Phased International Cooperation with North Korea's Civil Nuclear Programs

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North Korea's desire to produce electricity with nuclear power reactors is well known. Less well known are its civil nuclear programs focused on the use of radiation in medical, industrial, and agricultural applications. These latter programs deserve foreign assistance now that North Korea is moving to shut down its nuclear weapon plutonium production facilities under an agreement reached in February 2007 at the Six Party Talks in Beijing.

This report reviews the current status of North Korea's civil nuclear energy programs and the potential for cooperation, highlighting those areas that would benefit especially from foreign assistance.[1] It draws extensively on interviews and meetings that Joel Wit, a former State Department official, and I held with senior North Korean officials in Pyongyang between January 30 and February 3, 2007.

Like many countries, particularly its neighbors, North Korea is deeply committed to the use of civil nuclear energy, independent of its nuclear weapons program. Rather than denying North Korea access to nuclear assistance, pending full and verified nuclear dismantlement, a more productive strategy is to phase in such cooperation as part of the processes established in the Six Party Talks. This cooperation should start immediately with initiatives that would boost North Korea's capabilities in nuclear medicine and agriculture.

The established venue for these forms of nuclear cooperation is the International Atomic Energy Agency's (IAEA's) technical cooperation programs. As a result, a priority is for North Korea to rejoin the IAEA. Another area of cooperation, depending on progress at the Six Party Talks, is the conversion of the Russian-supplied IRT research reactor to low enriched uranium (LEU) fuels and the removal of its stock of about 40 kilograms of highly enriched uranium (HEU), all of which is in irradiated fuel. At a mutually agreed time, discussions among the nations in the Six Party Talks could resume about the restart of the project to build light water reactors (LWRs) to produce electricity.

Progressive cooperation to improve North Korea's civil nuclear program would not only be relatively innocuous with respect to international security concerns but it would also present a positive means of interaction with North Korea and lead to additional transparency of its nuclear programs. It would also improve the general welfare of North

[1] Nuclear energy is energy released in a nuclear reaction. The energy can be released when a neutron initiates the breaking up or "fissioning" of an atom's nucleus into smaller pieces (fission), or when two nuclei are joined together under millions of degrees of heat (fusion). In addition, the spontaneous radioactive decay of a nucleus releases energy.

Koreans and foster improved trust within North Korea that could enhance Six Party negotiations on how to dismantle North Korea's nuclear weapons program.

Civil Nuclear Industry and Radioisotopes: Background

Although the United States has one of the largest civil nuclear programs in the world, its nuclear power program is not the country's largest civil nuclear program in terms of annual industry sales and jobs. According to the Nuclear Energy Institute web site, each year in the United States radioactive materials, not counting those related to the generation of electricity, are directly and indirectly responsible for about $330 billion in total industry sales and about four million jobs.[2] In comparison, the direct and indirect economic impact of nuclear energy for generating electricity totals $90 billion in total annual sales of goods and services and about 440,000 jobs.

Medical Uses of Radioactive Isotopes

The medical profession relies extensively on radiation, particularly from radioactive isotopes, for identifying and treating disease. Radioactive materials are also used extensively to test new drugs and conduct research into cures for diseases. In the United States, one in three of the 30 million Americans who are hospitalized are diagnosed or treated with nuclear medicine techniques, according to the Nuclear Energy Institute.[3]

Each year in the United States, radioisotopes are used in over 11 million nuclear medicine procedures and in 100 million laboratory tests on body fluids and tissue specimens.[4] The biomedical community uses over 200 radioactive and stable isotopes for research, drug development, and diagnosis and treatment of human diseases.

Diagnostic Uses of Radioactive Materials

Radioactive isotopes are used as tracers to identify abnormalities within the body. This process works because some natural elements tend to concentrate in certain parts of the body, such as iodine in the thyroid, phosphorus in the bones, and potassium in the muscles. After a patient is injected with a radioactive element, a special camera takes pictures of the internal workings of the organ, in essence visualizing organ function. Nuclear imaging with radioactive tracers can detect diseases earlier and is more sensitive in evaluating many organ functions than x-rays or traditional methods.

A common camera used in nuclear imaging is a gamma camera, which creates a visible record of the distribution and relative concentration of radioactive tracer elements. An important diagnostic technique is positron emission tomography (PET) that uses certain short half-life radioisotopes, sophisticated gamma cameras to locate the radioactive tracer, and complex computer programs to interpret the data.

[2] Nuclear Energy Institute, www.nei.org, accessed August 2004.
[3] Nuclear Energy Institute, www.nei.org, accessed March 5, 2007.
[4] Ibid.

Therapeutic Uses of Radioactive Materials in Medicine

Radioactive materials in stronger doses are used to treat diseases. Radioactive materials are used both as external and internal sources of radiation in treating patients. In cancer treatment, radiotherapy has an advantage over chemotherapy, because it is specific to a cancer or tumor and does less damage to healthy tissue.

Radioactive Materials in Medical Research and Testing

Radioactive materials are essential to modern biomedical research into the causes and cures for diseases such as AIDS, cancer, and Alzheimer's disease. Pharmaceutical drug testing relies extensively on radioactive materials. A principle use is to determine where in the body the pharmaceutical is going and its concentration at these locations. In this way, researchers can better understand if adverse reactions in other parts of the body will occur. Radioisotopes are also used extensively in metabolic studies and genetic engineering.

Uses of Radiation in Agriculture and Industry

Radiation is used in pest control and to increase agricultural output. Radiation is also used to determine plant uptake of water and nutrients from the soil, enabling farmers to reduce over-watering and the over-application of fertilizers.

Radioisotopes are used in a wide variety of manufacturing processes to provide measurement, density, and other information; to ensure quality control of processes; and enhance properties, such as hardness, strength, and density of certain materials. The main industrial applications of radiation are based on the penetration and scattering of radioactivity, in particular the property that radiation loses energy as it moves through materials. As a result, industry has developed highly sensitive gauges to measure the thickness and density of many materials and imaging devices to inspect finished goods for weaknesses and flaws. Industry also uses radioactive tracers to observe the velocity of materials flowing through pipes and track leakage in buried pipes.

Manufacturing Radioactive Materials for Civil Use

Radioactive isotopes are made and marketed throughout the world. According to the Nuclear Energy Institute, about 50 countries produced radioactive isotopes.

Radioisotopes are produced in several ways, but mainly in reactors and accelerators. Some isotopes are produced by neutrons generated in reactors. Neutrons produced by fission irradiate specially-made target material that captures these neutrons and are transformed into the desired isotope.

Other isotopes require a source of energetic protons. These isotopes are produced in accelerators where protons are accelerated and then bombard targets, producing the desired isotope. A common low-energy accelerator used for isotope production is the cyclotron.

As of 2004, radioactive isotopes were produced in about 75 research reactors worldwide and 188 accelerators. Forty-eight cyclotrons were dedicated to the production of medical isotopes, and about 130 cyclotrons were dedicated to producing short-lived isotopes for positron emission tomography (PET).

After the production of an isotope in a reactor or accelerator, it must be extracted from the target material, purified, and packaged for transportation and use. This work is done in hot cells, which are closed work areas in which radioactive materials may be manipulated without exposing the operator to gamma radiation.

IAEA Assistance to North Korean Organizations to Process and Use Radioisotopes, Prior to 1994

North Korea's radioactive isotope programs benefited from the technical cooperation program of the International Atomic Energy Agency. But the nuclear crisis in the early 1990s and North Korea's withdrawal from the IAEA in 1994 ended this cooperation. The following is a brief review of several of the more important programs.

Medical Isotopes

North Korea has medical facilities that have imported radioisotopes, expertise, and equipment for nuclear medicine, including the following:

- The Institute of Radiochemistry in Pyongyang obtained assistance in the 1980s to upgrade its equipment for radioisotope production, particularly implementation of quality control.
- In the late 1980s, a 4,000 curie cobalt-60 radiation source was provided to Pyongyang's People's Hospital No. 2 to treat up to 60 cancer patients per day and research the biological effects of radiation. This source would have decayed significantly by now.
- The Academy of Medical Sciences at the Institute of Radiation Medicine in Pyongyang received some assistance in the late 1980s and early 1990s to upgrade and modernize its radiotherapy facilities for cancer treatment. A gamma camera was apparently obtained in the late 1980s or early 1990s for nuclear imaging associated with cancer treatment. This institute may have received a gamma camera from Japan that is currently inoperable, because it has a "cracked crystal."[5]

Nuclear Agriculture

[5] Interview with Dr. Ri Kwang Yong, Deputy Manager of the Institute of Atomic Energy with the author February 1, 2007.

In the mid-1980s, the Institute of Experimental Biology and the Institute for Crop Cultivation received assistance in using radioisotopes to increase food production. The assistance aimed to establish a capability to use radioisotopes to research more efficient utilization of fertilizers and green manures by field crops, such as rice, maize, and vegetables.

In the late 1980s and early 1990s, the Institute for Crop Cultivation received assistance in using radioisotopes to improve the nitrogen-fixing capacity and yield of soybeans. The status of this project and the associated isotope laboratory is unknown.

Production of Radioisotopes in North Korea

North Korea has had at least two ways to produce radioactive isotopes, the IRT research reactor at the Yongbyon Center and the cyclotron at the Institute of Atomic Energy (IAE) in Pyongyang. A main product of the IRT reactor is iodine 131 for thyroid treatment. The cyclotron produces a range of radioisotopes, although the major one is gallium 66.

The IRT Reactor

The IRT reactor, which has a power of 8 megawatts-thermal (MWt) and was supplied by the former Soviet Union, uses HEU fuel that was purchased many years ago. Most of the HEU has been fully used.[6] According to Ri Hong Sop, Director of the Nuclear Scientific Research Center at Yongbyon, the reactor operates only occasionally for experiments and isotope production because of fuel shortages.[7] For example, the IAEA research reactor database states that as of 1996, the last date for which information is posted, the IRT reactor operated about 120 hours per year.

Near the IRT reactor are hot cell facilities in the Isotope Production Laboratory that can separate and process a range of radioisotopes. In the past, the IAEA provided expert assistance in producing radioisotopes in the IRT reactor for nuclear medicine.

The Cyclotron

North Korea imported a 20 MeV model MGC-20 cyclotron, or accelerator, from Russia in 1985 to produce radioisotopes, primarily for use in nuclear medicine. The cyclotron was imported under the IAEA technical cooperation program, under which half the $2.5 million cost for the cyclotron was paid by the IAEA and the remainder by North Korea. The cyclotron was commissioned in April 1992 at the IAE, according to Ri Kwang Yong,

[6] The fuel contains 36 and 80 percent enriched uranium. In total, about 40 kilograms of HEU are in the irradiated fuel. North Korea is not believed to have any fresh HEU fuel. The reactor earlier also received a supply of 10 percent enriched uranium fuel, which is also irradiated. For more information see D. Albright and Kevin O'Neill *Solving the North Korean Nuclear Puzzle* (Washington: ISIS Press, 2000), p. 148.

[7] Interview with author in Pyongyang, February 1, 2007.

Deputy Director of the IAE.[8] In the same building is a radiochemical laboratory to separate and package the radioisotopes.

The annual usage of the cyclotron is about 2,000 hours per year, according to Ri Kwang less than half its expected usage rate of about 4,000-5,000 hours per year. The main reason is that the cyclotron experiences about 3-5 interruptions in electricity per day, which disrupt its operations. Ri Kwang said that the cyclotron requires about three hours to achieve a vacuum prior to operation of the proton beam. A cut in electricity during operation can result in the loss of the vacuum and require a lengthy restart process.

About 90 percent of the output of the cyclotron is dedicated to the production of gallium 66, which emits beta radiation and is used for liver and breast cancer treatment. Annually, the IAE produces about 600 becquerels of isotopes, of which 500 becquerels are gallium 66. The cyclotron also produces iodine 123 for use in diagnosis of thyroid illnesses and iodine 124 and iodine 126 for treating thyroid cancer. Normally, iodine 131 would be used to treat thyroid cancer, according to Ri Kwang, but he said the IRT reactor cannot make enough iodine 131 anymore, if any at all. The cyclotron also produces small amounts of other radioisotopes, such as iridium 111, cadmium 109, and cobalt 57, for industry.

The cyclotron has been out of order for significant periods. The high frequency system broke several years ago. The IAE tried to buy a replacement at the cost of 250,000 Euros several years ago, but was unable to buy one, leading to reports that the cyclotron was permanently inoperative. Instead, the IAE bought subcomponents abroad at a total cost of 70,000 Euros and rebuilt the high frequency system.

Ri Kwang said that he would like the cyclotron to produce isotopes with a half-life of less than a minute for use in medical diagnosis equipment, but North Korea lacks the necessary equipment. It was scheduled to receive a system to be able to conduct positron emission tomography under a technical cooperation program with the IAEA, but the crisis over the nuclear program and North Korea's subsequent withdrawal from the IAEA ended this program.

Nuclear Electricity Generation

Background

Nuclear power programs share a common goal of producing electricity using a nuclear reactor. The most common type of reactor is based on nuclear fission, which is sustained and controlled in a self-supporting nuclear reaction. The varieties of reactors are many, but all incorporate certain features, including fissionable material or fuel, a moderating material (unless the reactor is operated on fast neutrons), a reflector to conserve escaping neutrons, provisions for removal of heat, measurement and control instrumentation, and protective devices.

[8] The discussion about the cyclotron is based on an interview with Ri Kwang Yong, Deputy Manager (Scientific) of the Institute of Atomic Energy, February 1, 2007. See also Appendix.

An electricity-producing reactor may also be used for military purposes if, for example, plutonium produced in the uranium fuel of the reactor is used in nuclear weapons. Although light water reactors (LWRs), the dominant type of power reactor worldwide, are more proliferation-resistant than gas-graphite reactors, they too can be used to produce plutonium for nuclear weapons.

Nuclear reactors typically use uranium fuel. The uranium must be mined and converted into an acceptable chemical and physical form for use as fuel. For most reactors, the uranium must also be enriched.

Currently, most irradiated, or "spent," fuel is stored pending geological disposal. A fraction of the irradiated fuel is chemically processed to extract the contained plutonium and uranium. Programs to recycle the plutonium as mixed oxide (MOX) fuel have progressed very slowly, resulting in an increasing global stock of separated plutonium.[9]

Historically, many activities were dedicated to the research and development of nuclear power reactors. These activities involved a large number of smaller reactors that could test designs, fuel, and other key aspects of large-scale power reactors. Most of these programs have ended, although research and development continues, albeit on a smaller scale, into advanced reactors.

Nuclear Power in North Korea

North Korea developed dual-purpose gas-graphite reactors. In addition to being a source of plutonium for nuclear weapons, the 5 megawatt-electric (MWe) reactor at North Korea's Nuclear Scientific Research Center at Yongbon is considered a prototype for larger gas-graphite reactors designed to generate significantly greater quantities of electricity and plutonium. North Korea was building a 50 megawatt-electric reactor at Yongbyon and a 200 megawatt-electric reactor at Taechon, but construction was halted in 1994 when the U.S./North Korean Agreement Framework "froze" the entire gas-graphite reactor program and associated fuel cycle. North Korea developed and produced many items for its gas-graphite reactor program, including reactor components, nuclear-grade graphite, equipment for measuring personal dosimetry, environmental monitoring equipment, and instrumentation and control equipment.

Reprocessing of the irradiated fuel was designed as a critical part of the operation of these reactors. The Radiochemical Laboratory at Yongbyon was built to process all the spent fuel from these three reactors, according to Ri Hong, Director of the Nuclear Scientific Research Center at Yongbyon.[10]

Under the Agreed Framework, North Korea was to receive two 1,000 MWe light water reactors. The low enriched uranium fuel for the LWRs would have come from abroad.

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[9] See www.isis-online.org for detailed information about the growing stocks of civil separated plutonium worldwide.
[10] Interview with author in Pyongyang, February 1, 2007.

The irradiated fuel would have left the country to prevent an accumulation of plutonium in irradiated fuel. This fuel would become easier to reprocess over time as the radioactive fission products decayed to non-radioactive materials. Under this arrangement, North Korea would have had no need for any indigenous fuel cycle activities to support the LWRs. However, before these reactors could be built, the Agreed Framework broke down in late 2002 and the LWR project was subsequently cancelled.

After the breakdown in the Agreed Framework, North Korea re-started operation of the 5 MWe reactor and construction of the 50 MWe reactor, although progress on the latter has been slow.[11] The damage to the 200 MWe reactor was so great that North Korea decided not to restart construction.

On our visit to Pyongyang, Korean officials were unanimous that North Korea was deeply committed to nuclear power. Several officials said that a priority of the Six Party Talks is re-establishing the LWR project. Kim Kye Gwan, Vice Minister of the Foreign Ministry, said that North Korea would not agree to dismantle its nuclear weapon program unless the LWR project was re-established. If the Six Party Talks fail to achieve a disarmament agreement, North Korea could decide to re-activate its program to build large (50 MWe or larger) gas-graphite reactors for electricity production.

Phased Cooperation with North Korea's Civil Nuclear Programs

As North Korea shuts down and disables nuclear facilities at the Yonybyon site, renewed cooperation on civil nuclear energy should commence. North Korea will retain a substantial nuclear program even after verified dismantlement would occur. It will also have a large, highly trained workforce that created and operated its civil and military nuclear programs.

Rejoining the IAEA and Applying for Technical Cooperation

A priority is for North Korea to rejoin the IAEA and seek eligibility for technical cooperation once again. In the near-term, cooperation could be restarted in the areas of nuclear medicine and agriculture, areas which few would be expected to oppose. North Korea could also receive valuable technical cooperation in overall energy planning.

North Korea will need substantial assistance to establish medical diagnostic and treatment capabilities. A key part of this assistance could be the provision of modern medical equipment, such as positron tomographs and gamma cameras, and the training in their use. In addition, North Korea may need longer-lived radioisotopes, such as cobalt 60, for cancer treatment.

If rejoining the IAEA is not an immediate option, assistance could be provided in the area of nuclear medicine as a humanitarian and confidence building measure. The IAEA or a member state could facilitate this assistance.

[11] For more information about these reactors see Albright and Paul Brannon, "The North Korean Plutonium Stock, February 2007," www.isis-online.org.

Converting the IRT Research Reactor

DPRK officials have expressed interest in converting the IRT reactor to the use of low enriched uranium fuels. In the near-term, a study of conversion should be conducted, but conversion is likely to occur later. Once started, conversion, including the provision of new LEU fuel, would take a few years to accomplish. As part of this effort, any HEU should be removed from North Korea and sent to Russia.

Director Ri Hong indicated that if the reactor was converted, the activation area of the reactor would require modification and the shape of the fuel would need to be changed. But he did not object to conversion, particularly if conversion led to the supply of new fuel.

The same type of reactor was recently converted in Libya to LEU fuel at a cost of about $5-10 million. North Korea appears to have more HEU in spent fuel than Libya, which may lead to higher costs to reprocess and condition the spent fuel in Russia.
The conversion of the Libyan reactor involved upgrading the instrumentation of the reactor at a cost of about 700,000 Euros. The bulk of the cost covered the transport of the spent fuel to Russia (one million Euros), and its subsequent reprocessing, reconversion, and waste conditioning (greater than three million Euros).

New Equipment for the IAE and Other Institutes

The IAE and other North Korean nuclear institutes have depended extensively on technical cooperation programs of the IAEA for the acquisition of equipment. After North Korea rejoins the IAEA, discussions could start about the provision of a wide range of equipment and expertise. Dr Ri Kwang listed several types of equipment that he believes are needed:

- A small electron accelerator for materials research and treatment;
- A 10 MeV linear accelerator;
- Small Tokamak for experimental work by students. Estimated cost $2 million; and
- A 30 MeV cyclotron for additional isotope production.

Closing down, Decommissioning, or Converting of Nuclear Facilities, and Retraining of Work Force

A major component of agreements to disable and dismantlement North Korea's nuclear weapons program is expected to be the decommissioning of a range of nuclear facilities and the safe disposal of nuclear waste left over from the gas-graphite reactor program, particularly the 5 megawatt-electric reactor and the Radiochemical Laboratory. North Korea will likely need foreign assistance in upgrading its capabilities in nuclear energy to support the safe closure and ultimate decommissioning of nuclear sites and the environmentally sound disposal of nuclear waste. It will also need to upgrade its knowledge and capabilities in many specific areas, including education and training, nuclear dosimetry, nuclear instrumentation and control, nuclear safety, destructive and non-destructive analysis, physical protection, environmental monitoring, and emergency response.

An important consideration is the retraining of up to several thousand people involved in facilities that would be closed. Scientists, engineers, and technicians will likely require re-education or at least additional training to bring them up to date in their areas of expertise that can be applied in non-banned areas of work. After Libya closed down its nuclear weapons program, about 500 scientists and engineers received training that was funded internationally.

LWR Project

North Korea remains highly committed to restarting the LWR project. However, South Korea, Japan, and the United States are unlikely to agree to restart this program until at least nuclear dismantlement has started.

The most worrisome aspect of a North Korean LWR is the prospect of a diversion of spent fuel and its reprocessing to extract plutonium for nuclear weapons. To alleviate this concern, a dialog could be started in the near-term in the Six Party Talks and among NGOs and North Korea to ensure that verification and other measures, such as rapid removal of any spent fuel or multilateral control over the reactor, are adequate to minimize the chance of misuse of the reactor and its fuel. It may be more productive to explore a strategy of supplying North Korea with an LWR in which all parties to the deal are satisfied, rather than trying to find out just how committed North Korea is to attaining an LWR by insisting that such an arrangement is impossible.

Increased Regional and International Cooperation in Civil Nuclear Energy

In the longer term, achieving nuclear weapons dismantlement will open the door to regional and international nuclear energy cooperation, which in turn could open up other possibilities for additional nuclear energy projects. A priority should be increased cooperation between North Korea and South Korea on a wide range of civil nuclear projects.

Appendix Institute of Atomic Energy: Trip Report

On February 1, 2007, Joel Wit and I visited the Institute of Atomic Energy (IAE), which is the leading institution in North Korea dedicated to the development of nuclear energy. Our host was Dr. Ri Kwang Yong, Deputy Manager (Scientific) of the institute, who told us we were the first Americans to visit the facility. Ri Kwang raised his hope that his country could re-start cooperation with the International Atomic Energy Agency (IAEA). He then described in general terms the work at the Institute of Atomic Energy (IAE).

The IAE was founded in 1985 to apply atomic technology to the national economy. Initially, its main purpose was to house the cyclotron and associated facilities and laboratories.

In the early 1990s, a decision was made to greatly expand the institute and construction started on a large building next door. Because of a lack of financing, construction was halted by 1995. Recently, construction restarted and should be completed soon. Ri Kwang said that the institute will more than double in size after the new building is completed.

The main purpose of the IAE is threefold:

- Research fundamental atomic technologies;
- Study applications of atomic energy to the national economy; and
- Provide experimental facilities for students specializing in nuclear studies at the main universities, particularly Kim Il Sung University and Kimchaek University.

The IAE has many units and research laboratories, including:

- Fundamental nuclear research technology laboratory;
- Nuclear physics, including applications;
- Cyclotron operations;
- Radioisotope production;
- Chemical analysis and quality control;
- Nuclear fusion research laboratory;
- Nuclear safety research laboratory;
- Radiation detection laboratory;
- Nuclear electronic engineering laboratory;
- Computer laboratory; and
- Materials science laboratory.

After discussing the activities of the institute, Ri Kwang said that the IAE has depended extensively on technical cooperation programs of the IAEA. He said that if the relationship with the IAEA could be improved, he listed the type of technical cooperation that his institute would seek, could include:

- A Positron Tomograph. This piece of equipment would be installed at a medical facility, but once installed, the cyclotron could also concentrate on producing short-lived radioisotopes for it, which was the original purpose of acquiring the cyclotron. Ri Kwang estimated the cost at $2 million.
- A relatively small electron accelerator for materials research and treatment;.
- A 10 MeV linear accelerator
- Small Tokamak for experimental work by students. Estimated cost $2 million;
- A 30 MeV cyclotron for additional isotope production.