

The radioisotope ratio signature of core denuclearization facility in Democratic People's Republic of Korea

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1. Introduction

Since the Korean Peninsula's denuclearization was described, the Republic of Korea (ROK)'s role in the international community has been expected. Nuclear forensics analysis is essential to prove the management and nuclear material's integrity for the preemptive response to changing global conditions [1]. As part of the nuclear forensics process, specifying signatures was preceded considering the nuclear fuel cycle characteristics and facilities. These signatures include physical and chemical properties, radioisotope ratio, operational history, etc [2]. This study suggests the radioisotope ratio utilized for nuclear forensic analysis based on the facility's use and nuclear material acquisition route.

2. The core denuclearization facility and radioisotope signature of Democratic People's Republic of Korea

2.1 Nuclear material acquisition route [3]

The denuclearization core facility is directly related to nuclear weapons production, including the extraction of plutonium and high-enriched uranium through the reprocessing process. DPRK has a uranium mine and milling plant in Pyeongsan. This facility produces yellowcake (U_3O_8) through uranium mining and refining. Yellowcake that has not been converted is used as natural uranium (0.7% ^{235}U , NU) fuel of 5MWe gas-cooled reactor in Yongbyon nuclear complex. The converted yellowcake becomes uranium hexafluoride (UF_6). Then, low-enriched uranium (0.7% $<^{235}U < 20\%$, LEU) is used as the fuel for the 100MWth experimental light water reactor, high-enriched uranium ($^{235}U > 20\%$) is used as fuel for the IRT-2000 research reactor. The reprocessing process for plutonium extraction is known to be carried out in the radiochemical laboratory in Yongbyon nuclear complex. Recently, a facility estimated to be enriching uranium has been discovered in Kangson near Pyongyang. DPRK's major nuclear facilities include the Punggye-ri nuclear test site, which was abandoned after six times nuclear tests. Figure 1 illustrates DPRK's nuclear fuel cycle and weapons-grade nuclear material acquisition route.

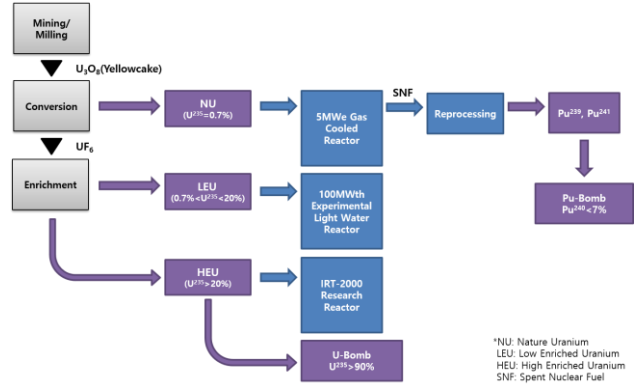


Fig. 1. Nuclear material acquisition route of DPRK

2.2 Radioisotope ratio signature of DPRK's facilities [4,5]

The uranium mine and milling plant for extracting and refining uranium ore are located in Pyeongsan. Uranium ore, uranium ore concentrates (UOC) could be sampled for this area. The signature at this placement is lead and strontium isotope ratio. It can provide information for the material's origin and age dating. In the uranium enrichment complex in Kangson, yellowcake or slurry is generated during milling, conversion, and enrichment. The uranium isotope ratio and strontium isotope ratio can identify these materials and determine the last separation after purification.

In Yongbyon nuclear complex, they are densely populated with facilities closely related to the production of plutonium to manufacture of nuclear weapons. The pellets, scrap, and waste materials are mainly used as samples in this placement's nuclear forensics. The plutonium and uranium oxide, plutonium nitrate, and uranium nitrate are representative materials in the reprocessing process. At this stage, uranium and plutonium isotope ratios become the main isotope ratio signatures. The 5MWe gas-cooled reactor and radiochemistry laboratory in the Yongbyon nuclear complex are directly related to plutonium production. Table I summarizes the radioisotope ratio signatures that can be used for nuclear forensics of DPRK's core denuclearization facilities.

Table I: Radioisotope ratio signature of DPRK's core denuclearization facilities

Location	Facility	Fuel and Materials	Radioisotope ratio signature
Pyeong san	Uranium Mine	Uranium Ore, UOC	$^{87}\text{Sr}/^{86}\text{Sr}$, $^{204,206,207}\text{Pb}/^{208}\text{Pb}$, $^{231}\text{Pa}/^{235}\text{U}$, $^{230}\text{Th}/^{234}\text{U}$
	Milling plant		
Kangson	Uranium enrichment complex	UF ₄ , UF ₆ , U ₃ O ₈ , LEU, HEU, DU	$^{87}\text{Sr}/^{86}\text{Sr}$, $^{204,206,207}\text{Pb}/^{208}\text{Pb}$, $^{234,235,236}\text{U}/^{238}\text{U}$, $^{214}\text{Bi}/^{234}\text{U}$
Yong byon	5 MWe gas cooled reactor	Nu, Pu	$^{232,233,234,235,236}\text{U}/^{238}\text{U}$ $^{238,240,241,242}\text{Pu}/^{239}\text{Pu}$, $^{18}\text{O}/^{16}\text{O}$, $^{241}\text{Am}/^{241}\text{Pu}$, $^{226}\text{Ra}/^{238}\text{U}$, $^{227}\text{Ac}/^{235}\text{U}$
	Radiochemical Laboratory	Pu	
	IRT-2000 Research reactor	HEU	
	Fuel rod Fabrication plant	UO ₂ (pellet), HEU	
	100 MWth Experimental Light water Reactor	LEU	

*UOC: Uranium Ore Concentrate, Nu: Nature Uranium,
LEU: Low Enriched Uranium, HEU: High Enriched Uranium

3. Conclusions

In this study, considering the DPRK nuclear fuel cycle, the radioisotope ratio signatures suggested using the nuclear forensic analysis of core denuclearization facilities. Designation and analysis of signatures are core procedures for nuclear forensics. It must be considered the operation history of facilities and nuclear fuel cycle of DPRK. In the future, it is necessary to establish a systematic procedure for nuclear forensics to utilize signatures, such as constructing a national nuclear forensics library.

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