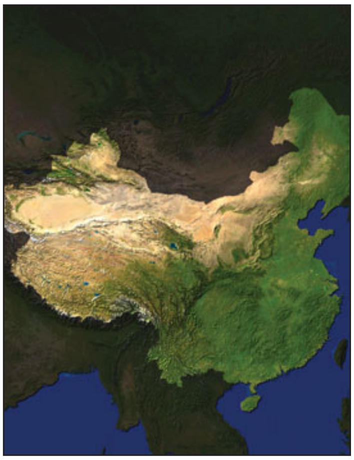

China's nuclear resolve

By **Angela Saini**
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Meeting the energy needs of a country as vast and populous as China is no mean feat—electricity consumption rose by 11.7% in 2011. It is also a challenge that is unlikely to be met without the help of nuclear power. Today, less than 2% of electricity in the country is produced by nuclear reactors, with more than 80% coming from coal, and the remainder from hydropower, renewable sources, oil, and gas. But by 2020, that proportion is set to go up to 5 percent. It means building at least 40 new plants, up from 14 operational reactors that are now producing 11.9 GW of electricity. In 2020, China's installed nuclear power capacity will reach 70 GW. Some of these units will also be built inland alongside rivers, rather than along coastlines as is usual, to meet the surging power demands of inland China.

Like the United Kingdom, the United States, and India, safety concerns raised by the Fukushima disaster have not shelved China's plans. In the aftermath of the Japanese tsunami, there were comprehensive safety checks on all plants, including those under construction, said En-Hou Han, head of the Corrosion Center in the Institute of Metal Research at the Chinese Academy of Sciences in Shenyang. "Some safety procedures were changed," he said. In February, the National Energy Administration also launched a series of research projects around nuclear safety, including the development of passive emergency power supply and cooling systems.

On top of this, the latest nuclear plant designs are far more advanced than older ones like Fukushima Daiichi, which was built in the 1960s. Among the 27 new reactors under construction in China right now—including French, Russian, and Canadian designs, as well as Chinese ones—are four third-generation AP1000 reactors, manufactured by the US firm, Westinghouse. "Even without people operating it, the system will cool down automatically in an emergency," said Han.

But constructing such a huge number of facilities is clearly an enormous materials challenge—even more so because the operating conditions inside reactors are particularly severe, and standards in the nuclear industry are so high. "From a materials point of view, nuclear power uses the most advanced materials, so they are very difficult to make," said Han. And this has proven to be a test for Chinese manufacturers. "For most existing reactors in operation in China, I would say that more than half are imported. Foreign companies supply most of the core materials," said Lumin Wang, a professor in the Department of Nuclear Engineering and Radiological Sciences at the University of Michigan, but is currently working with Xiamen University to develop a center to evaluate the radiation tolerance of reactor materials. Wang, a US citizen, said, "a nuclear accident anywhere in the world would be an accident everywhere, thus international collaboration in this area would benefit the whole world."

Now, as its energy plans mature, the country is finally beginning to develop a formidable nuclear manufacturing capability of its own. "China has a big campaign for localization, steadily increasing domestic production of materials in the next few years," said Wang. Such is the growth of this industry, said Han, that within 10 to 15 years, China may be able to produce all the materials required to construct nuclear plants from within the country.

The most important of the four major materials needed to do this is high-grade stainless steel, used in the main pipe that feeds water into the reactor, and in the reactor vessel itself. "The materials themselves are not so difficult to make. The material's actual structure, chemical properties, and mechanical properties, is not difficult. But it's hard to make big parts with good reliability and no defects," said Han. This challenge is down to scale. In some of the new generation reactors, the main pipe is nearly a meter in diameter. They must also last longer than their predecessors (typically for 60 years, rather than 30 or 40), which means that parts need to be more robust and resistant to corrosion. This has prompted a move away from cast to forged steel, said Han, because engineers believe it to have better mechanical and corrosion properties.

Another critical part of a reactor is the steam generator tube, typically made from a 690 nickel-based superalloy. In 2009, Baosteel, a state-owned company, and globally the second-largest steel producer, began production of Inconel 690, a high-chromium nickel alloy. This is now "widely used in chemical and nuclear industries in China," said Ning Wang, chief materials scientist at Baosteel, based in Shanghai.

But the challenges in producing Inconel 690 have been "great," he said. "From a metallurgical point of view, this material must be super clean and have uniform grain structure, a defect-free surface, and balanced mechanical properties. Every process, including melting, forging, extruding, rolling, polishing, tube bending, and heat treatment needs to be controlled very stringently. The process flow is

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comparatively long and complicated," he said.

Other important materials include A508-III low-alloy steel, which is used in the reactor vessel, and zirconium alloys, which are the first protective layer of cladding around the uranium fuel. Clearly, both must have very good anti-irradiation properties. Han said that Chinese firms are already producing both low-alloy steel and stainless steel for use in nuclear reactors. Zirconium alloys, however, have proven more of a challenge and are still imported, mainly from the United States and France.

"The problem with the zirconium cladding is that it is very thin and very long," said Lumin Wang. These tubes can be as large as four meters in length, and only half a millimeter thick. "The material also suffers strong radiation effects and corrosion—both oxidation and hydriding—from the high temperature and pressure inside the reactor vessel." Even so, several research groups and industrial companies inside China are working on the problem. "China wants to develop its own brand of material," said Wang.

But why is China so keen to develop its own materials, rather than continuing to simply import them? Part of the reason is cost: in the longer term, it may be cheaper for the country to produce its own materials than to buy them from overseas. Another reason is that the country has far bigger plans on the nuclear front that will see it attempt to become self-sufficient in reactor design. China developed its first indigenous nuclear reactor in 1985, and now has a technology transfer agreement with Westinghouse that will see it produce its own third-generation reactors in the future. Developing the materials for the construction and maintenance of these new plants "is a strategically important thing for China," said Lumin Wang. According to L.V. Krishnan, former safety director at the Indira Gandhi Center for Atomic Research in India, China's latest reactor designs are destined for export as well as domestic use. Potential markets include Turkey, Pakistan, and the United Arab Emirates, he suggests, adding that, "Chinese manufacturers have already begun supplying equipment for reactors in France."

Nuclear power seems destined to become a bigger slice of China's energy mix. The predominance of fossil fuels in China has led to high levels of carbon emissions. As a result, some of the most inefficient coal-fired power plants have already been closed, and annual coal consumption has dropped by around 82 million tons since 2006, according to the World Nuclear Association.

Two nuclear reactors, out of the six in operation at the Daya Bay nuclear power station, which began commercial operation in 1994. It was the second nuclear facility in Mainland China. *Credit:* Professor Lumin Wang, University of Michigan.

As well as investing in second- and third-generation nuclear plants, China is now actively developing fourth-generation reactors, said Han, which are designed to be safer, cleaner, and more cost-effective. "In this case, new materials are one of the main barriers," he said. For China to meet its nuclear targets, foreign materials manufacturers may not even be able to keep up with demand, and this makes it imperative for China to develop the necessary alloys itself. Indeed, these fourth-generation plants do not even use zirconium cladding, said Lumin Wang. This is driving Chinese researchers to develop new kinds of materials altogether, including silicon carbides and oxide dispersion strengthened steel, which is more radiation-tolerant than steels currently used in nuclear reactors.

In the longer term, the country has also set its sights on fusion power. With a 10% stake in the International Thermonuclear Experimental Reactor project, China is investing "relatively large efforts" into researching the types of materials such a reactor might need, said Lumin Wang. Among these are tungsten alloys, which would be used to build the wall that directly faces the thermonuclear plasma. Others include low-activation steels and silicon-carbide–based composite materials.

The challenge is as pressing as it is immense. At the end of 2009, China budgeted $600 billion for extending and upgrading its power grid. The country will struggle to meet these huge electricity demands with more nuclear power in the future unless the materials exist to make it happen.