World Nuclear Association

China's Nuclear Fuel Cycle

(Updated 7 December 2010)

- **Although China intends to become self-sufficient in most aspects of the fuel cycle, it relies increasingly on imported uranium as well as conversion, enrichment and fabrication services from other countries.**
- **Domestic uranium mining currently supplies about one-half of China's nuclear fuel needs. Exploration and plans for new mines have increased significantly since 2000, but state-owned enterprises have also entered into agreements to aquire uranium resources internationally.**
- **China's two major enrichment plants were built under agreements with Russia in the 1990s and, under a 2008 agreement, Russia will help build additional capacity and also supply low-enriched uranium to meet future needs.**

China has stated it intends to become self-sufficient not just in nuclear power plant capacity, but also in the production of fuel for those plants. However, the country still relies on foreign suppliers for all stages of the fuel cycle, from uranium mining through fabrication and reprocessing. As China rapidly increases the number of new reactors, it has also initiated a number of domestic projects, often in cooperation with foreign suppliers, to meet its nuclear fuel needs.

Uranium resources and mining

China's known uranium resources of 100,000 tU are inadequate for the country's needs. Production of some 840 t/yr – including that from heap leach operations at several mines in Xinjiang region – supplies enough for about 4000 MWe. By international standards, China's ores are low-grade and production has been inefficient.

Increasingly, uranium is imported from Kazakhstan, Namibia, Niger and most recently Australia, with other sources progressively being added.

Operating uranium mines

Mine[a]	Province	Type	Nominal capacity (tonnes U per year)	Started
Fuzhou	Jiangxi	Underground & open pit	300	1966
Chongyi	Jiangxi	Underground & open pit	120 expanding to 270	1979
Yining	Xinjiang	In-situ leach (ISL)	300	1993
Lantian	Shaanxi	Underground	100	1993
Benxi	Liaoning	Underground	120	1996
Quinglong	Liaoning	Underground	100	2007
Shaoguan	Guangdong	Underground	160	2008

China National Nuclear Corporation (CNNC) is the only supplier of domestic uranium. China Nuclear Uranium Corporation, a subsidiary of CNNC, plans to bring into production a new 200 tU/yr mine at Fuzhou, and expand the Yining ISL mine to 300 tU/yr. Pilot ISL tests have been under way on the Shihongtan deposit in the Turpan-Hami basin of Xinjiang. In addition, the Hengyang underground uranium mine is on stand-by. The mine, which started up in 1963, has a nominal production capacity of 500-1000 tU/yr.

CNNC is also developing a uranium-molybdenum mine at Guyuan, Hebei province, to start production in 2009. It has also reported the Dongsheng uranium deposit in sandstones of the Ordos Basin of northern Inner Mongolia, containing an estimated 30,000 tonnes of uranium in a palaeochannel system.

CNNC's Bureau of Geology and the Beijing Research Institute of Uranium Geology are the key organisations involved with a massive increase in exploration effort since 2000, focused on sandstone deposits amenable to ISL in the Xinjiang and Inner Mongolia regions. CGNPC subsidiary China Guangdong Nuclear Uranium Resources Co Ltd (CGN-URC) is investing in uranium exploration in Xinjiang, and also in Guangdong, via CGN-URC Guangdong Uranium Ltd.

Exploring alternative sources of uranium, in 2007 CNNC commissioned Sparton Resources of Canada with the Beijing No.5 Testing Institute to undertake advanced trials on leaching uranium from coal ash out of the Xiaolongtang power station in Yunnan. The ash contains 160-180 ppm U - above the cut-off level for some uranium mines. The power station ash heap contains over 1700 tU, with annual arisings of 106 tU. Two other nearby power stations burn lignite from the same mine.

Uranium imports and future supply from mines

With the prospective need to import much more uranium, China Nuclear International Uranium Corporation (SinoU) was set up by CNNC to acquire uranium resources internationally. It is setting up a mine in Niger and is investigating prospects in Kazakhstan (see below), Uzbekistan, Mongolia, Namibia, Algeria and Zimbabwe. Canada and South Africa are also seen as potential suppliers for SinoU.

Sinosteel Corporation holds minor equity in explorer PepinNini Minerals Ltd in Australia and has 60% of a joint venture with PepinNini to develop a uranium deposit in South Australia. China-based CITIC Australia holds 10.5% of Marathon Resources. Sinosteel is also involved with exploration on Quebec and Krygystan.

CGNPC has been more active in securing foreign supplies of uranium. In September 2007, two agreements were signed in Beijing between Kazatomprom and CGNPC on Chinese participation in Kazakh uranium mining joint ventures and on reciprocal Kazatomprom investment in China's nuclear power industry. These came in the context of an earlier strategic cooperation agreement and one on uranium supply and fuel fabrication. This is a major strategic arrangement for both companies, with Kazatomprom to become the main uranium and nuclear fuel supplier to CGNPC. A framework strategic cooperation agreement was then signed with CNNC. A CGNPC subsidiary, Sino-Kazakhstan Uranium Resources Investment Co, has invested in two Kazakh uranium mines: Irkol and Semizbai, while CNNC is investing in another: Zhalpak. In November 2010 CGNPC signed a long-term contract with Kazatomprom for 24,200 tonnes of uranium through to 2020.

In November 2007 CGNPC signed an agreement with Areva to take a 24.5% equity stake in its UraMin subsidiary, which is proposing mines in Namibia, South Africa and Central African Republic. (This appears to be part of the €8 billion Taishan deal – see Embarking upon Generation III plants section in page on Nuclear Power in China.) In October 2008, Areva announced that a further 24.5% would be taken up by other 'Chinese sovereign funds', though it would remain the operator. China also agreed to buy more than half of the uranium from UraMin over the lifetime of the three deposits – the total quantity involved is over 40,000 tU to 2022.

Then, in November 2010, CGNPC signed a $3.5 billion, ten-year contract with Areva for supply of

20,000 tonnes of uranium.

In March 2009, CNNC International, a 70% subsidiary of CNNC Overseas Uranium Holding Ltd and through it, of SinoU, agreed on a $25 million takeover of Western Prospector Group Ltd which controls the Gurvanbulag deposit in Mongolia, very close to the Chinese border. At the end of June CNNC held 69% of Western Prospector and acquired the remainder in August 2009. Western Prospector and its Mongolian subsidiary, Emeelt Mines, undertook a definitive feasibility study which showed that the project was barely economic, on the basis of 6900 tU reserves averaging 0.137% U. With radiometric sorting the head grade would be 0.152%U and the mine could produce 700 tU/yr for nine years. Mine development cost would be about $280 million. This whole CNNC stake in Mongolia appears to be on hold and its future in doubt.

In March 2009, CGNPC set up China Guangdong Nuclear Uranium Resources Co (CGN-URC) to be responsible for its uranium supply. It has embarked upon a 50-50 joint venture with Uzbekistan's Goskomgeo focused on black shales the Sino-Uz Uranium Resources Co Ltd (or Uz-China Uran LLC), in particular the Boztau uranium exploration project in the Central Qizilqum desert of the Navoi region of Uzbekistan.

In mid-2010, CGNPC signed a framework agreement with Cameco under which the two companies will negotiate long-term uranium purchase agreements and potential joint development of uranium resources. In November the Cameco sale of 11,200 tonnes of uranium through to 2025 was confirmed.

In mid-2009, CNNC announced that it planned to be producing 700 tU/yr of uranium from a mine in Jordan from 2010.

Conversion

A conversion plant at Lanzhou of about 1000 tU/yr started operation in 1980 but may now be closed. Another conversion plant at Diwopu, Jiuquan, near Yumen in northwest Gansu province, is about 500 tU/yr, though Areva quotes 2000 t/yr for both plants in 2006.

Enrichment and enriched uranium imports

In 2010 China will need 3600 tU and 2.5 million SWU of enrichment. In 2020 it expects to need 10,000 tU and 7 million SWU.

A Russian centrifuge enrichment plant at Hanzhun, SE Shaanxi province, was set up under 1992, 1993 and 1996 agreements between Minatom/Tenex and China Nuclear Energy Industry Corporation (CNEIC) covering a total 1.5 million SWU/yr capacity in China at two sites. The first two modules at Hanzhun came into operation in 1997-2000, giving 0.5 million SWU/yr as phases 1 & 2 of the agreements. In November 2007, Tenex undertook to build a further 0.5 million SWU/yr of capacity at Hanzhun, completing the 1990s agreements in relation to the Hanzhun plant. This is to be commissioned late in 2011.

The full agreement for this $1 billion plant was signed in May 2008 between Tenex (Techsnabexport) and China Nuclear Energy Industry Corporation. The site, or at least two phases of it, is under IAEA safeguards. Up to 2001 China was a major customer for Russian 6th generation centrifuges, and more of these are being supplied in 2009-10 for Hanzhun, under phase 4 of the agreement.

The Lanzhou enrichment plant in Gansu province to the west started in 1964 for military use and operated commercially 1980 to 1997 using Soviet-era diffusion technology. A Russian centrifuge plant of 500,000 SWU/yr started operation there in 2001 as phase 3 of the above agreements and it is designed to replace the diffusion capacity.

Another and larger diffusion enrichment plant operated at Heping, Sichuan province, from 1975 to 1989 for military purposes. It was indigenously built, about 200-250,000 SWU/yr capacity, but is likely no longer operational.

Enriched uranium

Much of the enriched uranium for China's reactors comes from outside the country.

A contract with Urenco supplies 30% of the enrichment for Daya Bay from Europe.

Under the May 2008 enrichment agreement Tenex is to supply (from Russia) 6 million SWU as low-enriched uranium product from 2010 to 2021 for the first four AP1000 reactors, this apparently being related to completion of the Hanzhun enrichment plant. It is expected to involve $5 to 7 billion of LEU and possibly more. Enriched uranium for the first four AP1000 reactors is being supplied by Tenex from Russia, under the 2008 agreement.

Fuel fabrication

CNNC is responsible for fuel fabrication, utilising some technology transferred from Areva, Westinghouse and TVEL. CNNC's main PWR fuel fabrication plant at **Yibin**, Sichuan province, was set up in 1982 to supply Qinshan 1. It is operated by CNNC subsidiary China Jianzhong Nuclear Fuel (JNF), and by October 2008 was producing fuel assemblies with 400 tU/yr. It now produces about 600 tU/yr, and aims for 1000 tU/yr or more by 2020.

VVER fuel fabrication at Yibin began in 2009, using technology transferred from TVEL under the fuel supply contract for Tianwan. (First core and three reloads for Tianwan 1&2 were from Novosibirsk Chemical Concentrate Plant in Russia – 638 fuel assemblies, under the main contract.) By August 2010, Yibin had produced 54 VVER-1000 fuel assemblies which were being loaded into the Tianwan units. In November 2010, TVEL contracted with Jiangsu Nuclear Power Corporation (JNPC) and the China Nuclear Energy Industry Corporation (CNEIC) to supply six fuel reloads for Tianwan 1, and the technology for fuel to be produced at Yibin thereafter, for about US$ 500 million. The two units run on 18-month refueling cycles.

CNNC set up a second fuel fabrication plant at **Baotou**, Inner Mongolia, in 1998. This fabricates fuel assemblies for Qinshan's CANDU PHWRs and some PWRs. It is operated by CNNC subsidiary China North Nuclear Fuel Co Ltd. It is also planned to make the 9% enriched fuel spheres for the HTR-PM high temperature reactors in Shandong province here.

In 2008 SNPTC agreed with both fuel companies to set up CNNC Baotou Nuclear Fuel Co Ltd to make fuel assemblies for China's AP1000 reactors (first cores and some re-loads of the initial units will supplied by Westinghouse).

In order meet its goal of being self-sufficient in nuclear fuel supply, additional fuel production capacity will be required. However, the fuel for Taishan being supplied to CGNPC by Areva, comprising the two first cores and 17 reloads, will be fabricated in France.

Areva has announced the prospect of a joint venture with CNNC to produce and market zirconium alloy tubes for nuclear fuel assemblies. The joint venture, CNNC Areva Shanghai Tubing Co. (CAST), could start production at a plant in Shanghai at the end of 2012.

Reprocessing, recycling

A pilot (50 t/yr) reprocessing plant using the Purex process was opened in 2006 at Lanzhou Nuclear Fuel Complex. This is capable of expansion to 100 t/yr and was commissioning in 2009, possibly at this level. A large (800-1000 t/yr) commercial reprocessing plant based on indigenous advanced technology was planned to follow and begin operation about 2020, but has probably been superseded by the Areva project.

In November 2007, Areva and CNNC signed an agreement to assess the feasibility of setting up a reprocessing plant for used fuel and a mixed-oxide (MOX) fuel fabrication plant in China, representing an investment of €15 billion. The 800 t/yr reprocessing plant will apparently be at Jiayuguan in Gansu province, employing advanced French technology and operated by Areva. Design, construction and commissioning was expected to take ten years from 2010. In November 2010, an industrial agreement on this was signed, which Areva said was "the final step towards a commercial contract" for the project.

The China Institute of Atomic Energy (CIAE) shows an industrial reprocessing plant of about 1000 t/yr in operation from about 2021.

Mixed-oxide (MOX) fuel

In October 2010, GDF Suez Belgian subsidiary Tractabel, with Belgonucleaire and the nuclear research centre SCK-CEN signed an agreement with CNNC to build a pilot mixed oxide (MOX) fuel fabrication plant in China. Belgium has experience in MOX fuel development and production dating back to 1960, including 20 years of industrial MOX production at Belgonucleaire's 35 tonne per year Dessel plant from 1986 to 2006 (see section on Fuel cycle in the information page on *Nuclear Power in Belgium*). MOX has been in use in Belgium's nuclear power plants since 1995.

Fuel for the BN-800 reactors (referred to as Chinese Demonstration Fast Reactors – see see section below on Fast neutron reactors) planned to be built at Sanming will be MOX pellets, initially made in Russia.

CIAE shows two 40 t/yr MOX fabrication plants in operation from about 2018. A 50 t/yr MOX reprocessing plant is under consideration for operation by 2030.

Waste management

When China started to develop nuclear power, a closed fuel cycle strategy was also formulated and declared at an International Atomic Energy Agency conference in 1987. The used fuel activities involve: at-reactor storage; away-from-reactor storage; and reprocessing. CNNC has drafted a state regulation on civil spent fuel treatment as the basis for a long-term government program.

Based on expected installed capacity of 20 GWe by 2010 and 40 GWe by 2020, the annual used fuel arisings will amount to about 600 tonnes in 2010 and 1,000 tonnes in 2020, the cumulative arisings increasing to about 3,800 tonnes and 12,300 tonnes, respectively. The two Qinshan Phase III CANDU units, with lower burn-up, will discharge 176 tonnes of used fuel annually.

Storage and disposal

A centralised used fuel storage facility has been built at Lanzhou Nuclear Fuel Complex, 25 km northeast of Lanzhou in central Gansu province. The initial stage of that project has a storage capacity of 550 tonnes and could be doubled. It or an intermediate-level waste repository there is 10-20 m underground.

Separated high-level wastes will be vitrified, encapsulated and put into a geological repository some 500 metres deep. Site selection has been under way since 1986 and is focused on three candidate locations in the Beishan area of Gansu province and will be completed by 2020. All are in granite. An underground research laboratory will then be built 2015-20 and operate for 20 years. Disposal of high-level wastes in to a national repository is anticipated from 2050.

Industrial-scale disposal of low- and intermediate-level wastes is at two sites, near Yumen in northwest Gansu province, and at the Beilong repository in Guangdong province, near the Daya Bay nuclear plant.

Industrial parks

Two significant industrial parks focused on nuclear power were announced in 2010 and are being set up.

The first is a nuclear technology base near Nanjing in Jiangsu province, known as the Nanjing Jiangning Binjiang Development Zone, and part of the China Nuclear Binjiang Production Base which includes a research facility for nuclear-grade concrete. China Huaxing Nuclear Construction Company (HXCC) will build this on the banks of the Yangtze River about 300 km west of Shanghai, in three phases to 2015. Nanjing is a transport hub, and the overall 51 square kilometre development zone will be served by a new river port including a bulk cargo terminal and 12 deep-water piers.

The zone will feature as its centrepiece a $146 million factory for pre-assembled structural and equipment modules for CPR-1000 and Westinghouse AP1000 reactors. The modules, weighing up to nearly 1000 tonnes each in the case of AP1000, can then be taken by barge to construction sites. Currently AP1000 modules are made by Shandong Nuclear Power Equipment Manufacturing Co. which has the capacity to support construction of two reactors per year. HXCC is the main civil engineering contractor for China Guangdong Group.

The second is the China Nuclear Power City, launched by CNNC at Haiyan, Zhejiang province, on the Yangtze delta about 120 km southwest of Shanghai and close to the cities of Hangzhou, Suzhou and Ningbo. As well as having the nuclear power plants in the Qinshan complex nearby, Haiyan hosts the headquarters of 18 leading Chinese nuclear equipment suppliers and branch offices of all the major Chinese nuclear design institutes and construction companies. The new China Nuclear Power City will cover 130 square kilometers and has a 10-year budget of $175 billion, according to reports. It is expected to have four main areas of work: development of the nuclear power equipment manufacturing industry; nuclear training and education; applied nuclear science industries (medical, agricultural, radiation detection and tracing); and promotion of the nuclear industry.

The Haiyan Nuclear Power City is entitled to all the preferential benefits granted to national economic and technological zones and national hi-tech industrial zones. Enterprises in the industrial park will enjoy priority for bidding quota, bidding training, qualification guidance and specific purchasing with CNNC. The concept is based on the French equivalent in the Burgundy area, and French suppliers will be involved at Haiyan, as will CGNPC.

As well as these major industry centres there is a factory for AP1000 modules set up at Haiyang, on the coast, and another planned for Hubei province to support inland AP1000 projects.

A further centre, the Taishan Clean Energy (Nuclear Power) Equipment Industrial Park, opened in February 2010 in the Pearl River Delta region of Guangdong province, and is expected to become a centre for nuclear power equipment manufacturing, initially supplying hardware and services to nearby nuclear power projects. The planned development will eventually cover about 45 sq km and include design, R&D and technical services. The initial 3.1 sq km phase of the park costing CNY 2 billion will be followed by second 2.4 sq km phase. Targets call for manufacturers at the park to have 45% of the nuclear equipment market in Guangdong and produce goods worth CNY 22 billion by 2020 while playing a leading role in R&D and maintenance of nuclear power equipment. The park also plans to produce CNY 20 billion in goods not related to the power industry by 2020.

Research & development

Initial Chinese nuclear R&D was military. A water-cooled graphite-moderated production reactor for military plutonium started operating in 1966, located at the Jiuquan Atomic Energy Complex some 100 km northwest of the city of Jiuquan in Gansu province, north-central China. The area is mainly desert and very remote. In the early 1980s it was decided to convert it to dual-use, and plutonium production evidently ceased in 1984. Reprocessing was on site. Another, larger, plutonium production reactor with associated facilities was in a steep valley at Guangyuan in Sichuan province, about 1000 km south. It started up about 1975 and produced the major part of China's military plutonium through to 1991.

Apart from military facilities, China has about 15 operational research reactors, including the 125 MW light water High-Flux Engineering Test Reactor (HFETR) run by the (Southwest) Leshan Nuclear Power Institute of China at Jiajiang, Sichuan province, since 1979. Early in 2007, this was converted to use low-enriched uranium, with the help of the US National Nuclear Security Administration (NNSA). The HWRR-II 15 MW heavy water reactor, which was operating since 1958, was shut down at the end of 2007. The 60 MW China Advanced Research Reactor (CARR) is under construction and the 65 MW China Experimental Fast Reactor (CEFR) started up in July 2010 (see see section below on Fast neutron reactors). At least one of the five research reactors in Sichuan province was near the epicentre of the May 2008 earthquake.

In October 2010, the Belgian nuclear research centre SCK-CEN signed an agreement with the China Academy of Sciences to collaborate on the Belgian Myrrha project[b], which China sees as a way forward in treating nuclear wastes.

In 2008, SNPTC and Tsinghua University set up the State Research Centre for Nuclear Power Technology, focused on large-scale advanced PWR technology and to accelerate China's independent development of third-generation nuclear power.

A 200 MWt NHR-200 integral PWR design for heat and desalination has been developed by Tsinghua University's Institute of Nuclear Energy Technology (INET) near Beijing. It is developed from the 5 MW NHR-5 prototype which started up in 1989.

The NDRC is strongly supporting R&D on advanced fuel cycles, which will more effectively utilise uranium, and possible also use thorium. The main research organisations are INET at Tsinghua University, China Institute of Atomic Energy (CIEA), also near Beijng, and the Nuclear Power Institute of China (NPIC) at Chengdu, which is the main body focused on the PHWR technology and fuel cycles. INET has been looking at a wide range of fuel cycle options including thorium, especially for the Qinshan Phase III PHWR units. NPIC has been looking at use of reprocessed uranium in Qinshan's PHWR reactors. CIAE is mainly involved with fast reactor R&D. China's R&D on fast neutron reactors started in 1964.

Recycled uranium in PHWRs; thorium in PHWRs

Early in 2008, CNNC subsidiary NPIC signed an agreement with Atomic Energy of Canada Ltd (AECL) to undertake research on advanced fuel cycle technologies such as recycling recovered uranium from used PWR fuel and Generation IV nuclear energy systems. Initially this seems to include DUPIC, the direct use of used PWR fuel In Candu reactors, the main work on which so far has been in South Korea. This blossomed into a strategic agreement among AECL, the Third Qinshan Nuclear Power Company (TQNPC), China North Nuclear Fuel Corporation and NPIC in November 2008. The four partners are jointly developing technology for recycling used nuclear fuel from other Chinese reactors (PWRs) with up to 1.6% fissile content for use in the Qinshan Phase III Candu units. The first commercial demonstration of this is underway in unit 1 of Qinshan Phase III, using 12 fuel bundles with recycled uranium blended with depleted uranium to give natural uranium equivalent, similar to normal Candu fuel. Subject to supply from reprocessing plants, a full core of natural uranium equivalent is envisaged.

Phase one of the AECL agreement was a joint feasibility study to examine the economic feasibility of utilizing thorium in the Qinshan Phase III PHWRs. (Geologically, China is better endowed with thorium than uranium.) This involved demonstration use of eight thorium oxide fuel pins in the middle of a Canflex fuel bundle with low-enriched uranium.

In July 2009, a second phase agreement was signed among these four parties to jointly develop and demonstrate the use of thorium fuel and to study the commercial and technical feasibility of its full-scale use in Candu units. This was supported in December 2009 by an expert panel appointed by CNNC and comprising representatives from China’s leading nuclear academic, government, industry and R&D organizations. The panel also unanimously recommended that China consider building two new Candu units to take advantage of the design's unique capabilities in utilizing alternative fuels.

China Institute of Atomic Energy

The China Institute of Atomic Energy (CIEA) near Beijing undertakes fundamental research on nuclear science and technology, and is the leading body in relation to fast neutron reactors. Its 15 MWt heavy water research reactor started up in 1958 and was shut down at the end of 2007. An updated version of this was supplied to Algeria and has operated since 1992.

CIEA built the new 60 MWt China Advanced Research Reactor (CARR), a sophisticated light water tank type unit with heavy water reflector which started up in May 2010, and it also built the sodium-cooled CEFR (see below).

HTR-10

A 10 MWt high-temperature gas-cooled demonstration reactor (HTR-10), having fuel particles compacted with graphite moderator into 60mm diameter spherical balls (pebble bed) was commissioned in 2000 by the Institute of Nuclear Energy Technology (INET) at Tsinghua University near Beijing. It reached full power in 2003 and has an outlet temperature of 700-950°C and may be used as a source of process heat for heavy oil recovery or coal gasification. It is similar to the South African PBMR (pebble bed modular reactor) intended for electricity generation.

In 2004, the reactor was subject to an extreme test of its safety when the helium circulator was deliberately shut off without the reactor being shut down. The temperature increased steadily, but the physics of the fuel meant that the reaction progressively diminished and eventually died away over three hours. At this stage a balance between decay heat in the core and heat dissipation through the steel reactor wall was achieved, the temperature never exceeded 1600°C, and there was no fuel failure. This was one of six safety demonstration tests conducted then.

Initially the HTR-10 has been coupled to a steam turbine power generation unit, but second phase plans are for it to operate at 950°C and drive a gas turbine, as well as enabling R&D in heat application technologies. This phase will involve an international partnership with Korea Atomic Energy Research Institute (KAERI), focused particularly on hydrogen production.

Shidaowan HTR-PM

A key R&D project is the demonstration Shidaowan HTR-PM of 210 MWe (two reactor modules, each of 250 MWt) which is being built at Shidaowan in Shandong province, driving a single steam turbine at about 40% thermal efficiency. The size was reduced to 250 MWt from earlier 458 MWt modules in order to retain the same core configuration as the prototype HTR-10 and avoid moving to an annular design like South Africa's PBMR.

China Huaneng Group, one of China's major generators, is the lead organization in the consortium with China Nuclear Engineering & Construction Group (CNEC) and Tsinghua University's INET, which is the R&D leader. Chinergy Co. is the main contractor for the nuclear island. Projected cost is US$ 430 million, with the aim for later units being US$ 1500/kWe. The licensing process is under way with NNSA, the EPC contract was let in October 2008 and construction was due to start in September 2009 with completion expected in 2013.

The HTR-PM will pave the way for 18 (3x6) further 210 MWe units at the same site in Weihai city - total 3800 MWe - also with steam cycle. INET is in charge of R&D, and is aiming to increase the size of the 250 MWt module and also utilise thorium in the fuel. Eventually it is intended that a series of HTRs, possibly with Brayton cycle directly driving the gas turbines, will be factory-built and widely installed throughout China.

In March 2005, an agreement between PBMR of South Africa and Chinergy Co. of Beijing was announced. PBMR Pty Ltd has been taking forward the HTR concept (based on earlier German work) since 1993 and is planning to build a 125 MWe demonstration plant. Chinergy Co. is drawing on the small operating HTR-10 research reactor at Tsinghua University which is the basis of their 100 MWe HTR-PM demonstration module which also derives from the earlier German development. Both PBMR and HTR-PM were planned for operation about 2013. The 2005 agreement was for cooperation on the demonstration projects and subsequent commercialisation, since both parties believe that the inherently safe pebble bed technology built in relatively small units will eventually displace the more complex light water reactors. In March 2009, a new agreement was signed between PBMR, Chinergy and INET.

Fast neutron reactors

China's R&D on fast neutron reactors started in 1964. A 65 MWt sodium-cooled fast neutron reactor – the Chinese Experimental Fast Reactor (CEFR) – at the China Institute of Atomic Energy (CIAE) near Beijing, started up in July 2010.[1] It was built by Russia's OKBM Afrikantov in collaboration with OKB Gidropress, NIKIET and Kurchatov Institute. It will be grid connected at 40% power in mid-2011, reaching full 20 MWe power in December. It has negative temperature, power reactivity and sodium void coefficients. Its fuel cycle is designed to use electrometallurgical reprocessing.

The CDFR-1000, a 1000 MWe Chinese prototype fast reactor based on the CEFR, is envisaged with construction start in 2017 and commissioning 2022 as the next step in CIAE's program. This is CIAE's 'project one' Chinese Demonstration Fast Reactor (CDFR). With a 40-year design lifetime, it will be a three-loop 2500 MWt pool type, with active and passive shutdown systems and passive decay heat removal. The reactor would use MOX fuel with average 66 GWd/t burn-up, run at 544°C, have breeding ratio 1.2, with 316 core fuel assemblies and 255 blanket ones. This could form the basis of the Chinese Commercial Fast Reactor (CCFR) by 2030, using MOX + actinide or metal + actinide fuel. MOX is seen only as an interim fuel, the target arrangement is metal fuel in closed cycle.

In October 2009, an agreement was signed by CIAE and CNEIC with Russia's Atomstroyexport to start pre-project and design works for a commercial nuclear power plant with two BN-800 reactors[c] (see section on Sanming in the information page on *Nuclear Power in China*). These reactors are referred to by CIAE as 'project 2' Chinese Demonstration Fast Reactors (CDFRs), with construction to start in 2013 and commissioning 2018-19. The reactors will use ceramic MOX fuel pellets.

The CIAE's CDFR-1000 is expected to be followed by a 1200 MWe China Demonstration Fast Breeder Reactor (CDFBR) by about 2028, conforming to Generation IV criteria. This will have U-Pu-Zr fuel with 120 GWd/t burn-up and breeding ratio of 1.5 or more, with minor actinide and long-lived fission product recycle.

PWR capacity in China is expected to level off at 200 GWe about 2040, and fast reactors progressively increase from 2020 to at least 200 GWe by 2050 and 1400 GWe by 2100.

Water-cooled reactors

CNNC declares a strong research interest in an ACP600/1000, in addition to an ACP100 modular small reactor for electricity, heating and desalination. It appears that the ACP600 is developed from the CNP-600 (also referred to as CP600). CNNC has said that the ACP600 design should be ready for deployment on Hainan or in the northwest province of Gansu by 2013.

CGNPC is working on the CPR-1000 and developing it to the Generation III ACPR-1000 with Chinese intellectual property rights, which CGNPC expects to make available for local build and overseas markets in 2013.

Cobalt-60 production

China has started production of the medical and industrial radioisotope cobalt-60 using CNNC's Candu 6 power reactors at Qinshan. This will be China's first domestic production of the isotope. Candu reactors are also used to produce cobalt-60 at Wolsong in South Korea, Bruce in Canada and Embalse in Argentina. The core of a Candu 6 has stainless steel adjusters that help to shape neutron flux to optimise power output and ensure efficient burn up of uranium fuel. The normal cobalt in these can be replaced with cobalt-59, which absorbs neutrons to become Co-60. After about 15 months the stainless steel 'targets' with Co-59 are withdrawn for processing. The development is part of China’s 11th Five Year Plan, and should lead to the production of 220 petabecquerels (PBq) of Co-60 per year – enough to satisfy 80% of Chinese needs. The addition will boost global production by around 10%.

Non-proliferation

China is a nuclear weapons state, party to the Nuclear Non-Proliferation Treaty (NPT) under which a safeguards agreement with the International Atomic Energy Agency (IAEA) has been in force since 1989, with the Additional Protocol in force since 2002. China undertook nuclear weapons tests in 1964-96. Since then it has signed the Comprehensive Nuclear Test Ban Treaty, although it has not yet ratified it. In May 2004, it joined the Nuclear Suppliers Group (NSG).

The NSG membership gives rise to questions about China's supply of two small power reactors to Pakistan, Chasma 3&4. Contracts for Chasma units 1&2 were signed in 1990 and 2000, before China joined the NSG, which maintains an embargo on sales of nuclear equipment to Pakistan. The agreement for units 3&4 was announced in 2007, and signed in October 2008.

China has a bilateral safeguards agreement with Australia, and peaceful use agreements for nuclear materials with Canada, USA, Germany and France. The Canadian one is very similar to Australian bilateral safeguards agreements.

China uses Australian-obligated nuclear material only at nuclear facilities covered by its safeguards agreement with the IAEA. However, uranium conversion facilities are before the 'starting point' for IAEA safeguards procedures and are not included in IAEA safeguards agreements with nuclear weapons states. In accordance with long-standing international principles of accounting for nuclear material, on receipt of Australian natural uranium oxide concentrate in China an equivalent quantity of converted natural uranium in the form of uranium hexafluoride will be added to the inventory of a facility designated for safeguards – *e.g.* an enrichment plant. This will have exactly the same effect as if the natural uranium oxide had moved through the conversion plant, and will ensure that after receipt in China, such material remains in a facility designated for safeguards and listed under the bilateral agreement at all times.

All imported nuclear power plants – from France, Canada and Russia – are under IAEA safeguards, as is the Russian Hanzhun centrifuge enrichment plant in Shaanxi.

A significant number of military production reactors and other plants, with the related Chinese Academy of Engineering Physics, are in Sichuan province.

Further Information

Notes

a. The Fuzhou mine in the southeastern Jiangxi province is in a volcanic deposit, as is Quinglong. Xinjiang's Yili basin in the far west of China, in which the Yining (or Kujiltai) ISL mine sits, is

contiguous with the Ili uranium province in Kazakhstan, though the geology is apparently different. The other mines are in granitic deposits.
Source: Uranium 2009: Resources, Production and Demand, OECD Nuclear Energy Agency and International Atomic Energy Agency (2010). [Back]

b. Myrrha (Multipurpose Hybrid Research Reactor for High-tech Applications) will be a sub-critical assembly relying on accelerated neutrons to achieve periods of criticality in a low-enriched uranium core. As well as being able to produce radiosiotopes and doped silicon, Myrrha's research functions would be particularly well suited to investigating transmutation. Earl in 2010, the Belgian government approved its share of funding of the facility at SCK-CEN's Mol site in northern Belgium. Belgium is to contribute 40% towards the €960 million ($1.3 billion) investment the project will require, but SCK-CEN is looking to set up an international consortium to ensure additional financing. Myrrha itself is scheduled for operation in 2023, but a reduced power model, Guinevere, became operational at Mol in March 2010. [Back]

c. This October 2009 agreement followed a call 12 months earlier by the Russian-Chinese Nuclear Cooperation Commission for construction of an 800 MWe demonstration fast reactor similar to the OKBM Afrikantov design being built at Beloyarsk 4 and due to start up in 2012. [Back]

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