Nonproliferation Policy Education Center (NPEC) Research Memorandum:

# On the Westinghouse AP 1000 Sale to China and its Possible Military Implications

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Commentary (*in italics*) is provided by Charles D. Ferguson, Fellow for Science and Technology at the Council on Foreign Relations and a former nuclear submarine officer.

WHILE DIFFERING in some respects, the paper and the commentary have reached general agreement on at least three points. First, China could reverse engineer advanced technologies acquired under the Westinghouse-Toshiba deal. Here the only dispute is about how difficult a task this would be for the Chinese. In particular, China could try to adapt the reactor coolant pumps in the AP1000 to its nuclear submarine program to make its submarines quieter. Quieter submarines can provide huge tactical and strategic advantages. Certainly, the Chinese have already reversed engineered very complex imported technology in the aerospace and nuclear fields. Second, the massive number of highly technical Chinese jobs created by the civilian nuclear deal would allow China to train more people for its naval nuclear program. China has been struggling to keep competent people in its naval nuclear program, which has been hemorrhaging engineers to its previous commercial programs. Under the deal, Westinghouse-Toshiba would help grow the training programs for the new reactors to be built. At a minimum, such training would help stop the loss of technically trained people from the naval program. Third, while the paper and the commentary differ somewhat on an assessment of China's intentions with its nuclear weapons program, they agree that the deal would stimulate further growth in China's uranium enrichment program. Intentions can change depending on the state of U.S.-China relations as well as other political factors. Nonetheless, an increased technical capacity is a prerequisite for further potential expansion of China's nuclear arsenal.

**Subject: Toshiba/Westinghouse Sale of AP1000 Reactors to China**

Media reports and government announcements about the sale of Westinghouse AP1000 pressurized light water reactor (LWR) nuclear power plants to China have emphasized the economic benefits of the deal. In the Department of Energy Press release about the signing of an MOU with China for the sale, Secretary of Energy Samuel W. Bodman announced: "This is an exciting day for the U.S. nuclear industry. This agreement is good for the people of China and good for the people of the United States."[i] The chief executive and president of Westinghouse, Stephen R. Tritch, indicated that half the value of the contract would be done in China, but that the work would support 5000 design, engineering and manufacturing jobs in the United States.

Tritch also acknowledged that the deal would make it possible for China to build future nuclear reactors with less help from foreign partners.[ii]

Little has been written about the potential national security implications of the sale of these reactors to China. Westinghouse's bid included the transfer of technology to the Chinese. The technology transfer is unspecified in the announcements, but it will include the passive safety technologies that are advertised as the advantages of the new design Generation 3+ reactor plant, and engineering construction techniques for the plant. While members of the United States—China Economic and Security Review Commission noted that civilian nuclear reactors had little military value for China, they also expressed concern that early transfer of technology was part of the sale. In his press conference after the announcement of the sale, Secretary Bodman commented that "the Chinese were very demanding." It was not clear whether he was referring to the technology transfer issue, or to other issues.[iii]

This paper examines the national security implications of the sale by addressing four key questions:

**1. What attributes, if any, might the AP 1000 reactor design or its related reactor codes have that might help to improve the performance or reliability of China's naval reactors (both for large naval surface ships as well as submarines)?**

China has a fairly advanced civilian nuclear power program. The program has been aided by the provision of technology from France and Russia. Technologies provided as a result of this assistance can be assumed to have been assimilated by the Chinese nuclear power industry. So the question really to be addressed is what additional attributes beyond those already obtained by China could help to improve the performance or reliability of China's naval reactors?

The AP-1000 reactor is a Generation 3+ reactor, the standard nomenclature for the new generation of reactor designs that follow the Generation III Advanced Light Water Reactors developed in the 1990s.[iv] The reactor plant design is a conventional two loop pressurized water reactor. As such, it is very similar to other operating reactor plants in China. This paper will attempt to identify the new technologies that will be supplied with the AP1000 that could have national security implications for the United States.

Naval reactors are much smaller than the AP1000 design. To apply the technology from advanced components of the AP1000 reactor to naval reactors, significant engineering would be required. In reviewing the AP1000 design, the most likely advanced component that might be applicable to China's nuclear submarines would be the Westinghouse canned motor reactor coolant pumps. Previous reactor installations provided by Russia and France used shaft seal pumps. Although the AP1000 reactor coolant pumps will be much larger than what would be suitable for a naval reactor, it is possible that China could downscale the design to improve the reactor coolant pumps for submarines. The military significance of improved reactor coolant pumps is that they could potentially diminish the noise signature of Chinese submarines, thereby making them less detectable. The reverse engineering would likely be difficult, as Westinghouse is unlikely to share their manufacturing techniques with China. According to Westinghouse, canned motor reactor coolant pumps have been used in U.S. naval reactors for many years.[v]

A second technology attribute that might provide advantages to China's naval reactor program could be the digital instrumentation and control (I&C) system designed for the AP1000. The AP1000 I&C system uses a microprocessor-based, distributed digital system to perform plant protection functions and safety monitoring, as well as plant control functions. This system is advertised to improve reliability of the control systems, while ensuring that the operator knows the status of the plant continuously.[vi] The improved reliability of the software, electronics, and sensors in these systems could potentially be reverse engineered for application to naval reactors to improve reactor reliability.

However digital I&C systems are not new to China's nuclear power industry. The Russian VVER-91 reactors have modern digital Siemens-Areva I&C systems. Therefore the new technology gained from the AP-1000 I&C systems is likely to be marginal. Additionally, the reliability advantages of a digital I&C system are not completely clear- cut. The U.S. Nuclear Regulatory Commission (NRC) has been concerned about the potential that undetected software malfunctions in a digital I&C system could lead to safety or reliability problems.

Most of the design elements of the AP1000 reactor are extensions of previous designs, and appear to be either the same as previous designs, or refinements, rather than technological breakthroughs. For example, the fuel bundles are standard 17x17 matrices of fuel rods that have been used in a number of reactor designs in the U.S. and Europe. The AP1000 version is the same as the 14 foot 17x17 XL Robust Fuel Assembly used in earlier reactor construction, except for the addition of some Intermediate Flow mixing grids in the top mixing vane grid spans. The fuel element manufacturing technology is conventional, and well known.

The ceramic fuel pellet design for the AP1000 uses a dished in middle to account for fuel pellet swelling. The ZIRLO tube that holds the pellets is made of a zirconium based alloy. The fuel rods are internally pressurized with helium during fabrication to minimize clad stress. Information about this kind of modern manufacturing processes may help China develop some new engineering capabilities as a result of the AP1000 deal, but these advantages are likely to be small, because nuclear fuel manufacturing is already a mature industry in China.

Westinghouse touts the passive safety design attributes of the AP1000 as its chief advantage. These are described as:

" •No reliance on AC power
•Automatic response to accident condition assures safety
•Long term plant safety assured without active components (natural forces only)
•Containment reliability greatly increased by passive cooling
•In severe accidents, reactor vessel cooling keeps core debris in vessel
•Large margin to safety limits
•Defense in depth-active non-safety systems provide additional first line of defense"[vii]

The passive safety systems include passive safety injection, passive residual heat removal, and passive containment cooling. The natural forces referenced include gravity, natural circulation, and compressed gas.[viii] There appears to be no application of these passive safety design technologies to submarine reactors. For large surface ship reactors the techniques might be used to simplify some design features of emergency core cooling fill systems. In these cases, the technologies provided are conceptually very simple, and would replace systems that are only for emergency core cooling in case of an accident that caused a loss of reactor coolant. These passive safety systems would not confer any additional military advantage.

Codes used in the reactor design are standard NRC approved codes. For example, Westinghouse used the PHOENIX-P core design code in developing the AP1000 core design. This code is publicly available, and was issued in 1988. The methodology for evaluation rod ejection accidents uses an NRC approved code issued in 1975. The core thermal hydraulic design bases were evaluated using the VIPRE-01 code. According to the NRC approval document: "VIPRE-01 is a subchannel, thermal-hydraulic computer code used to analyze the reactor core of a reactor system. [The code was developed] …and submitted to the NRC for generic review in 1984. The NRC approved VIPRE-01 for application to PWRs in 1985, with the condition that each VIPRE-01 user submit documentation describing the proposed use for the code, other computer codes with which it will interact, the source of each input variable, and the selected correlations and their justification. … The [NRC] staff has determined that use of VIPRE-01 for the AP1000 core thermal-hydraulic analysis is acceptable because the AP1000 is a Westinghouse-designed PWR for which the VIPRE-01 modeling is qualified."[ix]

***Commentary:*** *One of the main underlying themes of this section is whether China could reverse engineer major AP1000 technological advances such as improved quieter reactor coolant pumps and digital instrumentation and control (I&C) system. As the paper correctly points out, these types of coolant pumps could provide China within much quieter nuclear submarines, and the I&C system could enhance the reliability of China's naval reactors with the caveat that China already has some experience in I&C systems and the U.S. NRC has expressed some concern about software glitches in such systems. Quieter and more reliable nuclear systems on submarines can give a country a distinct advantage in warfare. China is struggling with developing a "blue water" navy, in general, and with deploying nuclear power projection capability beyond its coastal waters, in particular. Presently, China has a very small nuclear naval fleet, which has rarely sailed into deep blue water far from China's coast. Thus, China would likely welcome and work hard to apply any technology that could offer China the needed jumpstart to improve the reliability of its nuclear submarines.*

*China has already displayed its ability to reverse engineer (or "guo chan hua" in Chinese) other militarily useful technologies. In the late 1970s, China acquired intact U.S. Mark 46 torpedoes. Although the reverse engineering of this torpedo system was a daunting technical challenge, China accomplished this feat in eight years, giving it an enhanced naval power capability. It is also known that China had reverse engineered Soviet-designed ballistic missiles, submarines, and other military equipment. Tellingly, in 2001, the Bush administration was worried about the possibility of China reverse engineering the intelligence gathering technology on the EP-3E plane that was forced to land on Hainan Island after an incident with a Chinese fighter jet. The* *crew of the American intelligence gathering plane tried to destroy as much of the equipment as possible before the Chinese gained control of the plane.*

**2. How relevant might the facilities relating to the fabrication of a large LWR be to the fabrication of key components of a naval reactor?**

Large commercial reactors such as the AP1000, VVER1000, GE's Advance boiling Water Reactor, and Areva's EPR are an order of magnitude larger than a typical naval reactor. Many of the design, safety, and control mechanisms of the AP1000 are driven by the large size of the core. For example, the complex control and safety shutdown mechanisms consisting of control rods, gray rods, and boron dissolved in the reactor coolant are necessary to ensure proper flux distribution, to manage axial fuel burnout, and to compensate for such phenomena as xenon stability issues. These issues are simpler to manage in a smaller core such as for a naval reactor.

With respect to construction engineering, the design of the AP1000 reactor is a conventional pressurized water reactor, so construction techniques such as welding, pipe manufacture, and pressure vessel manufacture are little different from earlier nuclear power plant construction projects. The AP1000 uses modular construction to permit parallel construction activities, which saves construction time. China already has the capability to perform modular construction, such as is used in modern shipbuilding. Therefore, there would likely be no additional construction related technology from the AP1000 construction project that would advance China's naval reactor program.

**3. How might training and experience in the design, fabrication, and operation of large LWRs be relevant for the design, fabrication, and operation of a naval reactor? How many people that might be relevant to the design, fabrication, and operation of naval reactors would be needed to design, fabricate and operate a large LWR?**

Evidence that the training and experience in large reactor design fabrication, and operation would be helpful to a naval reactor program is sparse. The engineering disciplines for design, fabrication, and operation of any pressurized water reactor would be applicable to any other pressurized water reactor. As to whether there could be any unique information in newly designed and constructed reactors that could be directly applied to the Chinese naval reactor program, it is hard to identify what it would be.

China will need a substantially increased cadre of nuclear trained and educated people if it is to expand its nuclear power production as much as has been announced. For China to achieve 40GWe of nuclear power generating capacity by 2020, essentially more than quadrupling its current capacity, it is unlikely that that cadre will be entirely Chinese. Western support for the design, construction and manufacture of component parts for reactor plants will continue to be required. Although China seeks to acquire indigenous capabilities, and seeks to develop its engineering training and education, nuclear power will be able to capture only a small part of the energy engineering and operational capacity that will be required. The expansion of energy requirements in China generally will create competing requirements for engineering graduates.

Extensive nuclear engineering training is already taking place in many U.S. colleges and universities and in similar institutions in other western countries. To cite one example, in 1998 the University of Michigan signed a memorandum of understanding with [China] to teach reactor safety and engineering principles to students from the People's Republic of China. The program at Michigan is advertised to expose Chinese students to the commercial nuclear power safety culture developed in the United States that is critical to the successful implementation of safe nuclear energy use in China.[x]

In addition, Chinese institutions are conducting nuclear training and education. According to the Chairman of the China Atomic Energy Agency: "Human resources are an important factor supporting the healthy and sustainable development of nuclear energy. In the whole world, however, lack of sufficient human resources has become one of the key factors restraining further development of nuclear energy….A university education system including undergraduate basic science education and graduate education and a vocational training system combining on-job training and school training have been established. At present, there are more than a dozen universities in China with nuclear-related specialty which provide hundreds of graduates to nuclear energy R&D institutions and enterprises every year. Enterprises also train their staff through practice, training on contract with universities and regular training. China's authorities for higher learning are making plans of strengthening or building nuclear energy specialty and expanding enrollment to meet the human resources requirement in the process of nuclear power development." [xi]

As mentioned in the Westinghouse announcement, the AP1000 sale to China will support 5000 design, engineering, and manufacturing jobs in the United States. The announcement did not indicate what kind of employment impact the sale would have in China. It can be assumed that the engineering, construction, training, and operations will be substantial. According to a series of Nuclear Energy Institute studies of the economic benefits of nuclear power plants in the United States a nuclear generating station will create on the order of 4000 jobs in the general area of the plant.[xii] Because of lower labor costs and less developed infrastructure in China, it is a fair assumption that the job creation of each of the AP1000 plants will be even greater than in the U.S.

As the Chinese absorb the capability for design, fabrication and operation of the AP1000 reactors, the employment for these functions is likely to mirror the U.S. numbers. There is no evidence that nuclear specialists working on the AP1000 are likely to displace those already working on naval reactors.

***Commentary:*** *This section underscores the human factor in an endeavor as complex as safely operating civilian and military nuclear reactor systems. Acquisition of the AP1000 as well as other state-of-the-art reactor systems will spur China to train a large cadre of people in management, engineering, and safe operation of nuclear power systems. While most of those people would work in the civilian nuclear sector, even a small fraction of these hundreds or potentially thousands of nuclear-trained people could help the naval nuclear sector by devoting part or all of their time to solving problems that have plagued the presently unreliable Chinese nuclear fleet. In the United States, for example, the civilian and naval nuclear sectors have had a symbiotic relationship for many decades.*

**4. How many SWUs would be required to fuel five AP 1000s both to start them up and then to keep them operating each year? How many SWUs does it take to fuel a typical naval reactor and to make 3 and 12 kilograms of HEU? What information is publicly available about how many SWUs of enrichment capacity China currently has?**

A separative work unit (SWU) is the standard unit of measurement for enrichment. A SWU is a unit of measurement of the effort needed to separate the U-235 and U-238 atoms, usually using a gaseous form of $UF_6$, in order to create a final product that has a higher percentage of U-235 atoms.[xiii]

About 100,000-120,000 kg-SWU are required to enrich the annual fuel loading for an AP1000 reactor.[xiv] An initial core load would require about 1.5 times as much SWU as an operating core.[xv] Therefore the initial core load for five AP1000 reactors would require about 800,000 kg-SWU, with annual requirements of about 550,000 kg-SWU thereafter.

The current SWU requirement for China's operating reactors is about 700,000 kg-SWU per year. The two CANDU reactors do not require enrichment services as they use natural uranium fuel. China does not disclose its uranium requirements, purchases, SWU requirements or sales, or LEU sales totals. However, according to a dated report by Monterey Institute's Center for Nonproliferation Studies, China annually exports 400,000 kg-SWU per year.[xvi]

The SWU requirements for China's naval reactors are even more difficult to determine. China's nuclear submarine fleet is small, does not operate very much, and seldom ventures far from home waters. To compare commercial power reactors with naval reactors it is necessary to compare thermal ratings. The AP1000 reactor has a thermal rating of 3415MW. Chinese naval reactors use low enriched uranium (LEU) fuel. Assuming a nominal naval reactor core size of 170MW for simplicity ($1/20^{th}$ the rating of the AP1000), and LEU enriched to about 5% U-235, the initial core load would require about 8,000 kg-SWU.

If China wanted to keep its nuclear submarine fleet at sea for longer periods between refueling, it could consider fueling its submarines with highly enriched uranium (HEU). HEU core designs would have little in common with the AP1000 design. Assuming that China did choose to design HEU cores for its submarines, the question of SWU requirements for enrichment of the HEU would be relevant. For purposes of the SWU calculation, we will assume that China would use HEU enriched to 90% U-235.

The Federation of American Scientists has an on-line SWU calculator. It includes a description of how the calculation is made:

"A cascade has three streams of material:

1) The Feed material at a specific concentration of the desired isotope. If the feed is natural uranium, the desired isotope is U-235 and the feed concentration is 0.007

2) The Waste (or stripped) material at a specified concentration of the desired isotope. The waste concentration will always be smaller than that of the feed. For most typical enrichments, the waste concentration will be in the range of 0.002-0.0003 of U-235.

3) The Product (or enriched) material with a desired concentration of the desired isotope, which is always higher than that of the feed material. Nuclear reactors usually require U-235 concentrations of about 5% (that is, 0.05) or so. Nuclear weapons require material of concentration of about 90%.

The equation defining Separative Work is:

$$SWU = P \cdot V(Np) + W \cdot V(Nw) - F \cdot V(Nf)$$

Where P is the product amount, Np is the product concentration, W is the waste amount, Nw is the waste concentration, F is the feed amount, Nf is the feed concentration, and V(x) is a value function that takes the form:

$V(x)=(2x-1)\ln(x/(1-x))$ where x is a given concentration.

The value function V(x) is dimensionless, so the units of SWU is contingent on the units of P, W, and F. The value of a SWU can, therefore, be in terms of any amount of material. If P, W, and F are in units of kilograms, then the SWU will be a kg-SWU."[xvii]

Assuming that China used natural uranium feed, and a tails assay of .3%, the SWU requirement to produce 3 Kg of 90% enriched HEU would be about 580 kg-SWU. To produce 12 Kg of 90% enriched HEU would require about 2300 kg-SWU.

Current information about China's enrichment capacity can be inferred from information about construction of enrichment plants, and the scheduled shutdown of some facilities. Various sources estimate that China's current enrichment capacity is between 1,000,000 and 1,300,000 kg-SWU per year.[xviii] Most of this capacity is centrifuge. There may be a small amount of gaseous diffusion capacity remaining, but it is in the process of being retired. It is known that there are two 500,000 kg-SWU per year centrifuge plants at Lanzhou and Hanzhong. There are reportedly plans to build further enrichment capacity. At least one estimate of enrichment capacity is as high as 1,900,000 kg-SWU, indicating that China may have already succeeded in expanding its centrifuge program.[xix] Although some SWU are being provided by Urenco for the Guangdong plants, the Chinese capacity is sufficient to supply its own power reactors and provide export market LEU fuel for reactors in Japan and Pakistan.

China is likely to continue to expand its enrichment capacity to try to accommodate its growing requirements for LEU fuel for its expanded nuclear power plant building program. Needed enrichment capacity for its naval reactors program is small by comparison with its power reactor needs. Even if China decided to begin to produce HEU for a new naval reactor design, the SWU requirements would be small in comparison to the overall enrichment requirements for power reactors.

The subject of China's Nuclear Weapons program deserves brief mention in the context of enrichment requirements. The Chinese government announced in November 1989 that it was ceasing production of HEU for military uses and that it would use its enrichment facilities exclusively for civilian applications.[xx] Although never announced, it is likely that weapons grade plutonium production also ceased by 1991. Albright and Hinderstein have estimated that China has roughly 21 metric tons of HEU and about 2.8 metric tons of weapons plutonium.[xxi] Because of the small size of China's nuclear weapons force, estimated to be in the neighborhood of 200 to 400 weapons, the amount of HEU and weapons plutonium that China has produced, and which is presumably stockpiled, is far greater than was needed for this number of nuclear weapons. The existing stocks of HEU and plutonium would therefore likely be sufficient to support a substantially greater number of nuclear weapons. Therefore it is unlikely that the increase in enrichment capacity that will be required for the expanding commercial power reactor fleet will increase the risk of a sudden surge to parity with the U.S. or Russia in nuclear weapons production.

***Commentary:*** *It is very uncertain how much uranium enrichment capacity China may or may not need in the future for its weapons program. But what is more certain is that China and the United States now confront a crossroads in their nuclear strategic relationship. The United States is trying to press forward with deployment of a national missile defense system. Chinese officials and military analysts have expressed concern that the relatively small American missile defense system could soon become large enough to threaten China's small nuclear deterrent. According to unofficial reports, China has about two dozen nuclear-armed intercontinental ballistic missiles. China might greatly increase this missile force in response to potential growth in U.S. missile defense.*

*For many decades, China has professed to have a nuclear no-first-use policy. Nevertheless, as China develops into a world economic power, it may feel compelled to reassess its nuclear policy. According to recent analysis on the Nuclear Threat Initiative Web site (http://nti.org/db/china/doctrine.htm), "The first hints of a [shift in] Chinese nuclear weapons doctrine surfaced in July 2000 during the Central Military Commission conference on strategic military equipment. Jiang Zemin outlined the 'Five Musts' on nuclear weapons.*

- *China must own strategic nuclear weapons of a definite quality and quantity in order to ensure national security;*
- *China must guarantee the safety of strategic nuclear bases and prevent against the loss of combat effectiveness from attacks and destruction by hostile countries;*
- *China must ensure that its strategic nuclear weapons are at a high degree of war preparedness;*
- *When an aggressor launches a nuclear attack against China, China must be able to launch nuclear counterattack and nuclear re-attack against the aggressor;*
- *China must pay attention to the global situation of strategic balance and stability and, when there are changes in the situation, adjust its strategic nuclear weapon development strategy in a timely manner."*

*The last "must" indicates that China would seek to maintain the flexibility required to "adjust its strategic nuclear weapon development strategy in a timely manner." Such flexibility would* *include adequate reserve uranium enrichment capacity. Thus, while the recent nuclear deal with China does not directly lead to an increased Chinese nuclear weapons capability, it could partially and intentionally offer China the means to boost that capability depending on political and strategic dynamics in the future.*

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