Nuclear Power: "Made in China"

Andrew C. Kadak, Ph.D.
Professor of the Practice
Department of Nuclear Science and Engineering
Massachusetts Institute of Technology

Introduction

There is no doubt that China has become a world economic power. Its low wages, high production capability, and constantly improving quality of goods place it among the world's fastest growing economies. In the United States, it is hard to find a product not "Made in China." In order to support such dramatic growth in production, China requires an enormous amount of energy, not only to fuel its factories but also to provide electricity and energy for its huge population. At the moment, on a per capita basis, China's electricity consumption is still only 946 kilowatt-hours (kwhrs) per year, compared to 9,000 kwhrs per year for the developed world and 13,000 kwhrs per year for the United States.[1] However, China's recent electricity growth rate was estimated to be 15 percent per year, with a long-term growth rate of about 4.3 percent for the next 15 years.[2] This is almost triple the estimates for most Western economies.

China has embarked upon an ambitious program of expansion of its electricity sector, largely due to the move towards the new socialist market economy. As part of China's 10th Five-Year Plan (2001-2005), a key part of energy policy is to "guarantee energy security, optimize energy mix, improve energy efficiency, protect ecological environment . . ."[3] China's new leaders are also increasingly concerned about the environmental impact of its present infrastructure. They recognize that their nation's greenhouse gas emissions will increase as its population and economy grow. Even though China has signed the Kyoto Accords, indicating a desire to limit contributing to global climate change, as a developing nation it is not bound by the reduction protocols. However, China recognizes that it will be under considerable international pressure to limit greenhouse gas emissions. Even at the present level of development, China is the second

largest air polluter in the world (after the United States). According to the World Health Organization, China has seven of the world's ten most polluted cities[4] due largely to its use of coal and the increased use of automobiles in its major cities. In 2005, China produced 2.5 trillion kilowatt-hours of electricity,[5] mostly from fossil-fired generation that is mostly coal with little, if any, pollution controls.[6] Indeed, for China to achieve the quality of life deemed sustainable by the United Nations Human Development Index,[7] the per capita electricity demand alone would be a tremendous challenge.

In the past, China had shunned nuclear energy expansion due to the views of its leadership.[8] Recently, however, given its energy demands and accompanying environmental concerns, the nuclear alternative has been brought back to the table. A key Chinese strategic initiative contained in its 11th Five-Year Plan calls for a substantial increase in its nuclear generating capacity, from the present 1.4 percent of total electric supply to 4 percent by 2020. For China, this relatively small increase in percentage amounts to building 30 large nuclear power stations by 2020, which translates into almost two new nuclear power stations per year. The United States in its heyday of nuclear construction was able to build 109 plants from roughly 1960 to 1992, or over three plants per year. As this comparison demonstrates, once started, China aggressive new program is not unreasonable. However, many have raised concerns about whether China is capable of managing this tremendous expansion and, more importantly, operating these nuclear power stations safely while also dealing responsibly with the issues of nuclear waste and non-proliferation. As the world stands at the threshold of this ambitious and dynamic expansion, it is hence important to provide some perspective on the Chinese nuclear industry, its regulatory regime, expansion plans, and its ability to obtain and maintain the necessary culture of safety for nuclear power operations.

China's Existing Nuclear Energy Situation

China, at present, has nine operating nuclear power stations. Three of these reactors were indigenously designed (Qinshan 1, 2 and 3); four were purchased from Framatome with

Electricité de France managing construction (two each at Daya Bay and Ling Ao which are on the same site but have different plant names); and two were purchased from Atomic Energy of Canada under a turnkey contract (Qinshan 4 and 5). The indigenous reactors were designed and built by Chinese engineers, with Chinese manufactured components, replicating Western reactor designs. All of the units with the exception of Qinshan 4 and 5 are standard pressurized water reactors, which is the chosen technology for China. Qinshan 4 and 5 are Canadian CANDU-6's, which are pressurized heavy water reactors fueled with natural uranium compared to the low enriched uranium pressurized water reactors (PWRs).[9] Shown on Figure 1 are the Daya Bay and Ling Ao plants currently in operation. Four nuclear power stations are currently under construction in China. Two Tianwan Russian-designed pressurized water reactors (VVER 1060 megawatt electrical) are being built in Jiangsu with startup scheduled for 2006. In late 2005, the initial concrete was poured for two plants called Ling Dong units at the Daya Bay site. When the Ling Dong units are complete, the Daya Bay location will have six operating French pressurized water reactors. The Daya Bay, Qinshan and Tianwan units are all managed and operated by state-owned corporations.

Figure 1 : Daya Bay and Ling Ao Nuclear Plants (3600 Mwe Total)

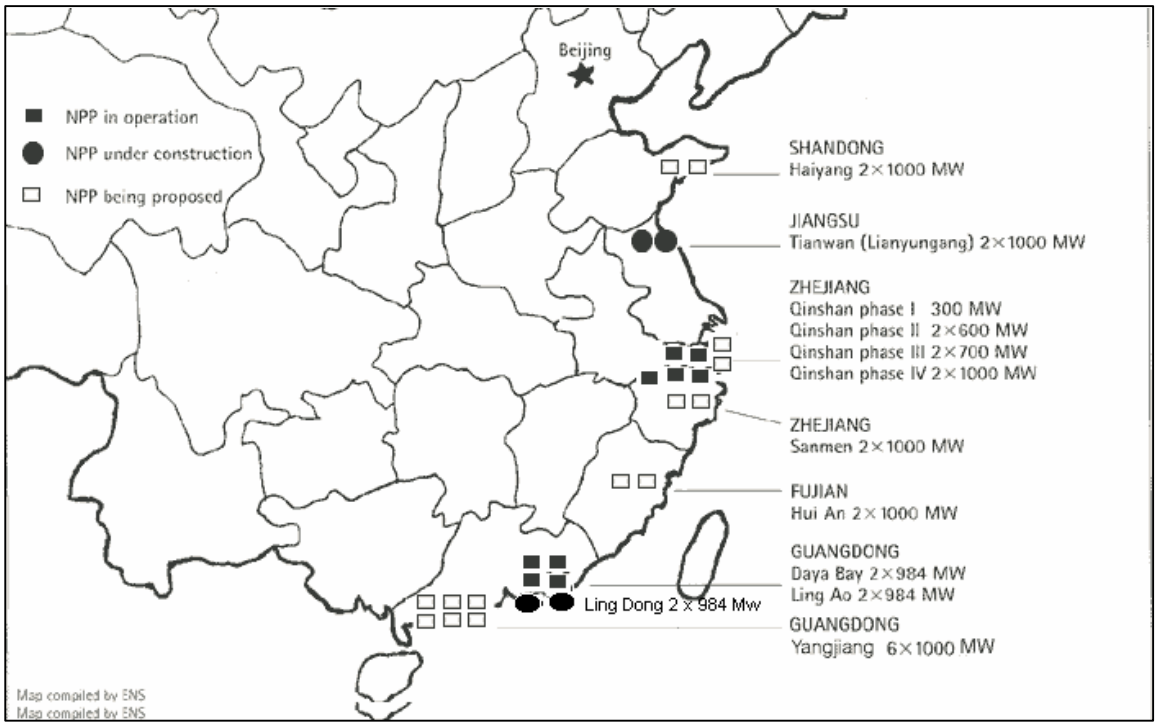
The China Guangdong Nuclear Power Corporation is operating the four French-designed pressurized water reactors at Daya Bay in south China's Guangdong province, roughly 45 km northwest of Hong Kong, where the largest nuclear development is occurring. The operating

record of these stations has been impressive.[10] While they have had some technical difficulties, the overall performance is comparable to that of Western nuclear power stations.

Plans for Expansion and Innovation

China's future plans for new nuclear plants are the most aggressive in the world; no nation has so many planned nuclear plants specifically identified. The locations of China's current and future plants are shown in Figure 2. The next round of orders calls for four units, which were in the competitive bid stage at the time this article was written. The China State Nuclear Power Technology Co. is in the process of choosing between three vendors from the United States, France, and Russia.[11] The ultimate decision made by Beijing will involve considerations of the United States' balance-of-payments concerns as well as the current climate in relations with the United States and other nations. Once these projects are underway, China has identified sites for an additional 49 nuclear power plants, representing a total generating capacity ranging from 47,000-52,000 MWe, in 16 provinces, regions, and municipalities, as part of their 11th Five-Year Plan.

Figure 2: China's Nuclear Reactors Present and Planned

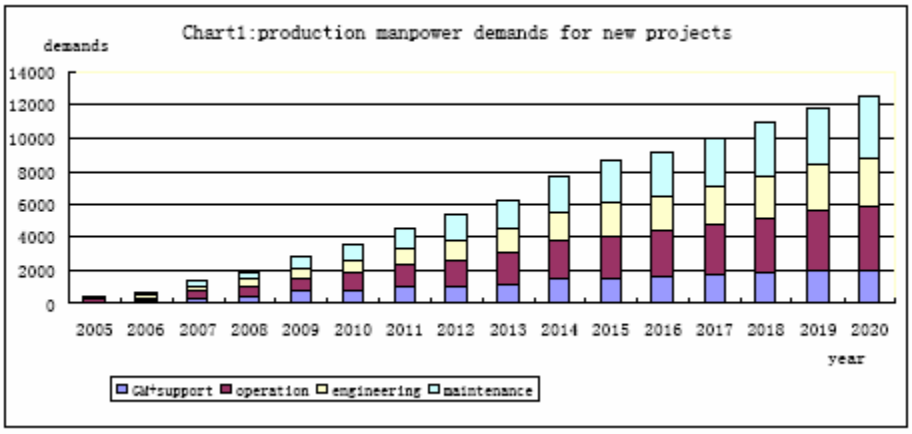


China is particularly interested in the degree of technology transfer that the vendors are willing to provide. For future plants, China intends to procure all the design basis information from the vendors so that it can be self-sufficient in design and engineering. China's ultimate plan is to take over, by license from the vendors, the complete design, manufacturing, and construction of future nuclear plants. This approach is quite similar to the introduction of nuclear energy in Europe; there, U.S. vendors licensed technologies to European companies for deployment. Some technology transfers in China have already taken place. For example, China is now manufacturing nuclear fuel for the Daya Bay plants under a French license.[12].

At present China lacks the qualified people to manage this kind of expansion. According to the Commission on Science, Technology and Industry for National Defense, there is a need for 13,000 new university graduates in the nuclear industry in the next 15 years.[13] While 360,000 Chinese scientists and engineers graduate each year,[14] few of them are trained in nuclear engineering disciplines. In order to deal with the lack of adequate personnel, the Guangdong Nuclear Power Company is instituting special programs with universities to provide the needed

personnel for their expansion plans. Shown in Figure 3 are the manpower needs of the Guangdong Nuclear Power Company, which indicate that 13,000 new staff (of all types) will be needed to support its expansion plans alone.[15] In addition to operating the four nuclear units, the company participates in the national training program for qualified future managers and operators. Each year, numerous promotions occur at the plant with senior managers moving to leadership positions in the design, construction, and operating organizations of the new units. The average age of a nuclear worker at the Daya Bay plants is approximately 34 years, significantly lower than the 45-plus average age for the U.S. nuclear industry. The major challenge for the Chinese nuclear industry is to train sufficiently prepared and experienced people who can operate future nuclear plants. This is a challenge well-recognized by the Chinese government and operators of the plants.

Figure 1 : Manpower Demands for the Daya Bay Nuclear Plants



Planning for the long-term, China has also taken the lead in developing advanced nuclear technologies.[16] Chinese scientists and engineers, trained in Germany at the Juelich Research Institute, have introduced high temperature pebble bed reactor technology into China. Pebble bed reactors are considered to be the first of the so-called “Generation IV” nuclear technologies that are expected to come to use in the next 10 to 20 years. China’s view is that these reactors can provide supplemental electric power for densely and sparsely populated regions and for

processing heavy oil and coal to reduce air pollution.[17] The Juelich Research Institute is where the first pebble bed research reactor was operated for over 22 years. Tsinghua University's Institute of Nuclear Energy Technology (INET), with the assistance of German engineers, designed and built a 10 megawatt thermal (Mwth) high temperature helium-cooled pebble bed reactor capable of producing four megawatts of electricity using a steam turbine generator. The reactor began operations in December of 2000 and has demonstrated its inherent safety characteristics by completing significant safety tests. At present, it is the only operating pebble bed reactor in the world. China has advanced this technology to the point where a full scale 190 megawatt electrical (Mwe) demonstration plant has been approved by the Chinese government to be built at Weihai in Shandong province, with construction beginning in 2007 and operations starting in 2011.[18] An artist rendering of the proposed site is shown on Figure 4.

Figure 4:
Rongcheng Pebble Bed Plant - 3600 MWe - 19 PBR Modules- Helium Steam Plants

Organization of the Chinese Nuclear Industry

The organization of the Chinese nuclear industry is fragmented. The Chinese government sets the overall plan, which is then implemented by the various agencies of the government. The chief among these is the China Atomic Energy Authority. The State Development and Planning Commission is responsible for the approval of all nuclear projects. This committee reports to the

Committee for Science, Technology and Industry for National Defense (COSTIND), which is in charge of all facilities associated with the nuclear fuel cycle and radioactive waste management. The China National Nuclear Power Corporation (CNNC) essentially controls all business aspects of the nuclear industry, including research and development, design, uranium exploration, reprocessing, and waste disposal through subsidiary companies.[19] The major construction company in China is the China Nuclear Engineering and Construction Company, a subsidiary of CNNC.[20] The China Power Investment Company (CPIC) is one of the major state-owned nuclear operating companies.

The other major operating company is the Guangdong Nuclear Power Joint Venture Company, which operates the Daya Bay plants. It is partially owned by the Guangdong Nuclear Power Company and China Light and Power of Hong Kong. These companies are supported by institutes in China, some of which are teaching universities, others of which are design institutes. The organization of the Chinese nuclear industry relies upon the support of these institutes to provide technical input. This is quite unlike that of the United States, where the prime vendors, such as Westinghouse or General Electric, oversee the design and construction of nuclear power stations and develop the license application through to final approval by the regulator. Within its government system, China is now attempting to organize its nuclear industry in a more formal way, which would permit a major expansion.

Once the State Planning Committee approves the building of a new nuclear plant, local utilities must be willing to build the plant, and financing must be arranged from private and government sources. Local approval from the cities and provinces must also be obtained. Chinese local officials, like local officials in the rest of the world, are quite sensitive and responsive to public concerns, which are becoming increasingly heard in China. New plants must be demonstrated to be economically viable in order to be considered.

Safety

One outstanding question about China regards its safety culture and its capability of maintaining a safe nuclear operating system. Given the numerous stories of deaths and injuries in China's coal mining industry, there is the perception that all industries in China are operated in the same manner. This is not the case. China's commercial nuclear plants are subject to inspections by the World Association of Nuclear Operators (WANO) and are under the International Atomic Energy Agency's safeguards inspections. Using international performance indicators, the WANO inspections provide the Chinese operators with an assessment of how their operations compare to other nuclear power plants in the world. In general, the inspections show that the reactors are operated in conformance with international protocols and expectations.[21]

The intent on self-sufficiency has extended to the safety aspect of nuclear development in China as well. While initially China was dependent on the former Soviet Union for its nuclear technology, in its commercial nuclear activities, China decided to reach out to the West to obtain technologies that are considered by most to be safe. France has had a long history of extremely positive and safe nuclear operations, as well as good relations with the Chinese. Based on this experience, China decided to award major contracts to two French companies, Framatome and Electricité de France (operators of French nuclear plants), to design and build their standard 900 MWe nuclear power stations in China. While the decision was technologically sound, the unanswered question was the Chinese capability to safely operate and maintain the plants. China initially relied on French operators and engineers to assist the Chinese in operations, engineering, and reactor support, to assure that the plants operate in accordance with French design and operational practices. Gradually, as the Chinese gained more operational experience, they took over more of the responsibilities, to the point where today at the Guangdong plants, the French act only as

advisors. The Chinese have now also taken over all training responsibilities, including the training of plant operators using their on-site plant simulator at the Daya Bay site.

The safety performance of the Chinese reactors has been quite good, with no known abnormal releases of radioactivity or events that have threatened the safety of the reactor core. There have been operational events dealing with the station transformers, the fuel handling machine, and electrical systems that were effectively managed by the plant staff with regulatory oversight.

The senior management of the Guangdong Nuclear Power Company believes that much can be learned from U.S. plant experience to improve their overall performance. To that end, they have engaged the services of a U.S. group of experienced managers and engineers to assist them in instituting U.S. processes and procedures, in order to instill the operating regime and culture required for safe long-term operations. This team spends two weeks per year at the Daya Bay plants reviewing operating results, events, procedures, staffing levels, corrective action programs, engineering, safety culture, etc. The objective is not to inspect but to mentor. As a member of this team, my personal observation in over two years of engagement has been very positive. The management of the company is committed to change and is taking advantage of U.S. lessons in operations, engineering, safety, oversight, and training. Each bi-yearly visit starts with a review of past findings and recommendations, with actions taken by the staff to address the issues identified. The responsiveness of the management has resulted in the institution of a U.S.-like corrective action program, the use of traditional “root cause” analysis in senior management reviews of events, the use of probabilistic safety analysis in engineering and operations, the installation of a safety monitor in the control room, and changes to training and maintenance programs and control room operator practices, to name just of few of the recommendations accepted and implemented by the management. The team has unrestricted access to all parts of the plant with visits scheduled during refueling outages as well as during normal operations to

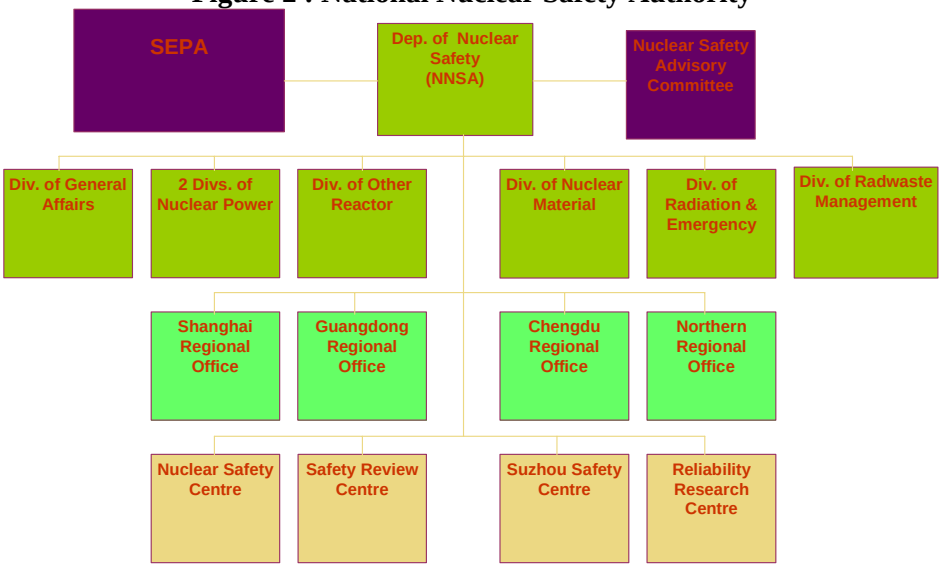
observe work practices. There is free access to management and working engineers. This openness to improvement is a positive sign for the future of China's nuclear expansion plans.

The issue of safety culture, which demands a critical approach, is also a challenge for the Chinese system. Asian culture, in general, respects authority and rarely questions it. In the Chinese political system, this challenge is exacerbated. The management of the Daya Bay stations recognizes this problem and has an active safety culture awareness effort underway that encourages staff to come forward with identified problems without retaliation. Management supports the process of questioning and having open discussions concerning differing professional opinions. Such lively discussions have been witnessed at Daya Bay Corrective Action Review Board committee meetings, where major safety issues are raised with resolutions agreed upon by management and staff. New programs have been instituted to monitor the resolution of concerns and to assign responsibility and accountability for problem resolution. While worker protections similar to those in the United States do not exist, China is developing a nuclear safety culture that requires constant reinforcement by management to be successful.

Regulatory System

The design criteria, operating procedures and safety regulations are adopted by China's National Nuclear Safety Administration (NNSA) for imported nuclear power stations. The basic NNSA organization is similar to Western nuclear oversight organizations in that there is a central regulatory authority supported by regional offices with onsite inspectors located near nuclear power stations.[22] The NNSA shares regulatory authority with the State Environmental Protection Agency (SEPA), which oversees radiological and environmental impacts. Shown in Figure 4 is the organizational structure of the Chinese regulatory system. Within the central authority, specific departments address power reactors, research reactors, nuclear materials, radiation and emergency preparedness, and radioactive waste management. In addition, the NNSA is technically supported by several centers dealing with safety, machinery reliability, and performance and safety assessment at the Beijing Institute of Nuclear Engineering (BINE).

Figure 2 : National Nuclear Safety Authority



China has developed top-level nuclear safety regulations on site location, safety in design, operations, and quality assurance. They annually set up inspection plans for each power station which focus on key areas of the regulations to assure compliance. They also have special inspections and reviews based on events that may occur at the plant. While the organizational framework is quite similar to the U.S. system, the intrusiveness of the regulator in day-to-day operations is not. The onsite inspectors follow the overall plans for inspections but are not as involved in day-to-day oversight of normal operations and outages. The local inspectors oversee the compliance reporting and review the notices of operating events that may not be in compliance with regulations. In U.S. plants, Nuclear Regulatory Commission inspectors spend a considerable amount of time independently reviewing plant operations, actively observing plant staff meetings, and having discussions with plant management and staff about current operations and activities. This is not the common practice in China since the regulator, while on site, is not as actively involved. Chinese regulatory personnel do perform inspections and oversee major activities during outages, however.

Should an event occur at the plant, NNSA inspectors will be involved in event review and response, but only to assure that the actions of the operator are appropriate. If needed, NNSA can

call on the resources of their technical support organizations to resolve questions. All design changes at the plant are reviewed and approved by the regulator and must comply with technical specifications and operating procedures much like those in the U.S. The NNSA has the authority to shut down nuclear plants should they not be in compliance to regulations. The Chinese government has made it quite clear that they will not tolerate injuries or radiation release. Given the power of the Chinese government, this clarity in expectations of the regulator and the government makes operational decisions of the plant very safety-focused. The challenge is for management to reinforce these expectations to all plant employees and contractors to be sure that no unsafe conditions exist.

Managing Nuclear Waste

The issue of nuclear waste always arises in regards to building and expanding the number of nuclear power plants. At present, China is managing its high- and low-level nuclear waste by storage. The low-level waste is being stored and disposed of at regional facilities near nuclear installations.[23] The spent high-level nuclear waste from nuclear power stations is stored in spent fuel storage pools at reactor sites. As in the United States, these pools are becoming full, and China has begun to ship the spent fuel assemblies to the country's reprocessing center at the Lanzhou Nuclear Fuel Complex, where a large interim spent fuel storage pool has been constructed.[24] Shown on Figure 6 is a shipment of spent nuclear fuel being loaded on a truck to be shipped 4,000 km to the Lanzhou site for storage from Daya Bay. China's future plants call for reprocessing of the spent fuel and recycling it into existing nuclear power stations. The recycling and reprocessing is currently practiced in France, and it is expected that China will follow a similar policy.[25] China is also considering the development of fast breeder reactors that would utilize Uranium-238 to make plutonium fuel for an essentially inexhaustible supply of nuclear fuel for the future. This program is in its infancy. For now, China's present plans call for expanding the use of light water reactors.

Figure 6: NAC International shipment of Spent Fuel From Daya Bay

China, like all nations that use nuclear power, has chosen deep geological disposal for the residual high-level waste coming from the reprocessing plants. The general area selected is in northwest China at Beishan, near the Gobi Desert. This area is sparsely populated and very dry. Several bore holes have been drilled in the area into granite formations. These exploratory studies will determine the suitability of the site for long-term disposal. China plans to build an Underground Research Laboratory by 2015 with an operational repository to be opened by 2040.[26] While China currently has fewer than 1000 metric tons of spent fuel in storage, it expects to reach 1000 metric tons by 2010. Once all the plants that are currently being ordered become operational, the country will be producing 1000 metric tons per year. It is for this reason that China believes that reprocessing and recycling is the proper path forward in terms of waste management and waste volume reduction.

Non-proliferation

One of the major concerns about expanding the use of nuclear energy on a worldwide scale is the fear of nuclear weapons proliferation. Because China already has nuclear weapons, the expansion of the commercial nuclear sector does not directly increase the proliferation threat. China is a signatory to the Nuclear Non- Proliferation Treaty and the "Additional Protocols." It has signed

the Comprehensive Test Ban Treaty, joined the Nuclear Suppliers Club, and subjects its commercial nuclear establishments to IAEA safeguards inspections. Its nuclear weapons capability was largely developed with the support of the former Soviet Union.[27] The concern about China's expanded use of commercial nuclear technology is not directly related to its use of nuclear energy but to whether it will transfer nuclear weapons technology to other nations. Here the record is mixed. It has been reported that China assisted Pakistan in its development of nuclear weapons. Technically, China can develop its commercial nuclear industry without spreading nuclear weapons technology. The technologies for producing electricity from nuclear energy that are sensitive from a proliferation perspective are enrichment and reprocessing. China has Soviet enrichment plants and is currently developing a pilot reprocessing plant with support from Russia and Europe.[28] What China does or does not do to spread nuclear weapons technologies at this point in their nuclear development is largely independent of its expanded use of nuclear power to supply its electricity needs. For technologies imported from the U.S., the U.S. and Chinese governments have signed technology transfer agreements requiring the permission of each state prior to the transfer and an agreement not to use the technology provided for the production of nuclear weapons. Whether these agreements will be followed will be determined by the domestic politics and foreign policy of each country.

Summary

China is emerging not only as a super economic power but also as the leader in the deployment and development of new nuclear energy plants. China's energy needs are enormous, and its path forward in terms of providing sufficient electricity calls for a dramatic expansion of the use of nuclear energy. The Chinese government has determined that, based on its experience and ongoing concern with the environmental consequences of burning coal and other fossil fuels, China needs to aggressively deploy more than 50 plants in the next several decades. Of concern is whether the Chinese can manage this expansion with the quality needed to assure that plants are operated safely, with personnel trained in the proper safety culture. Based on observations to date,

the Chinese appear to understand the challenges and are addressing them in order to assure the safe operation of the plants. As the United States and other nations have learned, such a task requires vigilance and a dedication to safe operations. With such rapid growth, it has yet to be seen whether or not the safety culture can be transferred to the next generation of operators and engineers.

In terms of proliferation of nuclear weapons technology, the choice is one of foreign policy rather than technology. The development of China's commercial nuclear industry can be done without fear of proliferation of nuclear weapons, provided China does not transfer the weapons sensitive technologies (enrichment and reprocessing) to less-than-trustworthy countries. As in all nations operating nuclear plants and defense facilities, the issue of nuclear waste disposal will be resolved on a country-by-country basis. It is fortunate that China has large areas (such as the Gobi Desert) where waste can be safely disposed of in geological formations.

As China aggressively deploys its light water reactors, develops pebble bed reactors for electricity, and processes heat applications, we in the United States are still waiting for our nuclear "renaissance" to occur. It is not inconceivable that as we wait and watch, we may, in the future, be buying reactors "Made in China".

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[5] A Gigawatt is 1 million watts of electric power.

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