**Long-term plans: reprocessing and fast reactors**

Beyond the current emphasis on strengthening safety provisions, China’s plans for introducing new fuel-cycle technologies create substantial proliferation risks. Since the mid-1980s, Beijing has declared its intent to reuse the plutonium in spent nuclear fuel for energy production through nuclear reprocessing, thereby ‘closing’ the nuclear fuel cycle. China’s second, closely related goal is to introduce sodium-cooled fast-neutron reactors – a type not previously used, which it will power with fuel containing plutonium – by around 2030. Operating a fast-reactor fuel cycle requires
continuous reprocessing, so China needs to master this technique before taking the next step.

Reprocessing involves the separation of uranium, plutonium and highly radioactive fission products from spent nuclear fuel. The separated plutonium can be reused for energy production in a nuclear reactor if it is combined with uranium oxide in a MOX (mixed plutonium and uranium oxides) fuel fabrication plant.

Alternatively, the separated plutonium can provide the essential ingredients for a nuclear weapon. Without the inclusion of highly radioactive fission products, diversion and transfer of separated plutonium would be relatively easy for states and, potentially, even terrorists. A crucial factor in the suitability of separated plutonium for use in weapons is how long the fuel has been used in a reactor. An LWR operating under normal condition keeps fuel in its core for 1–2 years, which complicates using the plutonium from spent fuel for weapons. Keeping the fuel in the reactor for a much shorter period will, following reprocessing, produce plutonium that is better suited to use in weapons. In such cases, just five kilogrammes of separated plutonium is sufficient for a single warhead.

China’s achievements in reprocessing have centred on a small pilot plant, commissioned in 2010, which has the capacity to recycle 50 tonnes of spent fuel per year. But China took an important step towards a commercial-scale reprocessing capability in April 2013, when the China National Nuclear Corporation (CNNC), the country’s biggest nuclear-energy company, committed to a deal with French firm Areva. Signed in the presence of Chinese President Xi Jinping and French President François Hollande, the agreement stipulates that Areva will supply CNNC with a modern, 800-tonnes-per-year reprocessing plant. The five-year negotiations leading to the agreement appear to have been challenging. Experts note that France was concerned about a possible use of the plant for China’s military nuclear programme, and insisted on technical and political assurances that any processed plutonium could not be used for military weapons. Specifically, the French
would object to locating the reprocessing plant close to the facilities at which China originally extracted plutonium for its weapons programme. It is unclear whether these matters were resolved in April’s agreement or will be addressed in the upcoming negotiations on a detailed contract, which Areva expects to last about a year.

**Arguments in favour of reprocessing**

The main argument voiced by Chinese proponents of nuclear reprocessing and fast reactors is that both technologies help increase China’s self-sufficiency in energy production, thereby strengthening its energy security. Given the scale of China’s planned nuclear-energy expansion in the next few decades, it is understandable that the country seeks technologies that make better use of uranium’s energy potential. Using MOX fuel in LWRs increases the energy utilisation of uranium by 20–30%, a modest amount. Using fast reactors in a plutonium-based fuel cycle, on the other hand, could increase energy utilisation by a factor of 50–60, according to senior Chinese experts. China currently imports more than half of its uranium, as domestic supplies are limited. However, the country is set to increase its uranium-mining efforts at home and abroad, which casts doubt on whether a shortage of uranium supplies can be used as an argument for closing the nuclear fuel cycle.

Another possible reason for China’s plans to introduce reprocessing might be the view that it should have all major technologies available for its civilian and military nuclear programmes. According to one well-respected estimate, China currently holds a military plutonium stockpile of 1,800±500kg, having ceased the production of plutonium for its weapons programme around 1990. The country is estimated to have a stockpile of 250 nuclear warheads. It cannot be ruled out that changes to China’s security environment might prompt decision-makers to restart plutonium production for military purposes. For example, China may wish to more closely match its strategic nuclear forces with those of the United States and Russia. Alternatively, China may wish to have an assured ability to overcome ballistic-missile-defence systems. The country is vocally opposing US efforts to strengthen ballistic-missile-defence systems in East Asia, despite
Washington’s claim that such moves are not aimed at China. Chinese officials fear their strategic capabilities may be undermined.\footnote{14}

There is no binding legal commitment that would hold China back from producing more plutonium for nuclear weapons. China is the only P5 country that has not officially declared a moratorium on fissile-material production for military purposes. Additionally, China is believed to support Pakistan in blocking negotiations for the Fissile Material Cut-off Treaty, an agreement that would place a global ban on the production of fissile material for nuclear weapons.

In another argument in favour of reprocessing, some Chinese experts point out that all other P5 countries, as well as India and Japan, have had commercial reprocessing programmes, so China should also master this technology.\footnote{15} Particular reference has been made to India, as Chinese thinkers see their country as lagging behind their South Asian rival in implementing fuel-cycle technologies.\footnote{16} Japan has built a major reprocessing plant in Rokkasho, although commercial operation has been delayed for years due to technical problems and safety concerns. South Korea also intends to embark on nuclear reprocessing, but this is currently prohibited under a nuclear-cooperation agreement with the United States.

**Fast-reactor development**

Fast-neutron reactors fundamentally differ from conventional LWRs in terms of fuelling, neutron moderation and cooling. Fast reactors require fuel with a much higher content of fissile material, so MOX or plutonium-based metal fuel – such as a uranium–plutonium–zirconium alloy – is preferred. LWRs use water as a neutron moderator to slow down the neutrons that maintain the nuclear chain reaction, whereas fast reactors use unmoderated, or ‘fast’, neutrons. In an LWR, water also functions as the core coolant, but in a fast reactor a material that can absorb heat more efficiently is needed. Liquid sodium is the standard choice of coolant in fast reactors.

The ultimate goal in fast-reactor development is to operate the devices in a ‘breeder’ configuration. Fast-breeder reactors have the astonishing ability to produce more plutonium than they consume, making it theoretically possible to have a fuel cycle that does not depend on access to uranium
resources. A 2010 study by the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), a forum of IAEA member states that have an active interest in this technology, goes so far as to say that a closed breeder-reactor fuel cycle ‘might de facto be considered as a renewable energy source’. Major outstanding technical challenges make such a fuel cycle a distant goal. But by incrementally integrating fast reactors and, eventually, fast-breeder reactors into its fuel cycle, China will take a big step towards achieving a high degree of energy security.

The first step came in July 2011, when the 20 megawatts (electrical) China Experimental Fast Reactor was connected to the grid. The reactor is currently fuelled with highly enriched uranium but this will eventually be replaced by MOX fuel. The next step in China’s fast-reactor programme will be the construction of the China Demonstration Fast Reactor. Beijing has not decided whether to base the reactor on a domestically developed 600MW(e) design or on a purchased Russian BN-800 reactor. Disagreements between China and Russia over the price of the BN-800 have prevented Beijing from choosing the second option.

**Technical hurdles**

The development of fast reactors has a long history; a number of countries have started down the path. But, despite many reactor-years of experience in operating experimental and pilot fast reactors globally, fast-reactor technology remains far from commercial deployment. Only four countries other than China are seriously considering further investment in their fast-reactor programmes. France is conducting studies on building a pilot fast reactor called Astrid, with a decision on its construction expected in 2019. In India, a prototype breeder reactor is due to start commercial operation in 2014. Japan’s prototype breeder reactor Monju faces long-term suspension. It has operated for only a few months since being connected to the grid in 1995, due to accidents and other safety concerns. In Russia, the BN-600 fast reactor has been operational since 1980, and the larger BN-800 is under construction and scheduled to begin operating in 2015.

One of the main reasons that fast-reactor programmes have a poor record on safety and reliability is their liquid-sodium cooling mechanism. Sodium
reacts vigorously if it comes into contact with water, and burns in air. Even minor leaks in the cooling system can cause damage to facilities. Russia’s BN-600 recorded 27 sodium leaks between 1980 and 1997, 14 of which resulted in fires. Despite these incidents, a high level of redundancy in the BN-600’s design has allowed it to operate with relatively few interruptions. The BN-600 has three parallel primary cooling loops, so if one loop needs repair following a sodium leak, the other two allow operations to continue.

To achieve a degree of reliability and safety that other countries have failed to attain, China will need to overcome major technical challenges and substantially invest in its fast-reactor programme. There is no guarantee of success, even though China has some unique advantages that might help it overcome certain barriers. Outside China, efforts to develop fast reactors have stalled because the high cost of new facilities deters investors and operators. China’s nuclear sector, in contrast, resembles a planned economy in many ways, and funding for research and development is provided by the central government. Strict regulatory requirements for new nuclear technologies and a generally uncertain future for nuclear energy in Western countries do not apply to the same extent in China. Although a state-controlled nuclear regulator may undermine nuclear safety, it can also help accelerate approval processes for new technologies.

**Security risks**

A fast-reactor fuel cycle significantly increases access to weapons Usable fissile material, as such reactors typically run on either MOX or plutonium-based metal fuel. This is another reason why the development of fast reactors has fallen out of favour in many countries.

There are some technical barriers that can be implemented to make the illicit diversion of fissile materials harder. The 2010 INPRO report notes several apparent advantages in the proliferation resistance of a hypothetical fast-breeder fuel cycle. Crucially, however, technical barriers can only delay a determined proliferator, and do not completely remove the proliferation vulnerabilities of a fast breeder system. For example, INPRO suggests that reprocessing could be made more resistant to proliferation through the use of technologies that do not produce a stream of separated...
plutonium – such as pyroprocessing – instead of the conventional PUREX (plutonium–uranium extraction) process. But pyroprocessing has never been tested on a commercial scale, and the extent to which it increases proliferation resistance is uncertain because plutonium can still be extracted in a separate step. The PUREX process is well documented and relatively straightforward, making it the technology most likely to be used in China’s planned commercial reprocessing facility.

Other apparent advantages noted by the INPRO report are that the fast breeder fuel cycle does not require uranium enrichment and that less plutonium would be accumulated over time in disposed LWR spent fuel. However, China and other countries that may establish a fast breeder fuel cycle will not give up the enrichment technologies they possess. In a fast-reactor fuel cycle, the amount of plutonium-laced nuclear waste that has to go into long-term underground storage is greatly reduced, but this is a negligible proliferation advantage in light of the fact that a large amount of relatively accessible plutonium would circulate between nuclear facilities.

If China becomes the first country to demonstrate that fast reactors can be safe, reliable and commercially viable, it may export its technology to states that seek an equally high degree of energy security. However, the spread of reprocessing technologies and reactors operating with plutonium-based fuel goes against international non-proliferation goals. Although China is a member of the Nuclear Suppliers Group (NSG), a coalition of nuclear exporters who have agreed to restrict their transfer of sensitive nuclear technologies in accordance with non-proliferation goals, it is possible that in certain cases Beijing will prioritise commercial and strategic interests over non-proliferation norms. Although this is only a hypothetical problem, China’s credibility has been damaged by an ongoing dispute with other NSG members over its export of two nuclear reactors to Pakistan. China is considered to have circumvented the NSG requirement that nuclear technologies only be supplied to countries that have reached a comprehensive safeguards agreement with the IAEA. (Pakistan does not have such an agreement because it has not signed the Non-Proliferation Treaty.)

The challenges of generating nuclear power securely intensify with the complexity of the fuel cycle. Additional reprocessing facilities and the use
of longer transport routes for nuclear materials increase a nuclear programme’s vulnerability to sabotage and the chance that such materials will be diverted by terrorists. A research project by the IISS found that China has made significant efforts to improve nuclear security in the past five years. For example, China’s intense cooperation with the IAEA and the US Department of Energy helped to reduce on-the-ground threats. China is also actively engaged with the Nuclear Security Summit initiative, a series of high-level political meetings intended to strengthen practices and regulations to prevent nuclear and radiological terrorism globally. However, China could do more to increase international confidence that its nuclear programme is secure through measures such as making its nuclear-security regulations and practices more transparent.

The rapid expansion of China’s nuclear-power programme justifies its research into technologies that promise a high degree of energy security and a reduction in the amount of nuclear waste that has to be put into long-term storage. But there is more at stake in the development of China’s nuclear fuel cycle than mere choice of technology. Beijing’s nuclear-energy policy has a direct impact on China’s energy security, the international nuclear industry and global security.

Although outside observers are predominantly concerned about global proliferation risks, China has three other good reasons to re-evaluate its plans to move towards a plutonium-based nuclear fuel cycle. Firstly, following Fukushima it makes more sense to direct financial resources and nuclear engineering capacity towards improving safety provisions of current and future LWRs. The October 2012 State Council decision made clear that in the long term, third-generation technology will play an important part in running China’s vast nuclear fleet safely. The country’s three nuclear operators have more actively promoted their new third-generation designs since summer 2012, but only six third-generation reactors are currently under construction in China, and they will be among the world’s first. It will require time and additional resources for operators and regu-
lators to gain experience with these reactors and to further improve their designs.

Secondly, many experts have concluded that using reprocessed MOX fuel in LWRs makes little economic sense for any country in the foreseeable future.\textsuperscript{29} Uranium fuel accounts for around 5\% of the electricity-generating cost of a nuclear reactor.\textsuperscript{30} A well-respected study by the Nuclear Energy Agency and the IAEA concludes that identified uranium resources will be sufficient for more than a century, based on current requirements.\textsuperscript{31} A significant increase in uranium prices appears unlikely in the next few decades, so there are no economic benefits to recycling spent fuel using highly expensive reprocessing and MOX-fuel production facilities. A 2011 cost estimate that considers various development scenarios for China’s nuclear fuel cycle illustrates this point. The cost of putting all of China’s spent fuel into storage until 2035 is estimated to be $319 million.\textsuperscript{32} In comparison, the cost of recycling plutonium and making MOX fuel is estimated to be around $17 billion.\textsuperscript{33} China argues that it requires MOX fuel for its planned fleet of fast reactors, but many technical hurdles must be overcome to obtain a commercially viable fast-reactor design. If fast reactors fail to materialise, much of the investment in reprocessing will have gone to waste and any plutonium that will have already been separated will pose a legacy problem.

Thirdly, public acceptance of nuclear power has become an increasingly important factor in Chinese nuclear policy. Before Fukushima, the Chinese public was considered to be relatively supportive of nuclear power because it acutely felt the environmental consequences of coal-powered electricity generation.\textsuperscript{34} But the accident in Japan brought the risks of nuclear power into the public consciousness. In the days after the accident, when radioactive plumes were thought to be threatening to drift over China, the rumour that consuming iodised salt protects against radiation led to the panic buying of salt across the country.\textsuperscript{35} This initial turmoil quickly faded but the Chinese public has become more sceptical about safety provisions at domestic facilities. No strong and well-organised anti-nuclear movement like those in Germany or Japan has emerged, but there is opposition to individual nuclear projects. In early 2012, for example, a formal request to suspend construction of the Pengze reactor in Jiangxi province was sent to Beijing, following public pressure.\textsuperscript{36}
This opposition to the construction of nuclear facilities by local residents can be seen as part of the wider trend of public protests becoming more frequent and effective in China. In recent years, there have been reports of numerous violent public protests against major industrial projects, mainly stemming from concerns about their local environmental impact. Beijing is right to be worried that a safety or security incident could provoke a substantial public backlash. China may therefore benefit from choosing to forego nuclear technologies that markedly increase safety and security risks.

Notes


6 Chinese participant in the IISS workshop on nuclear security, Qingdao, 14–15 June 2012.


China’s Nuclear Fuel Cycle and Proliferation Risks


15 Personal communication with Chinese expert, June 2012.

16 Chinese participant in the IISS workshop on nuclear security, Qingdao, 14–15 June 2012.


A summary report of the final workshop conducted as part of this project is available on the IISS website: http://www.iiss.org/en/events/events/archive/2012-4a49/june-7879/workshop-on-nuclear-security-qingdao-china-8c59.


‘China’s Gen-III – Safe and Reliable?’, Nuclear Intelligence Weekly, vol. 6, no. 22, 1 June 2012, p. 4.


Zhou, ‘China’s Spent Nuclear Fuel Management’, p. 4368. This estimate is based on the assumption that only the required amount of MOX fuel is produced (as opposed to running facilities at full capacity, which would cost more), and takes into account some foreseeable delays to the programme.


