Should the United States Supply Light-Water Reactors to Pyongyang?

Peter Hayes

The transfer of light water reactor technology to North Korea emerged as an important issue at the third round of high-level talks between North Korea and the United States held in Geneva in July 1993. This article provides some background to the negotiations to date over this issue, analyzes the relative proliferation intensity of the DPRK developing its present nuclear fuel cycle versus "trading it in" for a light-water-reactor fuel cycle, and appraises nuclear power technology in terms of the DPRK's energy economy. Implications of the likely poor economics of nuclear power in the DPRK and various constraints to transferring LWR technology to the DPRK are examined, as well as critical outstanding issues that must be resolved before LWR technology is transferred to the DPRK. In general, the proposed transfer of an LWR to the DPRK is found to be a two-edged sword. On the one hand, it may sow serpent's teeth by endowing the DPRK with a higher level of technical capabilities to proliferate in the future, should the deal struck in October 1994 go sour. On the other, it may the basis on which the DPRK reenters the NPT and IAEA safeguards system, and engages the United States and its allies including the ROK. The real issue lies with how the agreement to transfer the LWR is implemented, not with the agreement itself.
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The transfer of light-water reactor (LWR) technology to North Korea (DPRK) emerged as an important issue at the third round of high-level talks between North Korea and the United States held in Geneva in July 1993. This paper provides some background to the negotiations to date over this issue and analyzes the relative proliferation intensity of the DPRK’s developing its present nuclear fuel cycle versus “trading it in” for a light water reactor fuel cycle. It also appraises nuclear power technology in terms of the DPRK’s energy economy, reviews the implications of the likely poor economics of nuclear power in the DPRK and examines various constraints to transferring LWR technology to the DPRK. Finally, it discusses critical outstanding issues that must be resolved before LWR technology is transferred to the DPRK.

The Emergence of the LWR Issue

The DPRK has developed its nuclear fuel cycle capability for many years and has obtained substantial assistance from the international community (via the IAEA/UNDP) to this end, especially for uranium prospecting. The specific issue of DPRK cooperation with South Korea on nuclear research and development has been raised also in the Korean bilateral commissions pursuant to the 1991 nonaggression declaration, albeit with little progress.

The North Koreans denounced a South Korean proposal to build a nuclear power plant to be run jointly on or near the Demilitarized Zone.
But in June 1992 in discussions with the Director General of the International Atomic Energy Agency, Hans Blix they revealed an interest in light-water reactors. Blix had told the North Koreans that their reactors were outmoded and uneconomical, and North Korean officials recognized the economic advantage of shifting to light-water reactors.¹

After the DPRK announced its intention to withdraw from the Nuclear Nonproliferation Treaty in March 1993, interest intensified in this possibility. In my discussions with senior North Korean officials in May 1993, I asked three questions:

- Would North Korea cooperate with South Korea on joint development of peaceful nuclear power technology?
- Would North Korea agree to putting its plutonium (along with that of South Korea) under joint North-South Korean control?
- Would North Korea change to light-water reactors if South Korea or the international community provided the technology?

Senior party foreign policymaker Kim Yong-sun prefaced his response by stating that science and technology traverse political boundaries and ideology. He continued:

About the possibility of nuclear cooperation, whatever the form and size of such cooperation for peaceful purposes, it should be studied and researched. Science surpasses ideology and borders. There are several additional documents on exchanges and cooperation in which cooperation is scientific, not only political and cultural. If we seek broad scientific exchanges, why not nuclear cooperation; but not only nuclear, we should cooperate in all fields. In the ten-point program [for reunification, announced in April 1993], we also mention this issue where it refers to everyone's making their own contribution with power, knowledge and money. When we say knowledge, this contains fields such as scientific cooperation including nuclear cooperation for peaceful purposes and not only between North and South Korea, but also with the international community.²

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Thus, it was no surprise that the North Koreans raised the issue of shifting to a light-water reactor technology at the second round of high level talks in New York in June 1993. In response, the American negotiators indicated that the United States would support such a move because light-water reactor technology is inherently less proliferation prone than the graphite reactors under construction in North Korea. But they suggested that the issue was moot until the DPRK complies fully with its full-scope safeguards commitment under the NPT. Moreover, they informed the North Koreans that the appropriate way to pursue this possibility was to discuss it with South Korea and with Russia, which has already agreed to supply four such reactors (when the North complies with its NPT obligations and finds a way to pay for the transfer). There the matter rested until Geneva.

In Geneva, the North Koreans raised the reactor technology transfer issue on July 16th after an initial round of discussions had already been completed. The North Koreans stated that the real source of the problem in the nuclear issue is their inferior graphite nuclear reactors which they were forced to adopt because no one would help them with anything else. They suggested that the only way to solve the nuclear problem is for the DPRK to adopt and to obtain light-water reactor technology.

The Americans promptly agreed. They also stated, however, that only after the immediate problem was solved in relation to implementing the safeguards agreement, would the United States explore ways for North Korea to obtain light-water reactors. They cautioned the North Koreans to keep in mind that the US government does not sell power reactors. Moreover, North Korea would have to arrange finance with private corporate suppliers.

Although the North Koreans sought (and did not obtain) an American commitment that the DPRK should be supplied with light-water reactors, they also referred to the Russian deal to supply them four reactors. They appeared at the Geneva meeting to be satisfied with Russian LWR technology so long as the United States (or someone else) would finance it. In one aside, the Americans suggested that as South Korea has light-water reactors, the North Koreans should raise the issue of finance with Seoul.

The North Koreans also stated that the best way to proceed would be to implement their safeguards obligations step by step with progress in
achieving light-water reactor technology transfer, culminating in access to sites (they did not refer to conducting special inspections specifically, although referring to “sites” implies it). The American side promptly disabused them of this notion, insisting that substantive discussion and measures to transfer light-water reactor technology could come only after the DPRK was in compliance with the safeguards accord.

The text of the joint US-DPRK statement issued on July 19 in Geneva refers obliquely to all of these issues (see Appendix 1). One phrase states: “on the premise that a solution related to the provision of light-water moderated reactors (LWRs) is achievable,” which refers to the variety of obstacles that have to be overcome for the United States or any other supplier to transfer LWR technology to the DPRK including COCOM controls and US legislation on terrorism and trading with enemy states.

For all these reasons, the statement that “the USA is prepared to support the introduction of LWRs” and “to explore with the DPRK ways in which LWRs could be obtained” is qualified with the phrase “including technical questions related to the introduction of LWRs.” This phrase refers in turn to these difficult legal and practical questions outlined above which will be discussed in the next round of talks—should they occur.

Thus, the DPRK’s line in Geneva was new and potentially significant. The DPRK shifted blame from US policy to the fact that the North has inferior nuclear technology, which, this suggests, inadvertently implies that it is interested in nuclear weapons. It signifies that the leadership in Pyongyang may have tilted away from its anti-NPT hard line, at least temporarily. In short, the approach taken in Geneva appears designed to keep open a face-saving way out of the nuclear impasse Pyongyang created for itself, while allowing it to sustain its nuclear weapons option for the moment. While giving the appearance of a confidence-building measure that might increase the transparency of the DPRK nuclear program, the LWR issue gives the DPRK a tactical advantage in on-going negotiations as it maintains ambiguity as to its ultimate intentions.³ Kang Sok-ju (head of the North Korean delegation in the

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Geneva talks) said, for example, that his government proposed switching to more modern reactors to "prove the point" that it does not want nuclear weapons. 4

Undoubtedly, the DPRK also aspires to match South Korea and Japan in terms of perceived technological prowess and prestige associated with nuclear power programs although as I will argue they can ill afford to pursue this objective.

Some American officials at Geneva observed that it is easy for the DPRK to make this move knowing that the many obstacles to transferring light-water reactor technology cannot be overcome, at least not in a time frame that is meaningful to the nuclear issue. Others believe that the DPRK is setting its price for compliance at a level that requires the American side to clear the way for upgrading trade and investment relations between the two countries, and thus, with the rest of the world. In this sense, nuclear technology transfer impelled by the threat of nuclear proliferation is an excellent battering ram to pound against the American closed-door policy toward the DPRK.

**Proliferation Intensity of LWRs vs. Indigenous Reactors**

The DPRK has developed the basic infrastructure for a nuclear fuel cycle with a view to constructing and operating a nuclear power plant. In 1991, Kim Chol-ki, director of the Science and Technology Bureau of the DPRK Ministry of Atomic Energy Industry told me that North Korea has been planning to build a 1.76 GWe nuclear power plant as part of the third seven year plan for the DPRK. He anticipated that the plant would have four 440 MWe units operating on a two-on, two-off shift to provide back up against outage. 5

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5 Briefing from and interview with Kim Chol-ki, Director of Science and Technology Bureau, Ministry of Atomic Energy Industry, Pyongyang, October 4, 1991.
Recently, the South Korean Atomic Energy Research Institute released a report entitled "The Present Status of Atomic Energy Development in North Korea" according to which the DPRK has operated a five-MWe (approximately 25–30 MWt) reactor at Yongbyon since 1986; and has a 50 MWe reactor under construction at Yongbyon due to operate in 1995, and a 200 MWe power reactor under construction at Taechon due to operate in 1996. The report also stated that the DPRK plans to build a 635 MW power reactor at Sinpo on the Northeast coast.6

An American analyst has reported a range of reactor sizes and locations in the DPRK different from that listed in the more recent South Korean report.7 I have assumed that the former South Korean data

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is more accurate as it is consistent with the facilities declared to the International Atomic Energy Agency.\(^8\)

In May 1993, I visited the Heavy Industry Sector exhibit in Pyongyang which features a display of the DPRK’s nuclear fuel cycle facilities. It included a scale cut-away model of the 200 MWe reactor that revealed primary and secondary heat-exchange systems for the gas coolant, and two generators. From the SPOT satellite photographs of Yongbyon released by the Tokai Research Image Center in Tokyo, it is evident that the Yongbyon reactors are not intended for electricity production, as no power lines seem to exist to or from the reactor sites.

From this information, I infer that the DPRK’s power reactor program commences with the 200 MWe gas-cooled reactor, and not with the reactors at Yongbyon. The proposal to shift the DPRK to LWR technology therefore relates to this and any other nuclear power plants that the DPRK might construct.

**Cases for Comparison**

The rationale for proposing to shift the DPRK from its graphite-moderated, gas-cooled reactor program to LWR technology is the latter’s relatively lower proliferation proneness. Assuming that the DPRK will have to abandon its indigenous 200 MWe reactor in order to obtain LWR technology, the two fuel cycles must be compared with respect to two criteria (see following table). First, the DPRK could be either inside or outside of the NPT and the IAEA’s full-scope safeguards system will or will not be applied to its nuclear facilities. Second, it could have either its own or LWR technology. These possibilities produce four possible outcomes:

1. DPRK is in the NPT and has only its 200 MWe reactor operating in power, not weapons-grade plutonium mode, under full-scope safeguards;
2. DPRK is in the NPT, has only an LWR operating in power, not weapons-grade plutonium production mode, under full-scope safeguards;

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3. DPRK is not in the NPT and has only its 200 MWe reactor operating in weapons-grade plutonium production mode (worst case scenario), without safeguards.
4. DPRK leaves the NPT after obtaining an LWR, and operates it in weapons-grade plutonium production mode (worst case scenario), without safeguards.

In this study, I will conduct the comparison of proliferation intensity by comparing only two of the four possible cases, namely, the DPRK outside the NPT running a 200 MWe indigenous reactor (case B1 in the table) versus the DPRK inside the NPT running an 1 GWe MWe LWR under full-scope IAEA safeguards (case A2 in the table).

**Possible Reference Cases**

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<tr>
<th></th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DPRK in NPT with full-scope IAEA safeguards</td>
<td>DPRK out of NPT with no IAEA safeguards</td>
</tr>
<tr>
<td>2</td>
<td>In NPT; 200 MWe indigenous reactor</td>
<td>Out of NPT; 200 MWe indigenous reactor</td>
</tr>
<tr>
<td>2</td>
<td>In NPT; LWR transferred</td>
<td>Out of NPT; LWR transferred</td>
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</table>

To simplify the analysis, therefore, I assume that the United States will hold out for the following package before it seriously entertains LWR technology transfer to the DPRK:

- the "radiochemical laboratory" or reprocessing facility will be dismantled along with any other plutonium separation facilities, hot cells, etc.;
- the IAEA will be permitted to resolve discrepancies between North Korean operating records and actual plutonium separation activities as indicated by sampling, inspection of disputed sites, etc;
- the IAEA Board of Governors will have determined that North Korea is in compliance with its safeguards agreement under the
NPT, which will be applied fully to the existing reactors at Yongbyon (Alternatively, the DPRK will be persuaded to decommission these plants in return for shifting to LWRs, but this possibility is left open in my scenarios);

- North and South Korea will agree to and will implement an inspection arrangement in accordance with the bilateral denuclearization declaration.
- North Korea will abandon construction of its 200 MWe graphite-moderated, gas-cooled reactor in anticipation of receipt of LWR technology;
- North Korean spent fuel from an LWR will be kept in holding ponds at the reactor site or at a dedicated facility; and plutonium in it will not be separated in offshore reprocessing plants for recycling into LWR MOX fuel or into an eventual fast reactor program in the DPRK;
- North Korea will rely on external suppliers of enriched uranium LWR fuel.

I assume also that a one-GWe LWR reactor is supplied by South Korea (or that South Korea bankrolls Russia which already has contracts to supply LWRs to North Korea).  

### Relative Proliferation Propensity

At the end of the Geneva talks, international media reported that US officials prefer that the DPRK adopt LWR technology because it is inherently less suited for making nuclear weapons.

In reality, determining the relative proliferation intensity of different fuel cycles is a complex matter. John Holdren has suggested four factors

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9 South Korea would require US approval to permit licensed US technology to be transferred, probably in the shape of South Korean standardized LWR reactors. In the current budgetary climate, I presume that US Eximbank and PEFCO would neither finance US reactor vendors nor insure them from selling a reactor to the DPRK. Relatedly, I also suppose that second-hand reactors such as the Westinghouse 640 MWe plant at Bataan in the Philippines or for sale by utilities in the United States will not be available for sale to the DPRK due to the lack of financing. Given that Japan and the DPRK both wish to settle fundamental issues (such as reparations) before they deal with each other directly in areas such as nuclear trade, I conclude that Japan would not supply LWR technology to the DPRK.
against which different fuel cycles can be judged for their susceptibility
to diversion of fissile materials (see Appendix 2-1). These factors are:

Quality of fissionable materials: the degree of enrichment of uranium
and the ratio of fissionable to non-fissionable plutonium isotopes;

Quantity of fissionable materials: the number of critical masses per
GWe-year of operation;

Barriers: the chemical barriers to the diversion and use of fissile
materials such as form and dilutants of uranium and plutonium; and the
radiological barriers associated with spent fuel of low or high burn-up;

Detectability: the degree to which the fuel cycle requires new oper-
ations or significant modifications, and/or entails radiological releases
that can be monitored effectively.

It is evident that the once-through LWR (in the case presented by
Holdren, a pressurized or PWR) and CANDU10 fuel cycles are signifi-
cantly less susceptible to diversion of fissile materials than other
power-reactor fuel cycles.11 (I will ignore here denatured high temper-
ature gas-cooled reactor fuel cycles as these such reactors are not
commercially available due to their uncompetitive economics.) It is not
easy to compare directly the DPRK’s 200 MWe reactor (even after
scaling down to account for the difference in plant size between the
DPRK plant and that assumed by Holdren) because the DPRK has not
released detailed design information for its 200 MWe reactor. It is
necessary, therefore, to define a “reference” DPRK power plant to
juxtapose to an LWR in terms of their relative proliferation proneness.

DPRK Reference Reactor

Here are the basic physical parameters of the British plutonium produc-
tion reactors, outlined to help us “design” a reference DPRK reactor to
compare with LWR technology.

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10 CANDU is the Canadian national nuclear power company.

11 See Nuclear Energy Policy Study Group, Nuclear Power: Issues and Choices,
Ballinger, Cambridge, Massachusetts, 1977, p. 404; and American Physical
Society, “Report to the APS by the study group on nuclear fuel cycles and waste
management,” Reviews of Modern Physics, Volume 50, No 1, part II, January
The DPRK reportedly told the International Atomic Energy Agency that their reactors are modeled after the British Calder Hall reactors, which were built to produce plutonium for nuclear weapons. They were graphite-moderated, CO₂-gas-cooled reactors fueled with natural uranium metal rods clad in a magnesium alloy ("Magnox"). The second generation of four Magnox reactors were known as Chapelcross. Both generations produced plutonium but generated electricity as a by-product. All eight reactors were nominally rated at 50 MWe (net). Another source rates the early Calder Hall reactors at 225 MWth, and 41 MWe (net). I adopt 50 MWe in this study.

When operated primarily to produce electricity, the Magnox reactor operators typically set fuel burnup at 3–4,000 megawatt-days/ton of uranium fuel. The core measured about 14 meters wide by about 8 meters high. Each fuel channel in the reactor contained a stack of six fuel elements, each of which in turn consisted of massive, solid rods of natural uranium metal about a meter long and 3 cm wide. Each stack of six fuel elements weighed about 77 kg. Each core contained about 1,691 fuel channels for a total of assembly of about 10,146 fuel elements. The total uranium fuel contained in the core was about 112 tons of natural uranium (excluding cladding).

The fuel could be replaced in later, civilian Magnox reactors while producing electric power by using on-line, continuous refueling techniques, and about three fuel channels were refueled per week. Spent fuel from gas-cooled Magnox reactors cannot be stored indefinitely in water because the Magnox alloy (magnesium alloy containing 0.8 percent aluminium, 0.002–0.005 percent beryllium, 0.008 percent cadmium, and


15 A megawatt-day-thermal (MWdt) is a measure of the energy released by the fission of a given mass of nuclear fuel due to fission.
0.006 percent iron) corrodes slowly in water. (Dry storage, however, is feasible although difficult.) Each ton of Magnox fuel irradiated for 1,000 megawatt days contained about 998 kg of unconverted uranium and 0.8 kg of plutonium.\textsuperscript{16}

When operated to produce weapons grade plutonium, as they were between 1956 and 1964, the Calder Hall and the next-generation four Chapelcross reactors were run somewhat differently. Instead of continuous refueling, the whole core was irradiated and removed about twice a year (allowing for about three months repair and maintenance work). To produce very pure plutonium without the bothersome isotopes that impede weapons production, the burnup rate was reduced to about 400 MWd/ton of fuel, at which rate about 79 kg of weapons grade plutonium was produced per reactor per year.\textsuperscript{17}

On this basis, what can be said about the proliferation propensity of a 200 MWe scale-up of the early graphite-moderated, gas-cooled reactors compared with an LWR when measured against the factors listed above? Note the following table on relative proliferation intensity.

In terms of quality, replacing the DPRK reactor with an LWR would increase the international community's leverage over the front end of the DPRK's fuel cycle by virtue of an LWR's dependency on imported uranium enrichment services.

\textsuperscript{16} Nuclear Assurance Corporation, Nuclear Materials and Fuel Cycle Services, Sources, Inventories and Stockpiles, report to US Arms Control and Disarmament Agency, volume 2, September 1979, pp. IV-4, IV-5.

\textsuperscript{17} The Calder Hall (CH) and follow-on Chapel Cross (CC) reactors were rated at a nominal 50 MWe equivalent to 250 MWe (at a conversion efficiency of about 22.5 percent). The CH and CC reactors generated 19 TWh between 1956 and 1964, equivalent to a thermal output of 3,500 MWd over that period for all eight reactors. At a burnup of 400 MWd/ton of fuel to optimize weapons-grade plutonium, about 8,750 tons of fuel were irradiated to a level of 400 MWd/ton. At 0.36 kg of weapons-grade plutonium per ton of fuel irradiated to this burnup, total 1956–64 plutonium production in the eight CH and CC reactors was about 3.15 tons. The CH and CC reactors accumulated about 40 reactor years of operation in plutonium production mode up to 1964, resulting in an annual weapons grade plutonium production rate of about 79 kg per reactor year. D. Albright, F. Berkhout, W. Walker, \textit{World Inventory of Plutonium and Highly Enriched Uranium}, 1992, Oxford University Press, New York, 1992, pp. 41–42; personal communication, Frans Berkhout, September 14, 1993.
Relative Proliferation Intensity of LWR vs. DPRK Indigenous Reactors

<table>
<thead>
<tr>
<th></th>
<th>PWR Once through Fuel Cycle Per GWe-year</th>
<th>DPRK Indigenous Reactor Fuel Cycle Per 0.2 GWe-year Operated to Maximize Plutonium Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of fissile material and main dilutants at this point</td>
<td>855 kg U235 in 28,500 kg Pu U238, 3% enrichment</td>
<td>336 kg of U235 in 223,664 kg of U238 enrichment</td>
</tr>
<tr>
<td></td>
<td>250 kg of (69% fissile) in 26,000+ kg uranium and zero % fission products</td>
<td>315 kg of weapons grade plutonium in approx. 223,000 kg of U238 and fission products</td>
</tr>
<tr>
<td>Further processing needed from this point to use in nuclear explosives</td>
<td>extensive further isotopic enrichment required</td>
<td>chemical separation from uranium and fission products required</td>
</tr>
</tbody>
</table>

Proliferation Susceptibility Indices (5 = worst, 1 = best)

<table>
<thead>
<tr>
<th>Quality</th>
<th>PWR</th>
<th>DPRK</th>
<th>PWR</th>
<th>DPRK</th>
</tr>
</thead>
<tbody>
<tr>
<td>As is</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Enrichment</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Quantity</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Barriers</td>
<td></td>
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</tr>
<tr>
<td>Chemical</td>
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<td>4</td>
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<td>Radiological</td>
<td>5</td>
<td>1–2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Detection</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>


Note: see Appendix 2-2 for definitions of numerical weights.
At the back end of the fuel cycle, it would also reduce the quality of the plutonium available from spent fuel by increasing the amount of plutonium isotopes that may prematurely initiate a nuclear chain reaction in a weapon (unless the LWR were removed from the NPT regime and operated to maximize the production of weapons-grade plutonium).

In terms of quantity, a one-GWe LWR would produce about 250 kg of plutonium per year. A DPRK 200 MWe reactor scaled up from Calder Hall technology and operated in plutonium production mode could produce about 315 kg of weapons-grade plutonium. Thus, LWR transfer would decrease the quantity of plutonium to be controlled under safeguards, although only marginally. In neither case, however, would diversion of one percent per year yield a “bomb” quantity (5 kg for weapons-grade plutonium).

In terms of chemical barriers, LWR technology is fairly resistant on the front end in that the fissile material is in oxide form, albeit not mixed with an effective dilutant. However, the gas-cooled reactor would use natural uranium fuel which would be even more difficult to utilize for weapons purposes than low-enriched uranium oxide for LWR fuel. So long as neither fuel cycle introduces plutonium recycling, they are equivalent in terms of chemical and radiological barriers to diverting spent fuel from storage to weapons activities. Unfortunately, due to the difficulty of storing spent MAGNOX fuel in water for long periods, North Korea has argued that it may be obliged to reprocess the fuel for safety reasons and has already cited precedents to this effect in Britain, France and Japan. Some experts do contend that dry storage is feasible, however.

In terms of detectability of diversion, an LWR fuel cycle appears to offer significant advantages. If we assume that the DPRK operates its reprocessing plant in case B1 (go-it-alone with its own 200 MWe plant outside of the NPT system) but would abandon it along with the 200

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18 If the plant were operated to maximize electricity output (as it presumably would be so long as the DPRK stayed in the NPT) with a burnup of about 4–5,000 MWd/ton of fuel, then the 200 MWe plant would produce substantially less plutonium (about 50 kg according to expert sources) than the LWR. However, I have precluded this case from consideration in this study to simplify the analysis.

MWe reactor in case A2 (rely on LWR technology), then the LWR would reduce the opportunities for diversion at various points in the reprocessing and recycling portions of the fuel cycle from relatively high to essentially zero. The LWR is inherently easier to safeguard because shutdown is obvious and is required for removal of any fuel rods (although the fact that an LWR is relatively easier to control in this respect is not relevant to the comparison with the DPRK indigenous plant because I assume that this reactor would only operate outside the NPT whereby diversion detectability becomes moot).

Overall, therefore, the major reduction in proliferation intensity associated with switching to LWR technology would be (1) the increased dependency of the DPRK on the international community for enrichment services, and (2), the reduced opportunity for and enhanced detectability of diversion of plutonium from LWR spent fuel under safeguards versus an indigenous reactor operating outside the NPT. Finally, inducing the DPRK to abandon its 200 MWe reactor would lay to rest any possible rationale for completing and operating its reprocessing facility in order safely to store spent fuel. Other than these advantages, the LWR is only marginally less proliferation prone than the indigenous plant from a technical perspective.

**Other Considerations**

Six other factors offset or reinforce these marginal technical advantages of an LWR over an indigenous DPRK reactor.

First, an LWR in North Korea could legitimate continued accumulation of weapons-relevant skills that could be mobilized at short notice to produce nuclear weapons from a large stock of accumulated plutonium in spent fuel. Thus, the acquisition of an LWR is consistent with the DPRK's maintaining a posture of studied ambiguity as to its ultimate intentions with respect to nuclear weapons.

Second, the DPRK could reduce the leverage implicit in its reliance on imported enriched uranium fuel by stockpiling this material (assuming it could afford to do so, and that this step passed unnoticed by the international community).

Third, LWR or "reactor grade" fuel containing excessive amounts of the plutonium isotopes Pu 240 and Pu 242 is still useable for a nuclear weapon at a cost to expected yield and certainty of yield than weapons
using "weapons-grade" material. Moreover, it is not appreciably more
difficult to design a weapon using reactor- rather than weapons-grade
plutonium.\textsuperscript{20}

Fourth, the DPRK could operate an LWR (presumably after departing
from the NPT) to minimize the production of these inconvenient iso-
topes by shutting down the reactor more frequently to remove irradiated
fuel (but at a cost to electricity production).\textsuperscript{21}

A "modernized" DPRK that is rendered capable of running (or even
constructing) an LWR could also become a more active and disruptive
exporter of nuclear technologies than it would if it only has access to
its own relatively primitive nuclear technology. Weighing against this
disadvantage of an LWR is the fact that although the DPRK could
become a more capable and potentially disruptive supplier of nuclear
fuel cycle technologies, materials (such as graphite) and techniques, it
would be less likely to have developed as well as to transfer nuclear
weapons capabilities under the political conditions in which an LWR
might be transferred to the DPRK. Conversely, if left to its own devices
it might develop and share nuclear weapons-related expertise with other
states in the near term; whereas it would take many years (up to fifteen
years for advanced reactor-core components) for the DPRK to develop
exportable expertise in LWR manufacture.\textsuperscript{22}

One other issue is worth noting. North Korean officials have re-
marked that during a war South Korea's nuclear power reactors might
be hit; these reactors do present tempting radiological targets.\textsuperscript{23} By the
same token, a large-scale nuclear power plant in North Korea would
present the South with a reciprocal targeting option. Having a much

\textsuperscript{20}See J. Karsen Mark, "Explosive Properties of Reactor Grade Plutonium," Journal of
Science and Global Security, Vol. 4, 1993, pp. 111-28; and J. Karsen Mark,
"Reactor-Grade Plutonium' Explosive Properties," Nuclear Control Institute,
Washington DC, August 1990.

\textsuperscript{21}J. Holdren, "Civilian Nuclear Technologies," p. 173.

\textsuperscript{22}S. Droutman, International Deployment of Commercial Capability in Nuclear Fuel
Cycle and Nuclear Power Plant Design, Manufacture and Construction for
Developing Countries, Westinghouse Electric Corporation report to Oak Ridge
National Laboratory, ORNL/Sub-7494/4, October 1979, p. 6-122 and 10-9.

\textsuperscript{23}B. Ramberg, Destruction of Nuclear Energy Facilities in War, The Problem and
larger reactor program (twelve power reactors operating or under construction), the South proffers the North ten to fifteen times as much radiological damage potential as would one reactor in the North to the South. But a large reactor in the North would make the implicit threat to attack a radiological target in wartime a risk shared by both sides, which in principle provides the South with a qualitatively similar deterrent against such attack.\footnote{Of course, such targeting would be illegal under international law, but this law might have limited relevance to the behavior of the antagonists in the midst of a hot war in Korea.} Although an LWR might contain much more fission products and radioactive materials than would the DPRK’s 200 MWe plant, the switch to LWR technology per se would make little difference to this factor.

In this section, I have shown that an LWR offers some inherent advantages over North Korea’s own reactor in terms of the criteria of quantity and quality of fissile materials, chemical and radiological barriers, and detectability. I also noted that six other factors should be considered in relation to the transfer of an LWR to North Korea, namely: continued DPRK ambiguity as to ultimate proliferation intention, fuel stockpiling, the utility of LWR-grade plutonium for nuclear weapons, the possibility that an LWR could be used to make weapons-grade plutonium, North Korea’s export behavior, and the issue of wartime radiological targeting.

In the next section, I analyze the economic soundness of a nuclear power plant in the North Korean energy economy.

**DPRK Electricity Needs and Nuclear Power**

As of 1991, the DPRK planned to build only one nuclear power plant. When that is completed successfully, North Korean officials assert that they will develop further plants “in accordance with the needs of national economic growth.”\footnote{Briefing from and interview with Kim Chol-ki, Director of Science and Technology Bureau, Ministry of Atomic Energy Industry, Pyongyang, October 4, 1991.}

There is little doubt that the DPRK is suffering from acute energy shortages, both of petroleum fuels (especially in the transport sector,
probably in industry, and possibly in fertilizer production), and of electricity.

Energy Sector: As is well known, the DPRK relies heavily on coal, hydropower, and imported oil for its energy supplies.

The institutional arrangements in the energy sector are complicated and reflect a high degree of functional fragmentation. The energy sector in the DPRK has no single specialized institutional authority or ministry responsible for energy analysis, integrated planning and management. These tasks are scattered in agencies and ministries as depicted below:

(a) Coal exploration, mining and supply is under the jurisdiction of the Ministry of Coal Mining;
(b) The electric power sector development, power generation, distribution and sales are the responsibility of the Electric Power Industry Commission;
(c) Energy statistics and energy planning activities are performed by the State Planning Commission incorporating Central Statistics Bureau under its authority. The State Commission for Science and Technology acts as a consulting body in these activities mainly providing appropriate recommendations and software for energy plan formulation and decision making;
(d) Supervision of energy flow and reasonable consumption of the fuel in the transport sector is assigned as a function of the State Transport Commission;
(e) The Ministry of Atomic Energy is in charge of development, construction, and power generation of nuclear power plants, as well as nuclear fuel supply;
(f) The External Economic Affairs Commission is responsible for purchase of crude oil and petroleum fuels, and all imported machinery and equipment for the energy sector;
(g) The Ministry of Machine Building Industry is responsible for manufacturing and supply of domestic power equipment. Most of the research and development work for the energy sector is performed by the institutes affiliated with the Academy of Sciences, although all the above-mentioned Ministries and Commissions have their own research institutions; The non-standing State Committee for Energy, chaired by the Prime Minister, discusses and decides on major issues in the energy sector; Research and
development activities related to the energy sector performed by institutions affiliated with the various ministries are coordinated by the State Commission for Science and Technology.

Appendix 3 contains a flow chart illustrating this organizational arrangement. This functionally differentiated and fragmented institutional framework results in poor policy coordination and program implementation. There is no comprehensive energy policy in the DPRK. There is no apparent economic rationale to the existing price structure for different energy forms. There are not even rudimentary markets to facilitate economically efficient transactions between energy-related supply-and-demand entities. Planning and fuel allocation is also inhibited by the apparent nonexistence of a basic energy supply/demand balance in the DPRK. Indeed, a UNDP energy efficiency improvement project in the DPRK is meant to create just such a balance at the proposed Center for the Rational Use of Energy.

Electricity Sector: North Korea claims to have about 12,000 MWe of installed capacity, with an available capacity of 10,000 MWe. Approximately 50 percent of the generating capacity is hydroelectric, and about 50 percent is thermal, mostly coal-fired. About 84 percent of the electrical energy is fired by coal.

Generating Plant: Although there are more than 500 generating plants, only sixty-two major power plants are linked to the nationally interconnected transmission system, which in turn transports about 85 percent of the generated electrical energy. (The residual 15 percent of electrical energy is generated by self-reliant industrial facilities and by small, isolated and mostly hydroelectric units.) Of the plants linked to the transmission system, twenty are thermal (eighteen being coal-fired, two being oil-fired), and forty-two are hydroelectric.26 The largest

26 The DPRK imports oil, mostly from China (by pipeline) and Iran by sea. A trickle was supplied last year from Russia. Before the international situation changed in the early 1990s, the DPRK imported about 4 million tons per year. In 1992, the DPRK imported about 40,000 tons from Russia (down from its FSU level of 8–900,000 tons per month); about 4–600,000 tons/month from Iran, and about 100,000 tons/month from China. The DPRK is to pay for half of the Chinese oil in hard currency (although it reportedly has failed to do so much to China’s chagrin); the rest is financed by soft loans. The bulk of this oil is used in agriculture (for fertilizer production and in agricultural mechanized processing), and in the transport sector. The DPRK’s two oil refineries have about 4.5 million tons per
thermal unit is at Pukchang with an installed capacity of 1,600 MWe. The largest hydroelectric plant is at Supung and has an installed capacity of 700 MWe (seven 100 MWe turbines), whose output is shared by the DPRK and China.

The North Koreans run the thermal, mostly coal-fired plants as baseload units, and use the hydroelectric plants to meet peak load demands. When demand exceeds supply, the supply to consumers is suppressed. The DPRK Electric Power Industry Commission estimates that it has to accommodate a generating gap of at least 500 MWe. Blackouts occur and loads are shed regularly resulting in large production losses. In the winter, load shedding reaches 1,000 MWe due to the accumulation of snow. In summer—particularly in March through May—shortage of water at hydroelectric reservoirs forces the power system operators to shed as much as 2,000 MWe for up to an hour at a time. Bad weather can worsen the situation as storms, old and low-quality equipment, and incorrect operation of protective devices cause the transmission system to fail.

Consequently, the quality of electric power in the DPRK is also poor in terms of frequency (often found at 57–59 Hz, well below the permissible deviation from the standard 60 Hz) and voltage (which frequently fluctuates). The power factor at load centers is also low and averages 0.8, which can badly damage end-use equipment.

Transmission and Distribution System: The transmission system is isolated from neighboring countries (except for a 60 KV line feeding

year capacity. Russia also supplies about 245,000 tons of coking coal for use in the DPRK steel industry, paid for in part by barter of raw materials and goods, and by the export of North Korean labor in Siberian forestry projects.

27 The seven largest thermal plants are listed hereafter, along with the following parameters: name; in service data; number of units; installed capacity; actual loading; annual production in 1991. Bukchang, December 1973, 16, 1,600 MWe, 1,056 MWe; 9.25 TWhe; Chogzin, March 1984, 3, 150 MWe, 142 MWe, 1.2 TWhe; Chengchengan, March 1979, 4, 200 MWe, 116 MWe, 1.1 TWhe; Sunchon, May 1988, 4, 200 MWe, 133 MWe, 1.2 TWhe; Pyongyang, June 1968, 9, 500 MWe, 345 MWe, 3.0 TWhe; Oung gi (oil), April 1973, 4, 200 MWe, 146 MWe, 1.3 TWhe; East Pyongyang, February 1992, 1, 50 MWe, 28 MWe, under construction. The former Soviet Union/Russia supplied the technology for the following stations: Bukchang, Pyongyang, East Pyongyang (still under construction), Chanjin (which is being refurbished with Russian assistance), Oung gi, and Sun Bun. A new 170 MWe station to be built with Russian credit is under discussion.
power to a remote area of China). The DPRK uses 220 and 110 KV lines for bulk transmission; 60, 10 and 3.3 KV for distribution; and 380/220 V at 60 Hz for distribution to consumers. The government states that 100 percent of households and industry are electrified. As not all consumers are metered, the exact quantity and sectoral distribution of electrical end use are not known. The government states that transmission losses are about ten percent, and distribution losses are about six percent. However, some observers believe that this official estimate (like generation figures) are optimistic, to say the least. The transmission and distribution system reportedly needs urgently to be refurbished.

Generation Difficulties: The DPRK government claimed that generation in 1989 was about 50–55 TWhe. Informed observers in Pyongyang estimate that the actual generation in 1992 was about 31–32 TWhe and that the annual shortfall is between 10–12 TWhe. This difference reflects all the problems of generation, load shedding, and transmission and distribution losses referred to above.

In the generating plants, machinery cannot be maintained or repaired adequately due to the shortage of spare parts, testing equipment, and obsolete and incomplete monitoring and control instrumentation in the power plants. The official estimate of thermal power generation of the thermal-to-electricity conversion efficiency of thirty-four percent is likely a substantial overestimate. At the Pyongyang Thermal Power Station, for example, major equipment is deteriorating due to the limited capabilities to track thermal performance, poor instrumentation and testing equipment, and the lack of a comprehensive maintenance program. All these technical problems are worsened by the shortage of skilled staff able to use what equipment exists. About 211 GWhe of electricity generated at the station (or five percent of its nominal and

28 Rural households and agriculture reportedly use about 2.2 billion kWh per year. Otherwise, little is publicly known about sectoral electrical consumption.

29 A TWhe is $10^{12}$ watt hours of electricity.

30 It is possible that the generation figures are more or less correct, but that upwards of 50 percent of generated electricity is lost in transmission and distribution, and that 31–32 TWhe is the correct figure for end use consumption.
seven percent of its actual rated output at a hundred-percent capacity factor) is lost due to acute problems such as boiler outage, etc.

**Coal Shortages:** The power sector is also afflicted by problems originating in the coal mining industry. Coal shortages (reportedly due to the classic command-and-control bind of shortage of coal for steel and power production on the one hand, and transport constraints on getting coal to end users due to steel shortages on the other) have constrained the power output at thermal power stations. Also, the Institute for Coal Selection lacks equipment to determine the energy content of mined coal. Consequently, power station operators may not know the quality of fuel loaded into steam boilers at generation plants. The DPRK lacks a long-range coal mining industry development program and a master plan for each coalfield and basin to determine the best allocation of investment resources in coal production in relation to projected consumption needs. Moreover, that coal which is produced is not cleaned before it is sent to consumers, which imposes operating and pollution problems (from ash) for power plant operators. Perhaps sixty percent of the coal used in power plants is wasted in inefficient combustion.

It has been estimated that the equivalent of at least six million tons of coal is wasted in the whole country and that simply using high temperature waste heat rationally would increase electricity generating capacity by 400 MWe. Most of the industrial furnaces and ovens that vent exhaust gases at temperatures of more than 500° centigrade do not recover the heat for preheating fuel or other uses. Nor are piping or furnace walls insulated due to the lack of insulation materials. Almost no use is made of modern heat exchangers or simple heat pumps.

**Expansion Plans:** The Government emphasizes expansion of the power sector in its plans and allocated three billion won during the most recent (1987–1993) plan. It aimed to increase power capacity to 19,000 MWe and to generate 100 TWh in 1993. These plans are ambitious and highly unrealistic.

To this end, the DPRK is building twelve new hydroelectric plants amounting to an additional 2,500 MWe (the largest is 800 MWe). The

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31 These are Supon, 735 MWe; Hojonggan, 394 MWe; Unbon, 400 MWe; Saduso, 451 MWe; and Kange, 246 MWe.
government also plans to construct 4,000 MWe of thermal power plant ranging from 200–1,600 MWe. As noted earlier, it also proposes to add a nuclear power plant of size indeterminate. Finally, the government intends to upgrade the transmission network by expanding it and introducing 330 KV transmission in the mid-nineties (to increase eventually to 500 KV).

Institutional Weakness: The Electric Power Industry Commission (EPIC) is the key power sector institution which plans and develops power generation, transmission, distribution, and end use sales and has ministerial status in the government. The organization chart for the EPIC is shown in Appendix 4.

Within the EPIC, the Electric Power Dispatching Bureau is responsible for the Electric Power Production and Dispatching Control Center (EPPDCC), which in turn monitors and coordinates the functions of the power system with its fifty-strong staff. EPPDCC is responsible for planning hydroelectric and thermal power plants; monitoring the status of generating units for efficiency and reliability of supply; monitoring the system flow of electricity at voltage levels at or above 110 KV; planning and implementing repair and maintenance of the system; responding to faults and contingencies in the power system; and collecting and storing data on system operation. It also supervises eleven regional power dispatching centers. It is supported by the Institute of Electric Power and Telecontrol in the areas of telecommunications and control, computer equipment, and software.

Load Dispatch Difficulties: Given the complexity of the power system, EPPDCC requires instant access to accurate and salient information on 62 power plants, 58 substations, and 11 regional transmission and distribution dispatching centers. The system operators at EPPCDD, however, rely on phone or telex messages for status updates on the value of such parameters as voltage; current; active power; frequency, etc., at a load center; or a drop in system frequency due to a fall in generation. Relatedly, if a transmission line is tripped out-of-service due to a fault, then the network configuration must be reconstituted immediately or

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32 The 1986 contract with the Soviet Union was for a 1,760 MWe nuclear power plant. The USSR also provided technical assistance to survey potential sites. This agreement has been taken over by Russia, and is on hold until the issue of IAEA safeguards is resolved.
whole sections of the system become isolated. The slow pace and unreliability of the information systems used by EPPDCC virtually ensure that the system operators cannot restore the system to working order. As of late 1992, EPPDCC operated one old desktop personal computer to collect and analyze system performance data, but it cannot handle the processing of planning and logging information.

Thus, the power system lacks any modern, automated, and computerized supervisory and monitoring capability that can support a load dispatching function in real time. The pilot project underway with UNDP support to rectify this deficiency covers four critical power plants and substations only, and will not resolve the problem at a system level.

**Vast End-Use Energy Waste:** In addition to the problems noted above, the consumption at point of end use of electricity is also very inefficient in the DPRK. The government estimates that industries typically waste between 30 and 50 percent of energy supplied. Many residential buildings are not insulated. Typically, heating is by hot water pipes embedded in the floor with a single on/off valve per apartment. The source of heat is centralized, and is linked to power plant waste steam output on a district basis. (Cooking is by bottled gas or kerosene with fuel stored on balconies).  

Aside from dramatically increasing comfort levels in North Korean buildings, properly insulating walls and windows would reduce the demand for “waste” steam from power plants which could be used better on-site at power plants to increase the generating efficiency (or reduce fuel usage) of electricity. The government has recognized that large opportunities exist to reduce energy waste and has decided to establish a Center for Rational Energy Use.

In short, the main characteristic of the DPRK’s power sector is its extraordinary wastefulness—waste in fuel production, waste in transmission and distribution, waste in end uses of electricity, and waste of scarce skilled labor. The DPRK’s power sector is badly organized and managed. It cannot operate efficiently due to obsolete equipment and procedures. It is hard to imagine it operating effectively a modern nuclear power plant.

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Implications for Nuclear Power in the DPRK

From an economic perspective, the DPRK’s priorities for public investment in increasing energy services obtained from its energy sector probably should be (in order of most to least important):

1. Improve energy efficiency in end uses, especially in large and centralized consumers such as industrial plants and buildings;
2. Reduce energy losses in generation, transmission, and distribution in the existing power system;
3. Increase the quality and quantity of domestic energy resources (coal and water storage);
4. Provide new energy service capacity based on integrated, least-cost power planning which puts marginal supply options on an equal footing with marginal end-use efficiency options.
5. Construct new generating capacity as needed after all the above priorities have been achieved.

This analysis suggests that constructing a nuclear power plant in the DPRK is likely to be a high-cost, low-priority way to fulfill energy demands. The demonstration effect of the Japanese and South Korean nuclear power programs make it difficult to argue this case effectively with North Koreans—but the fact that these two countries have over-invested in a costly energy option should not disguise the fact that the DPRK can ill-afford to waste money on a nuclear power plant when many other options exist to supply energy services at far lower cost, faster, and with less risk. Indeed, continuing to divert a large fraction of North Korea’s scientific and technological talent to a nuclear power program may worsen significantly the chronic and pressing problems of the conventional power sector described above.

Technical Problems: In addition to the opportunity cost of forgone energy services that a nuclear power plant will impose on North Korea’s economy, such a plant would also pose formidable technical challenges including: maintaining system reliability, following load patterns with a base load plant, safe operation; delay, and timing.

A nuclear power plant may also be technologically ill-suited for the DPRK power system. First, it is unclear whether a one-GWe plant at Sinpo (or elsewhere) will be small enough not to threaten the power system’s stability. Crudely, no generating unit should exceed more than
about 10–20 percent of the total system capability—or the available system reserve—or else the operation of the whole system may be threatened due to unexpected outages. Detailed review of the DPRK transmission system would be necessary to answer this question. Inspection of the following, however, indicates that the DPRK barely meets the reliability criterion—assuming that its total actual generating capacity of 10,000 MWe feeds into one national, highly interconnected transmission grid. Conversely, by the time that the DPRK might bring an LWR on-line, the grid may have grown enough to accommodate a large LWR.

Second, a nuclear power plant is usually operated as a baseload plant and cannot be quickly powered up and down to follow peak demand cycles. Ascertaining whether a nuclear power plant would be technically appropriate in relation to demand patterns would require access to data either as yet uncollected, or not released by the DPRK government.

Third, it remains an open question as to whether a nuclear power plant could be operated safely and its output dispatched, given the parlous nature of the current power operating infrastructure described in the previous section. Admittedly, it would take five to seven years (if South Korea were to be the supplier and architect-engineers) before an LWR could be built in the DPRK, which would provide some time to train power system and nuclear plant operators. Nonetheless, the status of the current power system does not inspire confidence that safety and operational objectives would be achieved in a DPRK nuclear power program. Attempting to operate an LWR (especially a Russian LWR) in the DPRK may pose an environmental threat to domestic

### Relationship between Installed Capacity and Size of Plant

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<th>Installed Capacity</th>
<th>Must Be at Least</th>
<th>To Accommodate A Single Plant of</th>
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<td>850 MWe</td>
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<td>3,300 MWe</td>
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populations as well as to neighboring states already sensitive to radioactive fallout issues in the aftermath of Chernobyl and Russian radwaste dumping in the Sea of Japan.

Fourth, transferring an LWR will take years—many years. The tasks of financing, site selection, power system upgrade, fuel cycle infrastructure, fuel supply contract, technology supply and architect-engineering contracts, training of operators and technicians, and actual construction and testing would all have to be completed before a nuclear power plant would deliver the first kWhe into the North Korean power grid.

A *minimum* of six years (assuming South Korean financing, and South Korean or Russian LWR technology) would be required, being one year to set up the deal, and five years to construct an LWR.34 Given the difficulties of building a nuclear power plant in North Korea where basic legal and administrative barriers exist to the operation of foreign firms and in which the economic infrastructure is so poorly developed that an architect-engineering firm would have to import virtually all supplies and much of the requisite skilled labor force, a more reasonable estimate of the time to complete the plant might be eight to ten years.

Finally, a GWe-sized LWR will cost upwards of US$3 billion—money that the North Koreans do not and will not have in the foreseeable future, given their accumulated foreign debt of US$5 billion. If the North Koreans are serious about obtaining an LWR, then they must assume that they can persuade another state to provide financial guarantees to private financiers to bankroll the project, or to finance directly the transfer with a loan. Presumably, they have in mind that South Korea might finance either a Russian LWR or a South Korean LWR as doing so may be cheaper than the political and military costs of responding to a North Korean nuclear weapons program. The DPRK may also calculate that obtaining external financing for an LWR on this scale might help it to revive its sagging credibility with foreign lenders still angry at its failure to reschedule its $5 billion debt.

34 On July 24, 1993, South Korea's Unification Minister Han Wan-sang said that South Korea could provide financial and technological aid for the LWR transfer, conditional upon DPRK's compliance with the Geneva agreement with the United States. Reuters, "South Korea may help North convert nuclear reactors," wire story, July 24, 1993.
Critical Issues

In this section, I turn to the concern that lies at the heart of the LWR transfer issue: why did the North Koreans raise this demand and is it sensible to meet it? North Korean officials often repeat a slogan in international meetings: “We mean what we say and we say what we mean.” In reality, fathoming the North Koreans’ intention has been the most difficult aspect of the past and on-going nuclear negotiations, and the LWR transfer issue is no exception.

In sum, the following conclusions can be drawn from this essay:

Conclusion 1: the North Koreans raised the LWR transfer issue to keep their options open by defining a face-saving exit from the NPT impasse that they have created and to create a battering ram with which to break down the US closed-door policy on trade, investment and aid.

Conclusion 2: an LWR presents marginal advantages over the indigenous North Korean reactor in terms of relative proliferation intensity; but the critical issue is the implementation of full-scope safeguards and compliance with NPT obligations, not the relative technical characteristics of nuclear fuel cycles.

Conclusion 3: an LWR is probably an expensive way to meet North Korea’s energy needs and may be dubious from an economic perspective. In any case, demanding an LWR along with abandonment of the DPRK’s own reactors would delay the startup of its nuclear power reactor program by at least five years.

Conclusion 4: the DPRK is likely to insist that it retain its existing nuclear power program and operate it under safeguards while an LWR is transferred, in order to retain backstopping insurance against the whole deal’s going sour. Although the United States will find this stance difficult to accept, it may conclude that keeping the DPRK in the NPT with safeguards applied to its fuel cycle is better than having it outside the NPT without safeguards, especially if it judges that the actual transfer of LWR technology is unlikely to be completed in the lifetime of the Kim regime.

The North Koreans who make decisions in Pyongyang know these facts and will have drawn their own conclusions. The corollary of these conclusions is that they seek primarily to realize intangible benefits such as prestige, the impression of modernity, and symbols of external
recognition of the durability of their rule; and possibly more tangible gains in terms of reopening trade and financial relations with the external world (see the epilogue below).

The critical issue is whether provision of an LWR will induce the North Koreans to abandon their reprocessing plant (and possibly their own reactors) and allow full-scope safeguards to be implemented. If so, then providing an LWR is a cheap way to preserve the peace and restore the nuclear nonproliferation order in Northeast Asia. If not, then the transfer issue is simply a diversion introduced by North Korea to stall for time while they pursue a nuclear weapons program or seek other options.

Given that an LWR would not exist under the most optimistic scenario until after Kim Il Sung has passed from the scene, the abandonment of its 200 MWe reactor and reprocessing plant, and, by returning to the NPT fold, the resolution of outstanding ambiguity as to the North’s residual nuclear weapons capability arising from past reprocessing, would be a major concession by Pyongyang. Indeed, the DPRK’s current rulers would have no assurance that they would ever receive an LWR given the long lead times involved. It follows that however politically important an LWR transfer agreement might be to ensuring that full-scope safeguards are applied to the DPRK’s nuclear fuel cycle, an LWR cannot substitute for other benefits sought by the regime that may have an immediate and tangible impact on its survival prospects. These include negative security assurances, an end to Team Spirit, and a general upgrading of US-DPRK relations.

By demanding that LWR technology be transferred, North Korea has set a high price for complying with the NPT. But in doing so, it has at least defined a specific way to resolve the standoff that might be acceptable to all parties and against which progress can be measured quite precisely. Striking this deal would also symbolize that the United States, and by implication, the rest of the world, recognizes the political autonomy of the North Korean state.

It is difficult to be optimistic at this late stage in the endgame. North Korea has barely fulfilled the two conditions that it agreed to in Geneva—starting a serious dialogue with the IAEA to resolve the discrepancies identified by the IAEA as to past plutonium reprocessing, and entering into substantive talks with South Korea. Indeed, it has
backtracked by asserting that compliance with IAEA safeguards should follow, not precede striking a deal to transfer an LWR—a position it knows to be a non-starter with the United States. It has also done nothing to date to resolve the outstanding issues with the IAEA and has refused to allow the IAEA to conduct uninhibited routine inspections (although it did offer to let inspectors refurbish monitoring equipment at the end of October).

Until now, the DPRK has been able to curb moves to increase pressure on it by allowing the international community to maintain the transparency of its current nuclear activities. However, the IAEA inspectors who went to North Korea at the end of August were unable to conduct even routine inspections, and were barely able to maintain continuity of monitoring at declared sites. Now that, as the IAEA puts it delicately, continuity of observation has been “damaged,” the patience of the international community will be tested to the limit and time will run out for North Korea.

Shortly, therefore, we will know whether the LWR issue is simply another siren song to seduce the naive, or if it is a strategic commitment on the part of the DPRK intended to enable it to reenter the international community.

Epilogue

Fortunately, “shortly” is an elastic word. It could be some time before the IAEA and the DPRK identify enough common ground to permit the United States and the DPRK to reconvene high level talks. Also, US national technical means can substitute for IAEA ground monitoring, at least for a time and to some extent.

In my October 19, 1993, interview with Kim Yong-sun in Pyongyang, he made a number of significant points relating to the LWR issue. “The LWR issue,” he stated, “will be crucial to the success or failure of the next round of US-DPRK high level talks.”

"If the LWR issue is solved successfully," he added, "then the DPRK will stay in the NPT. If not, then we have no alternative but to seek to supply energy from our own nuclear technology."

"The DPRK doesn’t care where the LWR technology comes from, whether it is American, Russian, South Korean."

"But whatever the source," he said, "the arrangement must be made via an agreement between the DPRK and the United States." North Korea, he explained, fully understands that for the United States to provide LWR technology—for example, by allowing US LWR technology licensed to South Korean companies—to be exported to the DPRK will entail clearing away political and legal barriers that apply to all aid, investment, and trade between the two countries. Indeed, that is the major reason that the LWR issue is so important and why the high-level talks will succeed or fail according to the way the LWR issue is handled.

"It is crucial," he said, "that the next round of high level talks with the United States happen very soon. Only a comprehensive solution will work that declares that the United States and the DPRK will together bring about the LWR transfer. This could ease a lot of tension. If such a deal is made, the NPT issue will no longer be a big deal and it would contribute to the normalizing of relations between the DPRK and the United States."

Presuming that the immediate issues relating to the reactivation of routine inspections are overcome and US-DPRK high level talks are reconvened, then what obstacles to and opportunities for cooperation arise with respect to the transfer of LWR technology to the DPRK?

In this epilogue, I analyse these obstacles and opportunities in a hierarchy starting with high- and ending with low-order questions. I conclude with some suggestions as to practical steps toward cooperating with the DPRK that would be entailed by LWR technology transfer, including roles that nongovernmental organizations can play.

**The overarching quid pro quo**

**US Objectives:** Will the United States facilitate this transfer in return for merely reactivating routine inspections; or must the DPRK also allow special inspections to proceed? modified special inspections? dismantle its reprocessing plant? and allow it to be kept if inspected, but not insist that it be dismantled? dismantle its 200 MWe indigenous
reactor? or allow it to be kept if inspected, but not insist that it too be dismantled?

**DPRK Objectives:** Will the DPRK insist that the United States actually supply LWR technology (including the hardware)? commit to ensuring another supplier transfer the technology? merely facilitate discussions with another supplier? finance the transfer? over what time frame? and what will the DPRK give up in terms of fuel cycle capabilities that the United States wants dismantled and which represent fallback insurance if the LWR deal and related normalization of relations go sour?

**What Does the DPRK Mean by “LWR Technology Transfer”?** Does the DPRK mean the term to cover merely the supply of hardware, software, and peopleware required to plan, construct, operate and decommission an LWR in the DPRK? Or does it include equipping the DPRK with full LWR fuel cycle facilities? And/or transfer of LWR manufacturing capabilities? In the rest of this paper, I assume that only the first, most narrow definition of transferral is under discussion with the DPRK. However, it is important to clarify this point at the appropriate time with the North Koreans.

**What Price is the US Willing to Pay to Keep the DPRK in the NPT?** Is the effort worthwhile it for the United States? For the North Koreans, it is evidently necessary to transform their external political and economic relations if they are to commence the delicate process of internal reform, economic transition, and structural adjustment. The stakes for the North are regime survival. The nuclear lever is the only one available to it in which domestic and external factors converge.

But for the United States, the calculus is not so loaded in favor of an LWR transfer: a nuclear pariah state that is the exception that proves the rule of the NPT and forces allies back into US arms for extended nuclear deterrence may be preferrable to a creeping proliferator which retains residual nuclear options under the nose of the IAEA.

Conversely, the United States may be willing to pay a very high price to preserve the regional and peninsular peace, to keep the DPRK in the NPT in order to protect the 1995 NPT Extension Conference, and to avoid a chain reaction of Asian nuclear proliferation. (It should be noted that there appears to be relatively little technical advantage in terms of proliferation proneness of an LWR versus North Korean indigenous
reactor technology; the issue is how to keep the DPRK in the NPT/IAEA system versus having them withdraw, rather than one technology versus another.)

*Is There a Better Alternative than an LWR Transfer?* Is there another deal that makes more sense than LWR transfer? Should the United States propose instead to facilitate a major renovation of the DPRK energy sector, with particular emphasis on coal mines, power system, and boiler technology? Such a package deal would also entail overcoming the same legal barriers; would be more in the US Government's purview; could be done incrementally in smaller, faster chunks; and would have a much bigger impact on the DPRK's prospects for economic survival, attracting foreign investment, etc. Conversely, would the DPRK see this as losing face? as hooking up its economic train too fast and too much to an external locomotive? as foregoing its residual nuclear option to proliferate?

**The difficulty of moving forward together but separately**

*Who Moves First?* Can the two sides edge forward together toward normalization of political and economic relations without admitting it? Or will the United States insist that the DPRK fulfill its IAEA/NPT obligations down to the last letter before any formal upgrading occurs and it commits to facilitating an LWR transfer? Conversely, will the DPRK accept US "concessions" (such as cancelling exercises, declarations of no first use, negative security guarantees, and the like) as surrogates for formal upgrading of relations, or will it insist that the two move strictly in tandem (creating problems for the United States with its allies)? Will it insist that the LWR transfer be realized before it reimplements full scope safeguards?

**Political issues that arise**

*Political and Ideological Opposition:* Overcoming the political barriers in the United States and key allied states to allowing LWR technology to be transferred to a proliferation-prone state. In particular, the "non-proliferation at all costs" school will have to be overcome as well as hardline hawks who relish the prospect of a confrontation with North Korea, their perfect adversary.
The ROK's Reaction: Most important, how will the ROK react? What domestic political factors will come into play in Seoul that will affect the ROK's support or opposition to transferring LWR technology to the North?

The IAEA's Role: Can the IAEA play a productive role in the transfer given its recent history with the DPRK? (It continued to assist the DPRK on non-politicized projects until very recently to keep the door open to Pyongyang.)

Is a US Commitment Credible to the DPRK? Given the problems adduced above and below, is a US commitment to effect the transfer credible to all players in Pyongyang? Is this issue amenable to external inputs of any kind?

Obstacles to Transfer

Obtaining Congressional Approval: Negotiating a deal that is acceptable to not only the DPRK, but to all parties that must be consulted and agreeable inside the United States, especially in Congress. The relevant acts are quite stringent in this regard, particularly with respect to the legal obligations of the Nuclear Regulatory Commission.36

The Legal Barriers: Skirting the thicket of legal barriers to allowing a strategic technology to be transferred to North Korea, including COCOM, the London Suppliers Group/Zanger List, Terrorism Act, Trading with the Enemy Act, Nuclear Non Proliferation Act, and many (twenty plus) other US laws; and, in the ROK—the only likely supplier of LWR technology to the DPRK (see below), what legal obstacles have to be overcome given its own nuclear export controls, both for ROK nuclear technology, and for US-licensed technology exports?

Who Might Finance the Transfer? The DPRK is bankrupt and owes banks and creditors about $5 billion. The only conceivable source for the $2 billion plus that would be required is the ROK. The United States has virtually no manufacturing plant on line for making LWRs (although some components or parts of a second hand reactor from a US utility might be available cheap, or there is the BNPP in the Philippines) and

even less political will to finance such an export.\textsuperscript{37} Russia could supply the technology but not the finance, and it is difficult to conceive of barter trade on a scale that would meet the bill. Japan must resolve the reparations problem before the DPRK will entertain a specific deal like the LWR transfer. No one wants France to be involved.

\textit{What Role Might South Korea Play in the Transfer?} That leaves South Korea. What kind of financing package might be involved? Apart from a major government-financed grant-in-aid, what kind of loan-cum-in-kind-repayment deal might be negotiable? Could the DPRK repay the loan in raw materials? by exporting electricity from the plant via a linked grid across the DMZ? Does the ROK actually have the full complement of LWR-related manufacturing capabilities that it claims?

\textit{Building an LWR in the DPRK:} Constructing an LWR in the DPRK would be a nightmare. There is almost no supporting infrastructure. Materials and services are of very poor quality, so all steel and concrete as well as every nut and bolt of machinery, plus all the supporting suppliers of incidental and routine goods and services for large scale power plant production, all of this and more will have to be imported. A ROK supplier will have advantages in this regard: its management, skilled and construction labor speak the same language as their compatriots; they have large stocks of the relevant nuclear-specific materials and items produced up to US nuclear engineering and manufacturing standards, plus a well developed set of supporting suppliers of goods and services.

\textit{Time Horizon:} DPRK decision makers may not fully realize the time required to plan, construct, and complete an LWR. The DPRK has never undertaken an industrial project on the scale and complexity of an LWR plant. Its industrial and construction culture is attuned to massively engineered, low technology, labor-intensive approaches that have no or negative bearing on nuclear power plant construction techniques. It will take at least five to six or more likely eight to ten years before the DPRK sees the first kWhe from an LWR. This time horizon is beyond the political lifetime of the current generation of gerontocrats in Pyongyang. It is not clear that the decision makers who will inherit this

\textsuperscript{37} See S. Levy, "Supply of Light-water Reactor(s) to Pyongyang: Technological Issues and Their Possible Resolution," Northeast Asia Peace and Security Network, Nautilus Institute, Berkeley, December 2, 1993.
legacy will want to complete the project. If so, then the suppliers and financiers will incur additional risk of project non-completion and DPRK non-payment of the financing. The rulers-in-the-wings may also not thank the suppliers for locking them into a nuclear white elephant (the Aquino precedent is relevant here).

Operation and Maintenance: North Korea's electric agencies are singularly ill-equipped to operate a nuclear power plant. Also, their grid may be technically inappropriate for a large (GWe) LWR due to the reliability criterion (density of interconnection and peak load relative to size of biggest generation unit). Although the performance of system operators can be upgraded during the LWR construction period, there are practical limits on what can be done in this regard, even in five or six years. There are technical constraints as well as cultural and institutional constraints such as organizational pathologies associated with forty years of command-and-control economics, standard operating procedures that are incompatible with safe and economic operation of an LWR, etc.

Uneconomical Front and Back End Fuel Cycle Facilities: Also, with only one LWR (which is all it could ever hope to obtain, whatever the pretensions of its Ministry of Atomic Energy Industry), the DPRK would not be able to operate economical front (uranium supply and fuel fabrication) and back end (storage except racked on the LWR site, and disposal) fuel cycle facilities. Perhaps it is best to assume that by the time an LWR comes on line, the two Koreas will be merging and South Koreans would staff and operate the DPRK's LWR; if there are still two separate states, perhaps South Koreans could be seconded to the North Korean nuclear agency. Until a couple of years ago, DPRK nuclear officials assumed that they could reexport the spent fuel to the former Soviet Union; now, they do not know what they will do with spent fuel any more than do their ROK counterparts.

Safety: There probably is not much difference in the relative hazard of the indigenous DPRK nuclear reactor versus an LWR.38 Training and technical assistance in site selection, operating procedures, radiation

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38 The DPRK's indigenous reactors have a higher chance of catastrophe and less insulation from the biosphere, but less curies of radiation in a smaller core. An LWR is less likely to crash with more barriers against release, but has a bigger load of radioactive materials.
monitoring, and accident and emergency response procedures would be important aspects of a cooperative approach, and the DPRK would need to set up from scratch a sound, independent, regulatory framework.

**Practical Cooperation with the DPRK**

This list of obstacles to successful transfer is daunting. Equally, each obstacle represents an opportunity for possible cooperation and dialogue with the DPRK, even if the final outcome is not a realized LWR transfer. In addition to our first four conclusions, I add the following conclusions drawn from the preceding sections.

**Conclusion 5:** Governments must play the primary role if a transfer is ever to be achieved. Only governments can mobilize the requisite resources to address a number of the critical issues listed above.

**Conclusion 6:** Nongovernmental organizations have a role to play, but to be effective, they must enter the field only in areas where their flexibility, informality, and speed can help the negotiating parties to come to grips with and resolve critical issues. With a strategic approach aimed a key pressure points, NGOs can complement official work in all three capital cities involved in this question.

**Conclusion 7:** Governments are currently engaged in short term maneuvering and hard bargaining on other critical issues that will determine whether another round of high-level talks take place this year. Very little hard work on the core issues involved in an LWR transfer has been undertaken within any of the governments. All three governments with most at stake in the DPRK nuclear issue must become much more informed about the potential for and obstacles to cooperation if the LWR issue is to become a practical plank of cooperation rather than another issue of contention.

**Conclusion 8:** NGOs have a comparative advantage in their ability to address quickly some of the critical issues that will face governments (see below). They are unlikely to have much to offer in terms of defining legal and political barriers as legal counsel in the State Department and the Pentagon have already reportedly completed this analysis. Indeed, their main task may be to educate and restrain the more ideological anti-nuclear opponents who may take the US government to court using NEPA, mobilize Congressional and media opposition in order to block the transfer, etc. Such educational meetings should be
convened sooner rather than later, especially in Washington, DC, and could be usefully undertaken by the Carnegie Endowment, the Nuclear Control Institute, the Natural Resources Defense Council, etc.

Conclusion 9: In particular, NGOs could enter into dialogue with South Korean NGO and QANGO (quasi autonomous NGO) counterparts to clarify what reaction might be expected from Seoul to the ROK's being the LWR supplier, and what issues and will arise and obstacles have to be overcome should it become the major source.

Conclusion 10: NGOs could also usefully enter into a dialogue with the DPRK government to provide it with a better understanding of the critical economic, legal, and technological issues surrounding LWRs; in particular, they could address the relative economic and environmental performance of Russian versus US LWR technology. The Center for Energy and Environmental Studies at Princeton University; the Union of Concerned Scientists; the Federation of American Scientists could all supply such briefing missions at short notice. Such a mission could include some experienced Korean-American nuclear engineers with construction experience in the ROK, likely from Bechtel or from Westinghouse companies.

Conclusion 11: NGOs could also explain to DPRK decision makers some of the opportunity costs and possible advantages of switching its demand from LWR to energy efficiency and energy supply technologies. The International Institute for Energy Conservation with its Thai office; or the International Energy Efficiency Initiative, with its Indian base in Bangalore, could play an important role in sending briefing missions to the DPRK on the latter issue.
Appendix 1

Text of the July 1993 US-DPRK Nuclear Statement

The delegations of the United States of America (USA) and the Democratic People's Republic of Korea (DPRK) met from July 14–19, 1993, in Geneva for a second round of talks on resolving the nuclear issue.

Both sides reaffirmed the principles of the June 11, 1993, joint USA/DPRK statement.

For its part, the USA specifically reaffirmed its commitment to the principles on assurances against the threat and use of force, including nuclear weapons.

Both sides recognize the desirability of the DPRK's intention to replace its graphite-moderated reactors and associated nuclear facilities with light-water moderated reactors. As part of a final resolution of the nuclear issue, and on the premise that a solution related to the provision of light-water moderated reactors (LWRs) is achievable, the USA is prepared to support the introduction of LWRs and to explore with the DPRK ways in which LWRs could be obtained.

Both sides agreed that full and impartial application of IAEA safeguards is essential to accomplish a strong international nuclear nonproliferation regime. On this basis, the DPRK is prepared to begin consultations with the IAEA on outstanding safeguards and other issues as soon as possible.

The USA and DPRK also reaffirmed the importance of the implementation of the North-South Joint Declaration on the Denuclearization of the Korean Peninsula. The DPRK reaffirms that it remains prepared to begin the North-South talks, as soon as possible, on bilateral issues, including the nuclear issue.

The USA and the DPRK have agreed to meet again in the next two months to discuss outstanding matters related to resolving the nuclear issue, including technical questions related to the introduction of LWRs, and to lay the basis for improving overall relations between the DPRK and the USA.

## Appendix 2-1
### Relative Proliferation Intensity Rankings

<table>
<thead>
<tr>
<th>Fuel cycle and point of vulnerability</th>
<th>Quantity of fissile material &amp; main dilutant(s) at this point (per 1-GWe reactor/yr)</th>
<th>Further processing required from this point for use in nuclear explosives</th>
<th>Indices of relative susceptibility (5=worst, 1=best)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>As is</td>
</tr>
<tr>
<td>PWR/ONCE-THROUGH</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>enriched uranium</td>
<td>855 kg U235 in 28500 kg U238 (3% enriched)</td>
<td>extensive further isotopic enrichment</td>
<td>3</td>
</tr>
<tr>
<td>spent-fuel storage</td>
<td>250 kg Pu (69% fissile) in 26000 + kg U, fission products</td>
<td>chemical separation from U &amp; fission products</td>
<td>3</td>
</tr>
<tr>
<td>PWR/PU-RECYCLE</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>reprocessed Pu</td>
<td>440 kg Pu (61% fissile), possibly mixed with U</td>
<td>chemical separation from U (if present)</td>
<td>4</td>
</tr>
<tr>
<td>CANDU/ONCE-THROUGH</td>
<td>345 kg fissile Pu in 128000 kg U, fission products</td>
<td>chemical separation from U &amp; fission products</td>
<td>4</td>
</tr>
<tr>
<td>CANDU/PU-RECYCLE</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>reprocessed Pu</td>
<td>188 kg fissile Pu, possibly mixed with U</td>
<td>chemical separation from U (if present)</td>
<td>5</td>
</tr>
<tr>
<td>HTGR/U233 RECYCLE</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>enriched uranium</td>
<td>325 kg U235 with 25 kg U238 (93.5% enriched)</td>
<td>minor chemical processing at most</td>
<td>4</td>
</tr>
<tr>
<td>reprocessed U233</td>
<td>190 kg U233 + 50 kg U235</td>
<td>minor chemical processing at most</td>
<td>1</td>
</tr>
<tr>
<td>HTGR/DENATURED</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>fabricated fuel</td>
<td>650 kg U233, 235 in 5500 kg U + 10000 kg Th</td>
<td>chemical separation from Th, further enrichment</td>
<td>4</td>
</tr>
<tr>
<td>LMFBR/NATURAL FEED</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>reprocessed Pu</td>
<td>2350 kg Pu (80% fissile), possibly mixed with U</td>
<td>chemical separation from U (if present)</td>
<td>4</td>
</tr>
</tbody>
</table>

Appendix 2-2
Definition of ranking in factors

- **Quality.** The two categories under this heading relate to before and after possible isotopic enrichment beyond the state in which the material occurs ordinarily in the fuel cycle. The rankings are: 5 = uranium with U-235 > 90 percent; 4 = uranium with 60 percent < U-235 < 90 percent or U-233 > 40 percent, or plutonium with less than 75 percent fissile isotopes; 2 would be reserved for uranium with 20 percent < U-235 < 60 percent or 12 percent < U-233 < 40 percent; and 1 would relate to material, such as tritium or uranium with lower fissile concentrations than those already listed, which can play useful supporting roles in nuclear weapons but cannot by itself initiate a nuclear explosion.

- **Quantity.** Here the number of critical masses per 1-GWe reactor per year is the key to the rankings: 5 = > 100 critical masses (that is less than 1 percent/yr diversion yields a ‘bomb quantity’ of material); 4 = 30 to 100 critical masses; 3 = 10 to 30; 2 = 3 to 10; 1 = < 3.

- **Chemical barriers.** 5 = fissile material in metallic form and not mixed with effective-dilutant; 4 = fissile material in oxide form and not mixed with effective-dilutant; 3 = plutonium mixed with significant non-fissile uranium; 2 = plutonium mixed with fission products and non-fissile uranium; 1 = plutonium or uranium-233 mixed with fission products and thorium.

- **Radiological barriers.** 5 = radiation levels associated with high-enriched U-235, or lower; 4 = those associated with various plutonium mixtures; 3 = those associated with uranium-233 and associated isotopes; 2 = those associated with low-burn-up reactor fuel; 1 = those associated with high-burn-up reactor fuel.

- **Detectability.** While a more refined indexing scheme could certainly be developed, only two factors have been considered here: first (from easiest to hardest to detect), whether diversion requires qualitatively new operations (for example, reprocessing from an otherwise once-through fuel cycle), significant modification of existing operations (for example, use of an enrichment facility to attain a much higher U-235 percentage than for reactor fuel), or simply the redirection of existing process streams (as in plutonium diversion from a fuel cycle that is already recycling it); and, second, whether the radiological signature of the material is unusually helpful for monitoring.

Appendix 3

Energy Sector Flow Chart for the DPRK

Source: Author's files