ENGAGING THE DPRK ENRICHMENT AND SMALL LWR PROGRAM: WHAT WOULD IT TAKE?

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Introduction

The unveiling of the Democratic Peoples' Republic of Korea (hereafter) DPRK's enrichment and pilot light water reactor program offers another moment for engagement with Pyongyang, another point of leverage over how its nuclear weapons program evolves, and a new opportunity to determine whether it can be influenced to recommit to the global nuclear non proliferation and disarmament regime.

We believe that it may be possible to slow and even reverse the DPRK's nuclear breakout by collaboration that assists it to develop small light water reactors (LWRs) that are safe, reliable, and above all, safeguarded, and that integrates its enrichment capacity into a regional enrichment consortium, possibly as part of a Northeast Asian Nuclear Weapon Free Zone. Such an engagement could entail some or all of the following steps:

- Immediately deploying a small barge-mounted reactor (possibly Russian) to provide power in a coastal North Korean town;
- Helping the DPRK to make or contribute to production of low enriched uranium to fuel such a barge-based reactor;
- Jointly designing with North Korea a made-in-DPRK small reactor that meets international safety and manufacturing standards, possibly in a joint project with ROK LWR manufacturing firms;
- Undertaking the power system planning for the rational development of a national grid capable of supporting a fleet of small LWRs over a decade;
- Creating a multilateral financing scheme (possibly linked to a regional grid connecting the ROK with the Chinese and Russian Far East grids) for the manufacturing and construction of small LWRs in the DPRK over time, starting with a survey of DPRK manufacturing capabilities capable of contributing to or being upgraded to international standards required for safe, reliable LWR production;
- Creating a regional enrichment consortium involving Japan, the ROK and the DPRK (among other possible partners) whereby DPRK enrichment capacities are either incorporated into a safeguarded scheme, possibly operated as part of a multinational facility, in return for which the DPRK would reveal all its enrichment acquisition history; development of a small reactor export program as part of an inter-Korean nuclear export push; and a program of training and institutional development needed to support each of these activities that is currently almost completely missing in the DPRK today.

We outline these ideas in full recognition that other enabling conditions would be needed to move the DPRK away from its current nuclear weapons strategy, including many steps that have long been discussed, partly implemented but halted or stalled due to bad faith or coordination difficulties between the United States and the DPRK in the past, and between the five parties and the DPRK in the last four years. We understand that many policymakers suffer from "DPRK fatigue" and do not believe that any positive progress is possible until the North Korean regime changes or collapses, and that any dialogue under current conditions of high tension would be counter-productive.

However, we note that political and security conditions have changed very quickly in the Korean peninsula in the past, and that the DPRK itself has switched gears almost overnight based on decisions at the top—not least due to the absolute central authority wielded by its leader. Therefore, we believe it is critically important that apparently far-fetched concepts be examined carefully for their marginal costs and benefits before they are discarded based on old policy assumptions or worse, emotional or stereotypic reaction to the current situation.

We were prompted to undertake this analysis by the fact that the most important (but least covered by mass media) part of Siegfried Hecker's report[1] on the DPRK's uranium enrichment and small light water reactor (LWR) program was that this program offers a new entry point for engagement and leverage over the DPRK's nuclear weapons program.[2] His report was issued after a Stanford University team exited from the DPRK where they observed on their mid-November visit to the DPRK that the plant had about 2000 operating centrifuge units with modern-looking control facilities at a complex in Yongbyon. Moreover, they were told that the DPRK was planning to construct a domestically-built light water reactor (LWR) with an estimated size of 25 – 30 megawatts of electric generating capacity (MWe), and were shown a site where initial work on the reactor was underway. This unit is very small by global standards as typical modern reactors are 1,000 MWe or larger. The very small DPRK LWR is apparently designed to be a pilot unit for a fleet of small reactors, each perhaps on the order of 100 MWe, serving the DPRK grid.

Though their North Korean hosts told the Stanford delegation that the DPRK planned to enrich uranium only to about 3.5% U-235, consistent with production of low-enriched uranium (LEU) for LWR fuel, with some reconfiguration the facility could, in theory, produce high-enriched uranium (HEU), which could be used in making nuclear weapons. The acquisition by the DPRK of enrichment capabilities of this magnitude immediately raised for the United States and its allies the specter of Iran-like behavior, where a nominally peaceful enrichment program operating outside of full IAEA (International Atomic Energy Agency) safeguards gradually increases the fractional enrichment towards HEU levels. Faced with the distinct possibility that the DPRK could acquire, within a relatively short time, a second path to fissile material for

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[1] Siegfried S. Hecker (2010), A Return Trip to North Korea's Yongbyon Nuclear Complex. NAPSNet Special Report, dated November 22, 2010, and available as http://www.nautilus.org/publications/essays/napsnet/reports/a-return-trip-to-north-korea2019s-yongbyon-nuclear-complex. The fact that the DPRK chose to reveal this facility specifically to a group of visitors almost uniquely suited to appreciate its significance and to be listened to with respect when they returned to the US surely says something about the DPRK's feel for its international audience.

[2] David Sanger and William Broad, for example, managed to ignore entirely Hecker's own conclusion while reporting on the Administration's position that engagement, at least in the context of the negotiations as pursued in the past, was undesirable (David E. Sanger And William J. Broad (2010), "North Korean Nuclear Ability Seen to Far Outpace Iran's", New York Times, December 14, 2010, at: http://www.nytimes.com/2010/12/15/world/asia/15nukes.html). A significant exception to the generally abysmal reporting on the Hecker report was P. Stewart, "Q+A: North Korea's uranium enrichment: motives, details,", Reuters, November 21, 2010, available at: http://www.reuters.com/article/idUSTRE6AK1RH20101121

nuclear weapons, it is urgent, as Hecker suggested, to figure out what to do in response to these startling developments.

Possible Responses

There are only three possible ways that the United States and its allies can respond to the DPRK enrichment and, more broadly, its nuclear power/nuclear weapons programs.[3]

The first is to contain and eventually, launch a military strike to disable the DPRK's nuclear facilities. The second is to continue with strategic drift, that is, continue to do nothing of substance to engage the DPRK, thereby continuing to allow the North Koreans to develop their nuclear capabilities and gain leverage in dictating the terms of negotiations. The third is to find a way to engage the DPRK in negotiations to return to the denuclearization trajectory by offering it something of value, aware of its stronger negotiating position, but also mindful of its motivations.

Of these options, the first is untenable. In 1994 when this option was discussed in depth in the Clinton White House, it rapidly became clear that a strike without warning, while technically feasible, was not politically possible. The United States would have to warn its nationals living in the ROK of the pending threat of combat hostilities, including evacuation from Seoul, and the political impact of such an announcement internationally, especially in US-China relations, but also domestically in the ROK, would be unsupportable.

In addition, about ten thousand people live in the town of Yongbyon, and the enrichment complex itself is located in a cluster of large office and laboratory buildings[4]. Even with precision weapons, a significant number of civilian casualties seem inevitable to result from a missile strike, and would likely be denounced internationally.

A missile strike deep in DPRK territory would almost surely provoke a major military response, and with thousands of artillery emplacements within tens of kilometers of Seoul, the result could be full-scale war, with widespread destruction and loss of life on both sides of the DMZ. Undoubtedly the US-ROK alliance would prevail in another Korean War, likely in a matter of weeks or months (assuming that other countries do not join on the DPRK side). However, the American public, already fatigued by two nearly decade-long wars and reeling from the effects of the deepest recession in two generations, will be unenthusiastic about a third war and the pressure on the White House to avoid such an outcome is enormous—as is clear to everyone including the DPRK.

Recovery after a full-scale war would take at least a decade and trillions of dollars to reconstruct the physical and social capital of the northern part of Korea.[5] Even if a missile strike on the

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[3] See Peter Hayes (2010), *DPRK Enriched Uranium Highlights Need for New US DPRK Policy*, dated November 22, 2010, and available as http://www.nautilus.org/publications/essays/napsnet/forum/dprk-enriched-uranium-highlights-need-for-new-us-dprk-policy DPRK Enriched Uranium Highlights Need for New US DPRK Policy; and Peter Hayes (2010), Talk Best Path to Avoid a War Between North and South Korea", HeraldSun.com.au, 2010-11-25, available as http://www.heraldsun.com.au/opinion/talk-best-path-to-avoid-a-war-between-north-and-south-korea/story-e6frfhqf-1225960507768

[4] See, for example, satellite images shown in Siegfried S. Hecker (2010) "Redefining denuclearization in North Korea", Bulletin of the Atomic Scientists, 20 December 2010, available as http://www.thebulletin.org/web-edition/features/redefining-denuclearization-north-korea-0.

[5] The implications on reconstruction of the energy sector in a "war" pathway are outlined in part, in P. Hayes and D. von Hippel (2010), "DPRK 'Collapse' Pathways: Implications for the Energy Sector and for Strategies of

Yongbyon nuclear complex did not escalate to major war, it is not clear that it would set back the bulk of the DPRK enrichment program (or, for that matter, its nuclear weapons program) because the DPRK may have other enrichment components stockpiled, or even another entire functioning enrichment plant (again, Iran-like), buried deep in a granite mountain somewhere in the rugged spine of Korea.

The second option, attempting to apply additional international pressure but not coming to terms with the DPRK's current leverage and motivations, is unlikely to result in anything but further advances in the DPRK nuclear program, further inter-Korean military skirmishes, and shrill rhetoric on both sides. It also affords more time and incentive for the DPRK to align with nations and sub-national groups bent on proliferation of weapons of mass destruction or other international mischief. Short of China shutting off the DPRK's oil supply, which it is unlikely to do, the United States has little ability to inflict more pain on the DPRK or its leadership, given how isolated it already is. Simply waiting for the North Korean people to literally collapse under the strain of hardship arising from the regime combined with sanctions is both indefensible from a humanitarian perspective. Given how tough the Korean people are, it is likely a futile strategy in any case.

That leaves the third option, to engage the DPRK in a way that acknowledges their strategic gains of the last eight years,[6] and attempts to converge on a common goal with its leadership as it nears a national milestone year (Kim Il Sung's centenary in 2012) and a transition in leadership.

This approach assumes that China and other parties would also push forward the opening of the DPRK economy, that other political and military steps are taken to reduce tension in Northeast Asia; and that large-scale bilateral and multilateral assistance resumes that is aimed at benefiting the welfare of the North Korean people. We have previously described how such engagement must include assistance to the DPRK to improve its crumbling energy sector, including assistance with electricity transmission and distribution, coal production, renewable energy, fuels and electricity market development, and perhaps above all, energy efficiency[7]. These types of assistance must still form the backbone of engagement to stabilize and ultimately transform the DPRK into a "normal" state without taking a devastating detour via war or chaotic collapse.

But if the United States and its allies must now work to enable the DPRK to trade its enrichment and plutonium weapons over time, what could be done to assist it to develop and deploy small LWRs?

Redevelopment/Support", prepared for "The Korea Project: Planning for the Long Term", the 1st Annual Conference of the CSIS-USC Korea Project August 20-21, 2010 | Korean Studies Institute, University of Southern California, available as http://csis.org/files/publication/101215_Collapse_Pathways_North_Korea.pdf

[6] Specifically, since the October 2002 visit to the DPRK in which U.S. Assistant Secretary of State James Kelly confronted his North Korean counterparts with allegations of its pursuit of uranium enrichment capabilities.

[7] See, for example, D. von Hippel and P. Hayes (2009), DPRK Energy Sector Assistance to Accompany Progress in Denuclearization Discussions: Options and Considerations, produced as part of the project "Improving Regional Security and Denuclearizing the Korean Peninsula: U.S. Policy Interests and Options.", organized by Joel Wit of Columbia University's Weatherhead Institute for East Asia and the U.S.-Korea Institute at the Johns Hopkins University School of Advanced International Studies, Washington, D.C., and available as http://www.nautilus.org/DPRKPolicy/vonHippel.pdf

Why Does the DPRK Want Small LWRs?

Before we analyze what should be done, we need to explain why the DPRK wants LWRs in the first place. In turn, this question can be disaggregated into two queries: why does the DPRK want nuclear power? And, why is it now pursuing smaller reactors?

To answer the first query, we must delve into some obscure history. Starting in the 1980s, if not before, the DPRK's domestic nuclear power program had the stated goal of using the DPRK's uranium resource as a source of energy to augment its existing (mostly) coal and hydroelectric power plant fleet. Of course, production of fissile material for nuclear weapons (ultimately accomplished with their domestically-built 5 MWe-equivalent graphite-moderated reactor[8]) was a subtext of the nuclear power development program, but the DPRK also, like dozens of other countries, wished to be a member of the nuclear energy club, as a badge of technological mastery and development status[9]. Once established, that goal became a point of national pride. To this end, the DPRK contracted with the former Soviet Union to build two reactors at what later became the Sinpo site on the DPRK's eastern coast. This deal stalled over payment for the reactors, and was never completed, but the DPRK clearly linked its joining of the Nuclear Non Proliferation Treaty (under Soviet pressure at American behest) with gaining nuclear power plants.

The Soviet reactors became moot when the Soviet Union collapsed. A new discussion ensued in 1991 of light water reactors in the DPRK—first in the joint ROK-DPRK nuclear talks in 1992, and then as part of the US-DPRK talks over the discrepancies in its declaration of nuclear facilities to the IAEA as to how much plutonium it produced and separated. Thus, when as a part of the US-DPRK 1994 Agreed Framework, the DPRK agreed to give up its plans for a domestically-built graphite moderated reactor that would produce more plutonium, it was with the understanding that the DPRK would receive two modern, large (1000 MWe) LWR units, to be built at Simpo in the DPRK under the auspices of the multi-nation Korean Peninsula Energy Development Organization (KEDO), a consortium led by the United States[10]. At that point, the KEDO reactors, or their equivalent, became the benchmark for energy assistance, and all the more so because they had been blessed by Kim Il Sung, founding father of the DPRK, in his meeting with President Jimmy Carter in July 1994, just before he died.

Also buried in this history lies an important and largely unknown factor that explains why the North Koreans aren't trying to build a large LWR like those that were partly built at KEDO between 1996 and 2002, but instead, is now striving to build a small LWR.

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[8] The 5 MWe reactor at Yongbyon never actually generated electricity. The 5 MWe rating was nominal, based on the estimated amount of power that could be generated by the heat (about 25 thermal megawatts) that the plant produced, if the reactor were hooked up to a turbine and generator. In fact, the United States installed a heating system at Yongbyon as part of the Agreed Framework which used heavy fuel oil to heat the complex during the complex process of canning the spent fuel at this site.

[9] With reasonably ample supplies of coal and hydroelectric potential, and low reliance on imports (except of oil, which in largely unrelated to debates over nuclear power), the DPRK cannot claim the same need for nuclear power as an energy (supply) security strategy that has been used to justify investments in nuclear power by Japan, the ROK and Taiwan (for example). The DPRK can, however, claim a need for nuclear power on the same grounds that many other countries have been using in recent years, that is, that nuclear power development is needed to reduce emissions of greenhouse gases, as well as of local and regional air pollutants.

[10] KEDO LWR project was terminated in 2006, but documents from the project remain available at www.KEDO.org

First, the KEDO-DPRK plan for two (or even one) 1000 MWe units ignored one very big problem: these LWRs couldn't be used on the existing DPRK electricity transmission and distribution (T&D) grid, even in 1994.

By 1994 the DPRK grid was already in poor condition, using substations, switchgear, and control equipment equivalent to 1950s or 60s-vintage equipment in the West, with decisions on which plants should operate when communicated by telephone and telex, rather than computerized control equipment, and subject to frequent failures. Operating a 1000 MWe LWR would have been (and still is) impossible, in part because the grid is sufficiently unstable that the LWR would be shutting down regularly, requiring lengthy restarts and risking damage to the plant, but also because the DPRK power system, even if it were functioning perfectly, is simply too small, in terms of generating capacity, to allow the safe operation of a nuclear plant as large as 1000 MWe[11]. Only with two large electrical interties to much larger grid systems—for example, two interties to the ROK grid, or one each to the Russian and ROK grids—would the KEDO nuclear plants at Simpo have been able to operate safely.

Indeed, it has long been our assumption that had the KEDO plants been completed, they would have been operated by connecting them directly to the ROK (not DPRK) grid, whereby the DPRK would sell the power from the reactors to the ROK, using the proceeds to pay off the loan for the capital cost of the reactors, then re-importing smaller amounts of power from the ROK grid via different, smaller, and differently configured, transmission connections.

Why did the North Koreans ask for a large LWR if they couldn't run it on their grid? In fact, they didn't. A senior DPRK power engineer told us that knowing full well that the DPRK faced a grid constraint on the size of reactor (and had briefed their uppers on this technical reality) that what the DPRK actually asked for in 1994 were units of 400 MWe, but those were only made in Russia, and when the ROK and United States wouldn't agree to supply Russian-made units, the DPRK political delegation negotiating the US-DPRK Agreed Framework agreed to accept the larger units along with heavy fuel oil. Those negotiators on the US-ROK side who understood the problem of using large units in the DPRK grid either assumed that the DPRK T&D system would be "fixed" by the time (10 or more years) the KEDO reactors came on line, or that it was the DPRK's problem to solve, especially given that they had offered coal-fired power plants to the DPRK instead of reactors, and had this reasonable proposal rejected.

Today, the DPRK runs a fragmented grid that we estimate has average total nationwide generation on the order of only 2000 MWe. Its national electricity consumption, after accounting for losses, is about the same as that of the US states of Delaware or New Hampshire, but is used by a population 40 to 50 times larger. On such a grid, smaller LWRs make sense from a technical point of view. Smaller reactors could be deployed near demand centers, supported by nearby large (by DPRK standards) hydro or coal-fired power plants, reducing transmission and distribution losses, and accommodating the reality of a fragmented grid. Also, from a practical point of view, the DPRK cannot hope to be able to complete a large LWR without considerable outside help. At this point, in fact some key components of large LWRs, such as castings for containment vessels, can be made in only a few places in the world.

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[11] See J. Bickel (2001), "Grid Stability and Safety Issues Associated with Nuclear Power Plants". Prepared for the Workshop on Power Grid Interconnection in Northeast Asia, Beijing, China, May 14-16, 2001, and available as http://www.nautilus.org/projects/asian-energy-security/workshop-on-power-grid-interconnection-in-northeast-asia/papers/Bickel.pdf/at_download/file.

The DPRK could not hope to develop the technologies for modern LWRs in a reasonable time frame (say, less than 20 years) without considerable outside assistance.[12] The DPRK can, however, almost certainly build a pilot 25 MWe LWR, albeit of unknown safety, using crude electro-mechanical systems rather than modern LWR control technologies and materials. Our guess is that a crash job could be done in 2-3 years, depending on how much of a start they have on the task as of today. How well, long, or safely such a reactor would operate are certainly worthwhile questions, particularly for those nations (starting with Japan) likely to be downwind from the reactor site.

We surmise that the DPRK aims to design, construct, and turn on the plant by 2012 as part of its centennial celebration. Kim Jong Il has promised North Koreans a “strong and prosperous nation” by 2012, and exhorts the people to work toward that goal. By any standard measure of human progress, that goal looks unachievable, but having a LWR well under development (if not operating) would be an important national symbol for leaders to point to as a totem of national strength, as well as being an accomplishment to help cement the national credibility of the new leader, both with the populace as a whole and with the DPRK military.

In addition to the grid and other technical factors, from a geopolitical perspective, there are at least two additional possible reasons for the DPRK to pursue domestic small LWR development.

First, the domestic enrichment program needed to fuel small LWRs offers the DPRK a potential slow-but-steady second track to nuclear weapons using HEU (what is feared to be the Iran model), while maintaining possession of their existing plutonium stockpiles/plutonium nuclear devices to support their bargaining position.

Second, the development of a small domestic LWR is a negotiating ploy, though an expensive one, that will be used by the DPRK as another route to a reactor on DPRK soil, a “KEDO-LWRs Mark 2,” only this time on DPRK terms, rather than on international terms. The DPRK would likely see the enrichment-to-HEU option as a fallback position, available if acquisition of a small LWR fails and it remains in contention with the international community over its nuclear program rather than deeply engaged.

What Can We Do Now?

Now that the DPRK has been revealed to have a relatively mature uranium enrichment program, based on its own uranium resources, and is developing a domestic LWR, what is the international community to do? The first task is to block the independent HEU track. The DPRK does not appear to be pursuing a resumption of plutonium production, apparently satisfied that its existing inventory of plutonium suffices for political and military purposes.

The essence of the approach that we recommend is to commence dialogue with the North Korans to determine how to ensure that its light water reactor program is safe, produces reliable electricity, and that the DPRK becomes once again a member of the international nuclear energy community in good standing. Should the DPRK be inclined to resume dialogue on such a possible pathway away from the war and isolation it faces without engagement, some

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[12] L.J. Droutman et al (1979), *International Deployment of Commercial Capability in Nuclear Fuel Cycle and Nuclear Power Plant Design, Manufacture, and Construction for Developing Countries*, Oak Ridge National Laboratory report, ORNL/Sub-7494/4, dated October, 1979. This report is distributed as a companion NAPSNet special report to this report.

combination of the following possible steps are necessary if still insufficient to move towards a collaborative outcome.

1. **Deploy Barge Reactor Immediately**: One way to demonstrate good faith that is also easily revoked would be to deploy a reactor-based vessel, for example, a barge, that is able to supply power to shore, for example, a coastal town. This is easier said than done, because small LWRs are not a commercial commodity in the West, though a number of groups have proposed development of small LWRs for commercial sale. In the short term, the main option would be to work with the Russians to lease or buy a barge-mounted reactor from them for the purpose. This could be, for example, a reactor designed for use in icebreakers, which could generate about 35 MWe[13], as well as an equivalent amount of heat for district heating or industrial use. Such a reactor would be deployed at a major DPRK port, such as Nampo or Wonsan, at a smaller point in the vicinity of a major mine where the electricity from the reactor could be used to support legitimate foreign-exchange earning ventures, or in Rajin, in support of the free trade zone the North Koreans are setting up there with Russia and China. The Russians are also starting to build barge-mounted nuclear units in larger sizes—for deployment to Russian Arctic regions, for example—so depending on the timing of an agreement, purchasing or leasing a nuclear barge from Russia is a possibility, albeit probably a more expensive one.

   Another option would be to adapt a US military nuclear reactor from a mothballed naval vessel for use as a barge-mounted generator. A number of different naval reactor models would appear to be in the appropriate size range, though we have no information as yet about the cost of re-commissioning such a reactor and adapting it for power barge use. Different naval reactors (including US, Russian, and French units) use fuel with different levels of enrichment. Some apparently use HEU, and many use fuel more highly enriched than typical land-based LWR fuel. This higher level of enrichment could be a concern for an application involving North Koreans. Whatever reactor type is chosen, it would be operated under strict IAEA standards by a combined team of North Koreans and foreign technicians. The latter would simultaneously serve as operators and trainers to instruct the North Korean team members in the safe operation of LWRs. Using older nuclear technology would help to allay fears of that the DPRK would appropriate industrial secrets of reactor design.

2. **Develop DPRK LEU Fuel for Barge Reactor**: Work with the North Koreans to adapt the DPRK uranium enrichment facility to produce enriched fuel suitable for the barge-mounted reactor. Actual incorporation of uranium from the DPRK enrichment facility into fuel rods might or might not be done in the DPRK itself, in part because the DPRK may not have the metallurgical capabilities to produce suitable fuel cladding, but also in part to maintain control over the fuel fabrication process. A key stipulation here is that all of the DPRK's uranium production and enrichment facilities would have to come under IAEA safeguards, and be monitored by IAEA personnel.

3. **Commence Joint Design Negotiations**: Engage the DPRK on the design of a safe-to-international-standards design of a basic-but-serviceable made-in-DPRK or made-in-Korea small LWR, possibly as a joint venture ROK/DPRK product, around 100 MWe. Part of this engagement would be to determine which elements of such a reactor should be imported

[13] World Nuclear Association (2010), "Nuclear Power Reactors". Updated November 2010, and available as http://www.world-nuclear.org/info/inf32.html.

(especially, for example, the nuclear steam supply system—essentially, the reactor core) and incorporated into the reactors wholesale without technology transfer, and which elements should/could be made in the DPRK, given the limited industrial infrastructure available in the different parts (civilian and military industries, for example) of the DPRK economy; and therefore, what infrastructure investment should be undertaken. Part and parcel of such an engagement would be extensive and intensive capacity building with North Koreans on IAEA reactor design and operation safety protocols, development of national institutions to oversee the nuclear power sector, and training on nuclear materials management.

4. **Plan Small LWR Power Program for DPRK**: Work with North Koreans to determine how many 100 MWe reactors might be built over a specified time frame in the DPRK, in conjunction with grid refurbishment (itself, a roughly $20 billion rehabilitation/replacement effort), consistent with the technical safety requirements of the reactors for grid support by non-nuclear generators, and work with the North Koreans and the international community to figure out the financing-investment scheme required to support such reactor deployment. Our guess is 100 MWe reactors might cost $200 - $500 million each, with costs at the low end of the range if a simple, robust, and standardized design were to be adopted and produced serially, with assembly-line-style manufacture of key components. A plan for reactor deployment would have to be developed that specifically includes IAEA oversight of all nuclear elements of the fuel cycle in the DPRK, and IAEA/international expert training and manpower development programs in nuclear system planning, regulation, economics, and related disciplines.

5. **Undertake Manufacturing, Construction and Deployment**: Work with the DPRK to build and deploy one to five 100 MWe reactors in the DPRK after 2012, roughly a five-to-ten year long project. It would be crucial early on to determine which manufacturing plants in the DPRK exist and are capable of producing nuclear and non-nuclear components of sufficient quality to meet standards required for safe operation of an LWR. A small set of examples of the required manufacturing capacities would include high-strength concrete work, very large castings for pressure vessels, electronics for control facilities, machinery for lifting, moving, and placing heavy pieces of equipment, the ability to make, heat exchangers, steam generators, pressurizers, coolant pumps, valves, and control rod drive mechanisms of suitable quality for LWR use[14]. This review of DPRK manufacturing capabilities may yield some positive surprises regarding DPRK capabilities. For example, the DPRK has a 10,000 tonne forging press at the Chollima Steel Complex near the city of Kangson[15]. The few such presses that exist elsewhere in the world are used for making large, heavy pieces of equipment, including large reactor components such as pressure vessels.

6. **Create a DPRK LWR Safety Culture**: The DPRK is renowned for its appallingly bad occupational health and safety practices, especially the risks taken in the course of improvising in response to the extreme scarcity of spare parts and materiel, but also due to its culture of politically and ideologically imposed speed campaigns without regard to quality control. In the 1970s, the ROK was beset with similar problems in its construction and engineering culture, leading to collapsed bridges and shortcuts in construction of its early reactors.

[14] L.J. Droutman et al, *op cit*.

[15] This press, commissioned with Kim Il Sung present in 1989, has been mentioned in the DPRK press a number of times over the years (for example, KCNA, 14 Jun 1984, 9 Oct 1989, and 13 Oct 1989, Choson, 12 Jan 2006).

Salomon Levy, in his devastating 1982 review for the World Bank of the worrisome safety shortcomings of the early ROK LWR program, noted the need for a "…strong, independent, and competent nuclear regulatory function as well as associated Korean safety laws, regulations, criteria, codes, and standards."[16] Therefore, concurrent with the review of manufacturing needs and capabilities is underway, the international community will need to work with the DPRK to develop the domestic regulatory and safety institutional framework and capacity needed to oversee a nuclear sector under IAEA safeguards, noting the difficulties that the ROK had in this regard early in its light water reactor program.

7. **Create a Regional Enrichment Consortium:** Work with the DPRK and others in the region to develop, by the time that 100 MWe reactors are ready to be deployed, a regional enrichment consortium involving the ROK, Japan, and possibly China and/or Russia, whereby the enrichment is done (in the DPRK and other locations) under safeguards, inspected and possibly with the resulting LEU owned by the IAEA (which would then pay the DPRK for uranium sourced from North Korea and for enrichment services provided there). An indication that the selling of fissile materials by the DPRK to the ROK is not utterly farfetched can be found in the recent (unofficial) offer by the DPRK, as relayed following the December 2010 visit to the DPRK of former New Mexico Governor Bill Richardson, that the DPRK sell fuel rods from its graphite reactor to the ROK[17].

   The consortium would exist to increase nuclear fuel supply security for these countries. There are many possible institutional permutations for such a consortium. North Korean safeguarded enrichment (on a significantly larger scale than the pilot scale facility now operating at Yongbyon, which would only support the pilot LWR under construction[18]) might be cheaper than Japan's, for example, and attractive from that perspective. If the ROK benefited from increasing the diversity of its own uranium supply by participation in such a consortium, then resolving the DPRK nuclear issue would actually benefit the ROK thereby offsetting some of the cost associated with engaging the DPRK. This type of consortium, with the accompanying prestige of being a an enrichment club with major nuclear energy users, might be the engagement that would induce the DPRK to put all its enrichment cards on the table in a way so forthcoming that it persuades the US and their allies that they don't have an irresolvable on-going monitoring and verification problem hidden somewhere in the DPRK. A requirement here would be that the DPRK tell the international community about their sourcing of nuclear technologies, thereby burning some bridges with their suppliers, but also allowing the US/ROK and allies to check whether the DPRK is engaging in good faith.

8. **Develop a Small Reactor Export Program**: In conjunction with design and deployment of these small LWRs, work with North and South Koreans to develop a Korean "for export" 100 MWe reactor, thus hooking the DPRK wagon to the ROK LWR export train, including

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[16] S. Levy (1982), *Update Review of Safety Aspects of Nuclear Power Program in Republic of Korea,* prepared for World Bank/UNDP, April, 1982. This report is distributed as a companion NAPSNet special report to this report.

[17] J. Pomfret and C. Harlan (2010), "North Korea makes gestures toward calm after South's drills," *Washington Post*, December 21, 2010, available at http://www.washingtonpost.com/wp-dyn/content/article/2010/12/20/AR2010122005890.html.

[18] Rough calculations by the authors based on the reported annual capacity of 8000 kg-SWU (separative work units) suggest that the 2000 centrifuges the Stanford team saw would be able to support about 50-70 MWe of nuclear generation.

DPRK training for technology export controls, market development, and other export support functions.

9. **Undertake Other Enabling Conditions:** Concurrently with steps 1 through 7, determine the sequence of political and de-nuclearization steps that would go in lockstep with the above over a ten year period, leading to a DPRK uranium enrichment industry that is fully under international safeguards and supervision (thus, presumably, not a threat for proliferation of nuclear weapons based on HEU). The goal would be to strike a deal wherein the DPRK would verifiably freeze their plutonium production program, remaining a "nuclear armed" but not a recognized "nuclear weapons state" with what plutonium stocks, and plutonium-based explosive devices they have, but not sell either their plutonium or the technology used to make it to others, nor produce or separate additional plutonium (except in safeguarded LWR spent fuel). These steps would be required on their part, along with putting their enrichment under full safeguards, to get the US/ROK and allies to agree to the small LWR engagement scheme.

Although now may not be viewed as an opportune moment to engage the DPRK in the issue of its nuclear weapons security, due first to the high tension in Korea after the clashes between the DPRK and ROK military, and second, to the wish of the nuclear weapons states to avoid any appearance of agreeing with the DPRK that it has become a nuclear weapons state, we suggest that the opposite is the case. Now is precisely the time that the DPRK may be looking for a way out of the corner in which it has put itself.

Moreover, we note that any serious movement forward to incremental disarmament will also be a period in which serious and detailed discussions should take place with the DPRK on the urgent issue of command and control, security systems, and reassurance mechanisms that need to be established for its plutonium weapons and fissile material, including development of a declaratory and operational doctrine that accords with standard practices, along with the adoption of raft of non-proliferation controls required to ensure that the DPRK plutonium and dual use technology does not "leak" overseas.

What Would It Cost, Would It Work?

It is possible, though far from certain, that the offer of a "made-in-DPRK" small LWR engagement strategy (plus the other diplomatic and security engagements that would be necessary to achieve the desired outcome) would suffice to induce the DPRK to put their enrichment program under IAEA safeguards.

Would the DPRK accept a "KEDO Mark 2" package at this point? Possibly, if near-term use of a small nuclear reactor as in steps 1 and 2 above served their domestic needs as a symbol of national progress and victory. But the DPRK would have to be convinced that the international community would follow through on the small LWR commitment given its negative experience with KEDO Mark 1.

We previously estimated that the "value" to the DPRK of the two KEDO LWRs at about $1.25 billion in net present value terms.[19] This value (or rather, a value implicitly or explicitly determined by the DPRK based on their own assumptions), for better or worse, serves as the

[19] Author's calculations. Key assumptions include a DPRK discount rate of 15%/yr (nominal basis), reactor cost of $2500 per kW, sales of most of the electricity from the reactors to the ROK at a price of 6 US cents per kWh, and the DPRK pays for other costs of running the reactors out of the proceeds of its power sales to the ROK.

benchmark for the value of a package of engagement with the DPRK on small LWR development, together with non-nuclear energy sector assistance. A package of significantly lower perceived value will likely not induce the DPRK to freeze or abandon its routes to nuclear weapons. By our very rough and preliminary estimates, the $1.25 billion present value might be enough, over 5-10 years, to fund the startup of a small LWR industry in the DPRK (likely pursued in joint venture with the ROK for at least some hard-to-make components), plus perhaps two-to-three in-country prototypes/commercial demonstration units.

An engagement strategy like the one above has, as an ancillary outcome, the establishment of an ROK-DPRK joint venture to manufacture and market small LWRs. An international market for small LWRs may well develop on its own in the coming years, and certainly a number of nuclear industry and research groups have presented concepts for broad small LWR deployment.[20] We believe that the small LWRs produced by an ROK-DPRK consortium would probably find many willing buyers, particularly among countries not now using nuclear energy. Some of these nations will want nuclear power largely to fulfill specific resource needs or reduce their carbon footprint, but others, much like the DPRK, will want it primarily as a badge of status and development, largely independent of practicality or cost.

The sale of many small reactors is not necessarily a positive development, because many more different nations would have access to nuclear materials, as well as the existence of many more different nuclear materials locations and transport pathways for the international community to secure, monitor and safeguard.. But if deployment of small reactors in many countries comes tightly bundled with a stringent international regime of safeguards and fuel supply/take back arrangements in all countries, some of the risk associated with such large-scale deployment of small reactors can be reduced, although some of the key difficulties associated with nuclear power, most notably long-lived radioactive wastes to be managed nearly indefinitely, will be unavoidable.

A variant to the small LWR engagement strategy, one that is less complex but perhaps, at this point, less attractive to the DPRK, would be to replace steps 3 to 7 of the sequence above with a re-start of the now defunct KEDO LWR program. In this variant, construction would resume on one or both of the 2 x 1000 MWe Simpo LWRs, arrangements would be made for the DPRK to sell most or all of the power from Simpo units to the ROK over a purpose-built transmission intertie connecting the Simpo reactors to the ROK grid, and the Simpo LWRs would be operated under IAEA safeguards, with fresh fuel imported from international suppliers, and spent fuel removed for storage or disposal outside the DPRK. Capacity building on nuclear issues for DPRK technicians and officials would still be included, but would be more limited than in the small LWR engagement strategy, reflecting the more limited role that the DPRK will have in managing the nuclear fuel cycle associated with the large LWR(s). If the large LWR path is taken, our own preference would be to build only the first Simpo unit, at least initially, reserving half of the LWR “value” to pay for either the small LWR engagement strategy outlined above, or (preferably) a package of non-nuclear energy sector assistance.

[20] See, for example, “Mini nuclear reactors, Thinking Small”, *The Economist*, December 9, 2010; and research groups/companies such as Hyperion Power, which offers a (non-LWR) 25 MWe nuclear module unit (not including for $50 million (though it is not immediately clear what other major system components, such as the steam turbine or generator, are included in that cost), with initial deliveries “slated to begin in the second half of 2013” (http://www.hyperionpowergeneration.com/product.html).

In this regard, we believe that offering a phased and varied package of energy sector assistance to the DPRK—legal, institutional, and market reforms, energy efficiency, renewable energy, coal sector rehabilitation, transmission and distribution systems and power plant upgrading, and gas distribution, among others, with intense, small, on-the-ground pilot projects in the DPRK bringing outside experts into contact with North Koreans, and capacity-building throughout—is the best way to approach engagement on the inextricably linked DPRK energy sector and nuclear weapons issues.[21] Such a program would be an essential enabling condition for the kind of institutional and practical transformation of the DPRK energy sector needed for any change—especially one as challenging as the idea of creating small light water reactors and deploying them in the DPRK—a daunting challenge that must be confounding the DPRK's best and brightest tasked with producing the pilot LWR by 2012 given that the laws of material science and physics don't change because you happen to be in the DPRK.

A Regional Framework

The types of nuclear energy engagement activities described here, whether involving small or large LWRs, would benefit from the support of a regional agreement on nuclear weapons development. A treaty-based nuclear weapon free zone (NWFZ) in Northeast Asia might be the best option, provided it includes a fuel cycle collaborative activity with related monitoring and verification standards and capacities.[22] Using the Latin American precedent, the DPRK might join such a "zone" and its related oversight organization at the outset as a "nuclear armed state" nonetheless reaffirming its intention to become nuclear free; and in turn receiving sovereign guarantees from the Nuclear Weapons States that sign the treaty protocols that the DPRK won't be attacked with nuclear weapons. These guarantees would be calibrated by the Nuclear Weapons States to the degree to which the DPRK denuclearizes and comes into compliance with their NPT and IAEA obligations, as well as those of the NWFZ Treaty. The precedent is how Argentina and Brazil came into the Latin American Treaty, and along the way created ABACC to manage their mutual suspicions about fuel cycle activity, and then (after 18 years) fully complied with the treaty.

A zone treaty has the advantage that the same six parties that have been involved in the Six-Party Talks would have to sign on for it to work, so there would be some continuity and each party could play its joining of the Treaty for its own domestic political advantage. The NWFZ concept is also compatible with continued US nuclear extended deterrence, already largely recessed. And, China would likely support it, Russia too, and the North Koreans still rhetorically advance their version of a nuclear weapon free zone.

Conclusion

The DPRK has nuclear explosives based on plutonium and a small stockpile of additional plutonium, and will not be giving either up any time soon. They have just revealed a remarkably mature program of uranium enrichment, with a stated goal of fueling to-be-

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[21] D. von Hippel and P. Hayes (2009), DPRK Energy Sector Assistance to Accompany Progress in Denuclearization Discussions: Options and Considerations, produced as part of the project "Improving Regional Security and Denuclearizing the Korean Peninsula: U.S. Policy Interests and Options.", organized by Joel Wit of Columbia University's Weatherhead Institute for East Asia and the U.S.-Korea Institute at the Johns Hopkins University School of Advanced International Studies, Washington, D.C., and available as http://www.nautilus.org/DPRKPolicy/vonHippel.pdf

[22] See P. Hayes, "The Status Quo Isn't Working: A Nuke-Free Zone Is Needed Now," *Global Asia*, September 2010, at: http://www.globalasia.org/V5N3_Fall_2010/Peter_Hayes.html

developed domestic LWRs of small size, but raising fears of a second North Korean path to the bomb. Options for the US, the ROK, and their allies boil down to military attack with devastating consequences for the entire Peninsula, reliance on continued international sanctions in the vain and historically contra-indicated hope of DPRK regime implosion, and engagement.

Only engagement, however unappealing it might seem to some policy makers in Washington and Seoul, is tenable. The DPRK's desire to produce a home-grown nuclear reactor, likely targeted to be in time for the Kim Il Sung centenary in 2012 (but not likely to be operable then), offers an opportunity to engage the DPRK in the design and implementation of small LWRs. Starting with provision of a small reactor on a barge providing power to a port city, that opportunity could be expanded to include not only reactor design, production, and operation, in joint venture with the ROK and/or others, but also safeguards, oversight of enrichment facilities, regional cooperation on nuclear fuel cycle activities, and DPRK participation, by degrees, in a regional nuclear weapons free zone. All of these activities would proceed in parallel with a comprehensive and varied program of non-nuclear energy sector assistance, and matched on the DPRK side by progressively more meaningful confidence building measures related to their nuclear weapons program.