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What are Technical Hurdles of Verification for North Korea's Nuclear Program?

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The denuclearization of North Korea was unpredictable and resulted in radical changes. Despite the skepticism and disappointment surrounding denuclearization, it is important for certain verification technologies to establish what is technically possible or practically impossible, and how reliable these technical means are. This article presents the technical hurdles in nuclear verification by systematically categorizing them into issues of correctness and completeness. Moreover, it addresses the safety and security risks during the denuclearization process, including the radiological impact on humans, environmental effects, and the illegal transfer of material, information, and technologies.

Keywords: Denuclearization, Nuclear weapons, Enrichment, Reprocessing, Correctness, Completeness

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Table 1. Detailed content of North Korea's nuclear development program by category

Categories of the nuclear development program	Detailed list
Fissile material production facility	· Uranium and plutonium metallurgy facility · Spent fuel reprocessing facility · Research reactors (IRT research reactor and 5 MWe reactor) · Uranium centrifuge enrichment facility · Uranium conversion facility · Uranium refining facility · Uranium mining facility · Light water reactor (under construction)
Weapon design facility	· Nuclear weapon detonator production facility · Production facility for maraging steel for uranium enrichment facilities · Production facility for Al allows for uranium enrichment facilities · High-performance explosive production facility · Lithium-6 production facility · Tritium production facility
Nuclear material or proliferation-sensitive material	· Highly enriched uranium · Low-enriched uranium · Weapons-grade plutonium · Spent fuel · Lithium-6 · Tritium
Nuclear weapon carrier	· ICBM · SLBM
Nuclear testing-related facility and data	· Nuclear Test Site · Nuclear test data · Neutron transport computer codes · High-energy material state simulation codes · X-ray for high explosive test · Shock wave generator · Neutron sources

1. Introduction

The coronavirus pandemic (COVID-19) has caused a worldwide crisis. However, North Korea, which is the most isolated country, has declared that there is no confirmed case. North Korea was one of the first countries to shut its border, aware that widespread malnutrition could exacerbate the spread of COVID-19. North Korea's government is secretive, and the media are tightly controlled, making it hard for outside observers to determine what is really going on in the country [1]. This aspect of North Korea is perfectly in line with the factors that make it difficult to verify the denuclearization of North Korea. To cope with the growing concern on North Korea's nuclear weapon program, understanding technical hurdles in verification technology in a systematic way would be informative. Although there are no perfect technical and scientific measures to prove or disprove the accuracy of declarations, it is important to know what is technically possible or practically impossible, and how reliable technical means are. This article will address the technical hurdles for verifying North Korea's nuclear weapon program and related facilities in this manner.

North Korea's nuclear weapon program is as large-scale as its history is long. North Korea's nuclear weapon program has pursued two different paths: weapons-grade plutonium production (WgPu) and highly enriched uranium (HEU) production. Accordingly, the complexity of the program is significantly higher compared to those implemented by other countries that have attempted to develop nuclear arms thus far, such as South Africa [2]. Also, along with its efforts to develop missiles as nuclear weapon carriers, North Korea has continued its research to combine fission-based nuclear weapons with the effect of nuclear fusion reactions so that their power can be amplified. As shown in Table 1, over the past decades, the regime has established a nuclear weapons development system designed to realize its doctrine of self-reliance, which covers the entire process from uranium ore mining to nuclear weapons production. North Korea's nuclear weapon infrastructure includes all of its materials, equipment, facilities, documents, software, human resources, and knowhow. They can be classified into various categories, such as nuclear material production facilities, nuclear weapon production facilities, and nuclear testing facilities.

2. Objectives of Denuclearization Verification: Correctness and Completeness

The International Atomic Energy Agency (IAEA) is an international organization responsible for the safe, secure, and peaceful uses of nuclear energy. The key responsibilities of the agency include verifying whether the Member States are honoring their international legal obligations to use nuclear material and technology only for peaceful purposes through a set of technical measures or Safeguards. As provided in the Comprehensive Safeguards Agreements (INFCIRC/153), the key criteria for the verification measures are the correctness and completeness of the information submitted by facility operators [3].

Correctness can be achieved based on correct information on the initial report of the country. The Paragraph 62 of INFCIRC/153 requests the State to provide the Agency with an initial report of all quantitative data of the nuclear material subject to safeguards on a facility by facility basis. Such a report is expanded by attachments that provide details on the location and number of items of nuclear material contained in each respective facility. On the basis of the data contained in the initial report and subsequent inventory changes, it is, therefore, possible to establish an itemized list of the nuclear material inventory of each facility [4]. The reported information on the production, storage, transfer, usage, and consumption of nuclear materials is the key to determine whether any of them have been used for purposes other than peaceful purposes.

Meanwhile, the completeness means the absence of undeclared nuclear material and activities in a State as a whole. Therefore, the correctness of the initial declaration is the key to draw the conclusion about the completeness. The evaluation of the absence or presence of undeclared nuclear material or activities is based on the fundamental concept that nuclear activities have indicators of their existence [4]. The verification of completeness is preceded by that of correctness. Concealed or omitted nuclear materials and activities can be tracked by obtaining direct evidence through radiological and physicochemical measurements, or based on circumstantial evidence including records on materials, facilities, infrastructure, and imports and exports.

It is obvious that the verification of North Korea's denuclearization also requires in the same context of correctness and completeness to be verified even if this verification process might differ in nature from the regular safeguards measures taken by the IAEA on nuclear facilities which are mainly designed for the civil nuclear facility. In any case, whether the credible initial report is available or not, nuclear archeology, including state-of-the-art instrumental analyses, reactor model simulations, and investigative science techniques, will be used to provide insights as to the origin of North Korea's fissile material [5].

North Korea's participation in an open and honest dialogue means that the criteria of correctness and completeness can be achieved to a greater extent. This is because, given the lack of adequate records on its nuclear activities and the situation where nuclear materials and facilities can possibly be concealed, the degree of access to necessary information given by North Korea to the denuclearization verification team is critical. For example, the Comprehensive Safeguards Agreements of the IAEA was not given access to information regarding nuclear activities and facilities that had been omitted from reporting, and thus attempts could not be made to reveal Iraq's secret enrichment program. Afterwards, to address this limitation, the Additional Protocol was proposed, which grants the IAEA the authority to visit any suspected nuclear facilities regardless of whether they have been reported or not [6]. It is very unlikely that North Korea will become a part of the Comprehensive Safeguards Agreements or the Additional Protocol in the verification process for denuclearization, but while discussing the verification procedures, it is still necessary to come to an appropriate agreement as to how the criteria of correctness and completeness can be fulfilled.

2.1 Correctness in the Verification of North Korea's Denuclearization

In terms of correctness, it is highly likely that North Korea has not kept records on decades of its nuclear activities history including nuclear material flow and weapon development efforts. Also, those who can specifically verify such information may have died, resigned, or retired and are no longer in the field, and thus much of it may have been lost. There are concerns that North Korea might submit a false declaration of the current stocks of nuclear arsenals and fissile materials [7]. Considering South Africa, for example, its nuclear weapon program focused only on the HEU pathway and had a history of only 15 years, but records on the material accounting containing the production, consumption, and stock of HEUs were not available. As a result, the verification process turned out to be very difficult. In the case of Ukraine, as well, which did not run its own nuclear weapon program, there were similar difficulties in the verification due to a lack of accurate information [2]. Given that the significance of records, such as research notes, during R&D projects has not been properly appreciated until recently, even in countries proficient in records management, these outcomes were quite understandable. The lack of accurate records means that it will take a long time to verify the reported quantitative information on the production, storage, transfer, usage, and consumption of nuclear materials. While it is indeed possible to determine whether there have been any false statements in a report by collecting environmental samples from the corresponding nuclear facility, it is challenging to trace the exact amount of nuclear materials from scratch. Accordingly, the lack of accurate records means the inability to verify the quantitative correctness in a meticulous manner.

The foregoing assessments indicate that, although detection modes may exist for many pathways, countermeasures can usually be found to hide small programs. For this reason, a tight detection web able to discover any pursuit of a nuclear weapon appears to be infeasible for the time being [8]. Among potential verification methods measuring how much the material has been damaged by irradiation emitted from both α particles generated from the radioactive decay of uranium and neutrons generated from the (α, n) reaction of UF_6 has been the most actively developed. Even though there is a possibility of improvements in this method through further research and development, as it currently stands, it may be difficult to check the operating history after several months of operation because irradiation-induced damage tends to saturate as it accumulates. Accordingly, the determination of how long a uranium enrichment facility has been operated and how much enriched uranium has been produced in total will emerge as a matter of significant concern in the verification of denuclearization.

It is also important to confirm how much nuclear material has been consumed. This is because one may over-report the amount of nuclear material consumed during nuclear testing in an attempt to conceal weapons-grade nuclear material. The verification of such consumption information requires accessing actual nuclear test data. As it stands now, experimental evidence needs to be collected from a total of six nuclear tests at a nuclear test site with its entrance closed. To this end, it is necessary to spot these six locations where nuclear explosions took place and dig into the ground in each location to collect and analyze the remaining materials after the nuclear tests. Given that nuclear materials have a relatively long half-life and become less mobile under the ground, such sample collection is deemed feasible [9]. The examination of fission products will also make it possible to obtain more accurate information on North Korea's current nuclear weapon development stage, e.g., fission bombs or hydrogen bombs, instead of relying on its claims [10].

2.2 Completeness in the Verification of North Korea's Denuclearization

The criterion of completeness involves processes of searching for and identifying any information on nuclear materials and activities that has been omitted by North Korea, either deliberately or accidentally, so as to ensure that there is no omitted information. In the cases of research reactors and spent fuel reprocessing facilities, such verification is easier because a relatively large amount of waste heat, chemicals, and radioactive material is released into the environment in the process. In contrast, uranium centrifuge enrichment facilities, especially small-scale facilities, can be easily concealed underground and release only an extremely small amount of waste heat, chemicals, and radioactive material into the environment, which are very difficult to detect [11]. Uranium centrifuge enrichment facilities that North Korea operates, however, consume only a small amount of energy and therefore do not require such auxiliary facilities. This leads to the conclusion that the flow of UF_6, which is directly used during the uranium enrichment process, must be monitored. However, evidence related to respective elements, such as U and F, is not adequate to prove the presence of uranium enrichment facilities because these elements are frequent in nature as well. Therefore, it is necessary to identify chemical bonds between the two elements. Given the limited amount of heat and material released from centrifuge enrichment facilities, the minimum detection limit must be at the ppb or ppt level to obtain significant evidence [12]. As it stands now, however, this level can only be achieved with certain elements only by using some large-scale instruments with very high precision even when all chemical analysis methods available are considered. Thus, it is impossible to apply this approach in practice.

It is also very difficult to detect the concealed stock of separated HEU and WgPu. The primary reason for the difficulty is that the mass and volume of nuclear material needed to produce nuclear weapons is very small. About 5 kg of HEU or WgPu is adequate to produce a single nuclear weapon. For reference, it is an amount that can be held without effort by an average adult in their cupped hands. Understandably, any material of this weight and volume can be easily concealed [13]. Also, HEU and WgPu emit low levels of radiation into the environment [14]. Furthermore, even this radiation can be contained through gamma-ray and neutron shielding, and therefore it becomes more difficult to detect them through radiation measurement from the outside. Accordingly, it is necessary to attempt to narrow down the possible locations by referring to interviews of relevant persons, pay attention to circumstantial evidence, such as the simultaneous application of gamma-ray shielding and neutron shielding, and continue to monitor the situation through radiation or laser measurement.

3. Safety and Security Considerations During Denuclearization Verification

The denuclearization of North Korea, having not only complex fuel cycle and clandestine weapon program but lost credibility due to several repeated denuclearization claims, is bound to be very different from previous denuclearization experience in other countries. Considering North Korea's unique path on its nuclear weapon program, the key factors to consider in the process of denuclearization of North Korea are as follows.

3.1 Illegal Transfer of Technology, Equipment, and Human Resources

As mentioned above, North Korea has been pursuing both plutonium and HEU weapon programs, allowing it to have extensive experience in reactors, reprocessing, conversion, enrichment, actinide metallurgy, bomb design & manufacturing, missiles, ^{6}Li production, and tritium production. The fact that North Korea, an extremely isolated country from the international market, has been able to implement such different complex technologies means that there was help from the black market. Pakistani scientist, Abdul Qadeer Khan's decades-long involvement in the illegal transfer of nuclear materials and technologies assisted Iran, Libya, North Korea, and potentially others to develop their uranium enrichment capabilities through a complex international network of experts, suppliers, and front companies. In this regard, the ripple effect will be far greater than the Khan Case if a North Korean expert is involved in the illegal transfer of material, technology, and equipment. Therefore, thorough preparations are needed to prevent black market intervention in any means to achieve complete denuclearization of North Korea.

There are many reasons for conducting a nuclear test. It includes production verification of a developed design of weapons, demonstration of performance, proof of concept of new weapon design, and study of weapon effect, etc. [15]. However, it is no longer mandatory. Advances in technology can ensure that existing nuclear test results and computer modeling or simulation programs are sufficiently similar to nuclear tests. Computer simulation combined with experimental data will not only further advance nuclear weapon development but contribute to make weapons small and powerful.

North Korea already had several nuclear tests. This may lead North Korea's technology more attractive to the black market. Practically, this computer simulation codes or any software combined with experimental data will not completely be destroyed. Instead, it is easier to transfer. Therefore, it is imperative to prepare measures and management alternatives for intangible assets mentioned above, as well as nuclear materials, equipment, and facilities.

3.2 Radiological Impact on Humans and the Environment

North Korea has not able to operate its nuclear reactors safely and is increasingly being called into question given the North's isolation and lack of safety culture. No adequate radiological safety standards would be in North Korea. Nor does anyone think North Korea can respond to any nuclear incidents or accidents in a timely manner. It will make the difference between small events and catastrophic disasters. As all of us know, nuclear explosions without proper containment release enormous amounts of heat, energy, and radioactive materials. Decontaminating highly contaminated complex at acceptable costs and duration while ensuring safety is even demanding for countries with advanced nuclear technologies. The Hanford site in the United States, the Sellafield site in the United Kingdom are the good examples.

Considering the lack of North Korea's safety awareness, neighboring countries including China and South Korea are concerned about the radiological contamination of its nuclear facilities and nuclear test sites. Since no prior effort has been made for monitoring North Korea's radioactive contamination level, technical cooperation for contamination monitoring outside of nuclear fuel cycle facilities would be a good opportunity to begin cooperation between the two Koreas and the U.S. Monitoring of radioactive contaminants on groundwater flow, gases, and aerosols in uranium mining & milling sites as well as Yongbyon, Punggye-ri will be critical. And while the actual contamination would be localized, the lack of transparency from North Korea in dealing with the situation is likely to cause political panic in the region in excess of the actual radiological exposure and environmental impact. In this regard, technical cooperation on decontamination would be helpful to prevent such an accident from occurring would provide a rare opportunity for regional dialogue and could pry open the door for realistic and productive discussions of North Korea's nuclear program [16].

4. Conclusion

Despite the skepticism and disappointment about the denuclearization of North Korea, it is necessary to continuously develop technologies for the verification of denuclearization, which serves to verify the correctness and completeness of reported information on nuclear materials and activities. Even though this nuclear archaeology may involve high uncertainty and cannot be completely verified at this stage, technological advances will undoubtedly play a key role in the denuclearization process. First, these technologies allow us to assess any information reported by North Korea on nuclear materials and activities. Second, these technologies help detect and identify any false statements among the reported information, whether accidental or deliberate, and correct them. Third, these technologies provide support to detect any nuclear activities and materials and relevant devices and facilities that have been omitted from reporting. Fourth, these technologies allow us to detect and protect against the smuggling of nuclear materials in the verification process for denuclearization. Fifth, these technologies provide reliable containment and monitoring solutions for nuclear materials or facilities in the verification process for denuclearization. Sixth, the ability of these technologies to detect any deliberate omission of information and concealed nuclear materials will prevent North Korea from attempting to do so in the first place, contributing to engaging the regime in an open and honest dialogue.

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