- **IN CONFIDENCE –**
March 13, 2008

Discussions with Dr. Ri Hong Sop, Counselor to the General Department of Atomic Energy and former Director of the Yongbyon Nuclear Center, DPRK, Yongbyon, Feb. 14, 2008

Notes by Siegfried S. Hecker, CISAC, Stanford University
U.S. delegation: Siegfried S. Hecker, W. Keith Luse, Joel Wit
DPRK delegation: Dr. Ri Hong Sop, Counselor to GDAE
Yu Sun Chol, Chief Engineer, 5 MWe reactor (former Chief Engineer of IRT-2000 reactor)
Li Yong Ho, Section Head, Department of Safeguards
Son Mun San, Director, Department of External Relations, GDAE
Han Won Jong, GDAE, Department of Safeguards
Kim Jong Chol, GDAE, Department of External
Yongbyon Guest House, following visit to Yongbyon Nuclear Center
Jong Tong Hak, Chief Desk Officer, Department of USA Affairs, MFA
Hwang Thae Hyok, Researcher, Department of USA Affairs, MFA.

Dr. Ri Hong Sop welcomed us back. I gave a brief description of our visit to the center and my assessment of the disablement actions. Dr. Ri said he hoped that I can put on record what we had seen. He added that he hoped that we can make a contribution to the agreement and that it can be done in the spirit of action for action. He said that he had high expectations that I would be able to do so.

I also mentioned the importance of looking at the future of the Yongbyon nuclear workers now. He said that he has concerns about their future, but for now they are focusing on disablement actions for the facilities. If the agreement is finished, then perhaps the technical people can talk about the future. I reiterated why I thought it was important to do so now.

Dr. Ri answered that in the future they would like to be directed to energy; specifically peaceful nuclear energy. They expect that an LWR will be introduced. They could train their technicians and engineers for the LWR. They are also studying how to train their nuclear engineers to other areas. He said he is interested in my ideas. He wanted to know how to keep a scientific base for the future. This could be implemented after the agreement is fulfilled. To date, they are still only thinking about this. They are not ready to do anything.

I then presented some ideas for consideration. Some specific ideas for the utilization of the Soviet-supplied IRT-2000 reactor were suggested by Dr. Bekhzod Yuldashev (former director general of the Institute for Nuclear Physics in Tashkent, Uzbekistan and a MacArthur Science Fellow at CISAC in 2007). These are presented in the attachment. I presented the following ideas:
1) In the near future, the focus will be on dismantlement, which will require decontamination and decommissioning of facilities. These activities will engage a significant fraction of the Yongbyon workforce.
2) The Yongbyon nuclear complex has significant needs in radiation health physics and environmental remediation. Their facilities contain a lot of radioactive materials and there

is heavy contamination. It will be important for them to do the job safely. We could develop collaborations in radiation monitoring and assessment of health effects. The U.S. has many years of experience in assessing the health effect of radiation. Similarly, it has developed significant expertise in environmental assessment and remediation. Dr. Ri agreed that these are good areas for cooperation once dismantlement is complete.He indicated that they have also been thinking along these lines.

3) Potential use of the IRT-2000 reactor for research, medical, and industrial applications. I told Yongbyon officials that we have a lot of experience with research reactors. We had one at Los Alamos while I was director. I also have worked closely with colleagues from the former Soviet Union who worked with such reactors. I explained that I had asked Dr. Bekhzod Yuldashev, former director of the Institute for Nuclear Physics in Tashkent, Uzbekistan, about his views on the IRT-2000 reactor. He had an almost identical reactor at Tashkent. I told him that Dr. Yuldashev had met North Korean specialists at Dubna some years ago. Dr Ri said that he has been to Dubna on several business trips. I presented an extensive list of possible applications for the IRT-2000 reactor and told them that we need to know the specifications of the reactor to judge what applications may be feasible. The list included radioisotope production (primarily for medical applications), neutron activation analysis, neutron diffraction and radiography, neutron transmutation doping, reactor fuel studies, and neutron radiation cancer therapy.

Dr. Ri responded that they have had experience with some of the applications I had mentioned. He thanked me for the presentation and he was clearly very pleased with my discussion of the possible options. He said the key to the IRT-2000 reactor is the fuel. They have not been able to get deliver of new fuel (he had previously told me all fuel was supplied by the Soviet Union, and that they had not received any new fuel since the dissolution of the Soviet Union). They have experience in the production of medical and industrial isotopes. The Isotope Production Laboratory (IPL) has channels that allow them to extract targets and extract the radioisotopes of interest). They have not done cancer treatments – said they could not get results (it was not clear whether or not they actually tried). He said it would be helpful to have exchanges in this area. They have people with thyroid cancer, but can't treat them.

Dr. Ri said that before the nuclear crisis they were supplied from the outside, but not any more now. I asked him when in his mind the nuclear crisis began. Ri said that they currently use 36% HEU, which is the most recent fuel they received from the Soviet Union. He introduced Chief Engineer Yu Sun Chol, who was the chief engineer of the IRT-2000 reactor, and is now the chief engineer of the 5 MWe reactor. Yu said that they have now used up the 80% fuel that they received from the Soviet Union. They are storing it now. I asked if they could give it back to Russia. Yu said that no one speaks about that now.

I said that it would not be possible to get new HEU fuel because of proliferation concerns. I asked if they could go back to LEU. Yu said that when they first received the reactor from the Soviet Union it used bar (or rod) type 10 % LEU. It operated at 2 MWth. They could go back to that configuration with that fuel. I asked what the maximum and average neutron flux is. Ri answered that with a mix of 36 and 80% fuel, they were able to get 10^{13} and 10^{14} neutrons/cm^2 respectively. He also stated that the 80 % fuel is now all used up, and they are storing it. If they go back to 10% LEU fuel, then the maximum neutron flux will be 10^{12} neutrons/cm^2.

The reactor has six vertical channels and eight horizontal channels, including thermal columns. The maximum diameter is 70 mm. The maximum container diameter of the horizontal channels is 30 mm and 40 mm for the vertical channels. They used lead containers. He described a system of four concentric tubes, the inner one was aluminum. The four tubes were then put in a cask. (It was difficult to understand this because of the interpretation and the type of room we were in did not allow for making sketches). Ri said that the casks were transferred in pipes with air pressure to the IPL.

I asked Ri about run cycles. He said that they could operate the reactor three weeks per month if they had the fuel. They have a full team of radiochemists who can handle the separation of the isotopes. They have hot cells with manipulators provided by the Soviet Union. These are operational. They can also handle the packaging and shipping. They have only shipped domestically in the past.

I asked if they would be willing to give up the 36 and 80% HEU fuel. Ri said they would consider giving it up if they could get fresh fuel in return. I told him about U.S. – Russian cooperation to bring back HEU fuel from states that received HEU-fueled reactors from the Soviet Union.

I asked about the inventory of fuel. Yu explained the following:
- They have 60 rod assemblies of EK-10 (10% LEU fuel). 60 assemblies of 16 rods at 8 grams U-235/rod = 7.68 kg of U-235.
- 100 assemblies of 80% HEU. 100 assemblies at 130 g U-235/assembly = 13 kg of U-235.
- 20 assemblies of 36% at 220 to 230 g U-135/assembly = 4.4 to 4.6 kg of U-235.

Yu said that 40% of the U-235 has been burned up, so these inventories of U-235 must be reduced by 40%. Therefore, it appears that they have 25.2 x 0.6 = 15.2 kg of U-235 in their inventory of spent IRT-2000 fuel elements.

We returned to core conversion, Ri said that when they switched from the 10% LEU fuel to the HEU fuel, they redesigned the active zone of the reactor. To convert to LEU, they would now have to go back and redesign the active zone. I asked if they would have to do anything else. Ri said that they do not foresee any problems in converting back. I asked if they would redesign the core themselves. Ri said yes, that would present an interesting problem for their specialists. He also said that they would need personnel protective equipment for the installation. He said the reactor was built in the 1960s, so it may need some other replacements. For example, the reactor control and cooling system are old. He stressed again that they would be able to do the redesign themselves.

I asked if it was worthwhile to convert the reactor since it is 40 years old. He said yes, they would start with the current reactor. Ri said when the Soviets installed the reactor, they said it would last 20 years, but the DPRK has made modifications to extend the life. For example, they have replaced the aluminum vessel with stainless steel. Ri believes the reactor is good for 30 or 40 more years.

I asked if they had neutron beam lines for research. Ri said that they no longer have any. I asked if they had radiochemistry and analytical chemistry capabilities, such as chromatography, for example. Ri said that their equipment is sufficiently modern for radioisotope production. He said it is in good shape. Ri said that he appreciated our suggestions and that when the time comes, he will be able to use these ideas.

I returned to the LWR that he mentioned earlier in the conversation. I reminded him that he had previously told me that his people had nothing to do with the LWR KEDO project. He said that KEDO was a separate organization. Now, if Yongbyon is shut down, he has to be concerned about what they will do with their engineers. They have no LWR experience now, but they would retrain them. They will need to think about how to best accomplish that.

I asked him what he thought about getting into the ceramic fuel fabrication since LWR use oxide fuel. He said they have not thought about this. They would have to get an LWR first, and then they will think about how to make the fuel. To begin with, they would have to get the fuel from the outside.

I turned to what they Yongbyon workers could do outside the nuclear arena. I told him that this has turned out to be difficult in the U.S. and Russia. It depends on what skills and talents their workers have. Ri said there will be time in the future to share that kind of information about Yongbyon workers. He hopes that time will come. I told him that I look forward to continuing this dialogue in the future.

Joel Wit told Ri about the project in which he is involved with the U.S. National Academy of Sciences related to worker redirection. They want to think ahead about what to do when the facilities here are dismantled. For example, if there is ever an LWR, how would the Yongbyon workforce be involved? He also said that they would like to see what can be done with the IRT-2000 in the civilian arena. They are also interested in possible collaboration in radiation health physics and what can be done in nonnuclear industries. Ri told him that the principal interest is energy and, in particular, nuclear energy.

Keith Luse told Director Ri that Senators Lugar and Biden are interested in helping out with worker redirection. Keith raised the question of nuclear materials security. He said that he appreciates the diligence of Yongbyon workers in preventing nuclear materials of getting into the hands of terrorists. He told Ri that someone may approach DPRK officials or Yongbyon workers to acquire nuclear materials. Dr. Ri answered that they have strict standards for storage of nuclear materials. They have strict regulations. Even the General Department of Atomic Energy officials cannot get into these facilities without their (Yongbyon officials') permission. They have a small amount of nuclear material and they have strict regulations to protect access. These materials are stored under strict control. Keith Luse asked if nuclear specialists from Myanmar (Burma) have visited here at Yongbyon. Ri said that as counselor to the GDAE he has no idea. Then he added that he believes that no foreigners have come here for training.

ATTACHMENT

How the 8 MW Reactor in Yongbyon Facility Can be Used in Future?

Bekhzod Yuldashev, Science Fellow at Stanford University CISAC
Former Director General of Institute of Nuclear Physics, Tashkent, Uzbekistan (currently at IAEA, Vienna)

The thermal power of that reactor is 8 Mwatt which should provide the total flux neutrons of, at least (1.5-2.5) x 10^{14} neutrons per cm^2sec^{-1}. In this case the following programs could be proposed for future utilization of that machine.

1. **Neutron Activation Analysis** (or Determination of Elemental Composition of Different Objects and Materials) for needs of basic and applied sciences as well as for electronics, highly purified materials production, geology, medicine, forensics, agriculture, environmental studies. The Neutron Activation Analysis (NAA) technique developed different methods which allow determining the concentrations of elements with content up to 10^{-10}% which is very important, for example, in electronics and material sciences (e.g., purified silicon, germanium and other semiconductor materials, pure metals and alloys, nano-materials) and other fields.
In order to use NAA methods the facility needs to have qualified personnel, including radio-chemists, and apparatus which consist of NaI- and semiconductor (Si/Li, Ge) spectrometers as well as detectors of alpha- and beta-radiation. Also the Genie-2000 software as integral part of any NAA center should be mentioned.
For express analysis in field conditions the center could also have so-called mobile laboratory equipped by portable detectors of radiation and spectrometers as well as by chromatographs for identification of chemical compounds.
Once developed the NAA methods are finding very wide application in many fields.

2) In addition to NAA described above and which determines quantitatively the elemental composition of given object **the neutron diffractometry (or neutron radiography)** helps to reveal the structural features of materials and the role and place of composing elements or impurities at subatomic scale. This is, in particular, very important for materials like alloys, semiconductors, ceramics, optical crystals, gems etc.
Normally almost all research reactor facilities have a possibility for performance of neutron diffractometry (neutron radiography) for scientific, technical and commercial needs. The commercial application of these methods is well developed at South Korean KAERI facility in Taejon.

3) The South Korean electronics companies like LG, Samsung and others are utilizing research reactors (e.g. in Australia and Sweden) for **neutron transmutation (doping)** of silicon used in fabrication of so-called big integrated circuits. For the same purpose the mentioned reactor could be used. The only demand in this case is that reactor should have as large as possible in diameter (not less than 100 mm) vertical channel in which the gradient of neutron field is less than 3-4% and the channel has a device for in situ measurements of electro-resistance of silicon bars as well as a device which allows to

rotate silicon bars within 4п-geometry. In principle, this technique despite scientific needs could help to earn some profit from contracts with electronics companies.

4) **The Radioisotope Production** is one of the main activities of research reactors. Normally for production of isotopes commonly used in medicine (like, e.g. Tc-99-generators for screening and diagnostics but not for treatment like Co-60, Sr-89 etc)
the fluxes of neutrons in research reactors with thermal power 2-3 Mwatt are enough unless very high specific activity of radioisotopes are required. Therefore depending upon the request of internal market the production of isotopes like Tc/Mo-99 generators,
I-131, S-35 etc can be organized provided at least 20 days/month operation of reactor and a team of radio-chemists having corresponding equipment (hot cells, specific air-filtering systems, chromatography apparatus, chemical extraction methods and devices, quality control apparatus etc) and raw materials in form of stable isotopes, super-purified chemicals and so on.

5) **The Neutron Cancer Therapy,** as it was demonstrated last years, has very good perspectives and nowadays it is one of priorities in developing nuclear methods in cancer therapy. Even IAEA accepted the new corresponding program which is deploying very fast. Despite not all details of that technique are clear and understandable yet the experiments which are carrying out by several research groups revealed many properties of that method which could be very useful in treatment of vital human organs.
No high fluxes of neutrons are required in this case and few horizontal channels build for transportation of neutron beams with different energy range would be required in parallel with related apparatus.

6) **The Changing Properties of Materials and Study of Radiation Hardness** is also a subject of interests because using the intensive neutron-gamma fields in the reactor one can modify the properties of materials like glasses, semiconductors, gems, crystals, ceramics etc. as well as to test the radiation hardness of different materials including those which will be used or already using in reactor technique, space research, Tokamaks (ITER for example) etc.
In this case due having in reactor very high fluxes of neutrons and gammas one can check the changes of the properties of various objects with neutron integrated fluxes up to 10^{21-22} neutrons per cm^2.

7) **Testing the New Types of Reactor Fuel** is very important from the point of view of future development of reactor technique and creating new types of reactors. In this case research reactors can be used for different experiments with that type of fuel elements.