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# Preliminary Research on the Verification Task of North Korea's Plutonium Declaration

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## 1. Introduction

The denuclearization of North Korea seems challenging. North Korea has recognized itself as a nuclear weapon state by carrying out two nuclear tests while many other nations including South Korea have opposed North Korea's nuclear proliferation. As a result of longstanding negotiations, North Korea provided nearly 19,000 pages of operation history of three Yongbyon nuclear facilities on May 8, 2008 and a 60-page declaration of its nuclear activities and programs on June 26, 2008. However, one should notice that declaration documents are by themselves meaningless without their verification. To completely dismantle North Korea's nuclear programs, the verification task based on its declaration documents should be performed very thoroughly, considering the possibility of the presence of the undeclared nuclear materials and facilities.

The verification task of North Korea's nuclear declaration consists of many broad themes to deal with, such as the review of declaration documents, the interview with facility operators, the sampling in the field, the laboratory analysis of the sample, data interpretation, and so on. One of the important themes is to verify North Korea's declared plutonium stockpile by comparing the declaration documents with measurement data which can be obtained from the sampling in the field and laboratory analysis. To prepare for the possible future verification of the declared plutonium stockpile, it is meaningful to give a thought on what data can be compared and what samples need to be taken and analyzed. In this study, we focus on the data to be compared and samples to be taken and analyzed for the plutonium accounting, as a preliminary research. To give a quantitative example, the nuclear material of the most recent North Korea's spent fuel rods discharged from the 5 MWe reactor is analyzed. On June 13, 2009, North Korea declared that more than one-third of the spent fuel rods had been reprocessed.

## 2. Methods and Results

### *2.1 General Description*

Plutonium used for nuclear weapons is typically produced by operating a nuclear reactor. As a fuel is irradiated with neutrons in the reactor, some of uranium element in the fuel is converted into transuranium elements or fission products. Plutonium isotopes are one of those transuranium elements. The amount of plutonium and isotopic composition of plutonium produced are determined by the amount of the fuel and the burnup of the fuel in the reactor. Since various elements including plutonium remain mixed in the spent fuel, the spent fuel needs to be reprocessed in the reprocessing facility in order to separate plutonium from other elements. Since some of the plutonium is lost in the extraction process of the reprocessing, it remains in the byproduct of the reprocessing considered as a high-level radioactive waste, so that the amount of the separated plutonium is less than that of the plutonium produced in the reactor.

### *2.2 Verification of North Korea's Plutonium Production in the 5 MWe Reactor*

The 5 MWe nuclear reactor known to be used for the plutonium production in North Korea is a magnox-type gas cooled reactor. For the gas cooled reactor, the carbon dioxide and the graphite are used as a coolant and a moderator, respectively. A magnox fuel used in the magnox reactor is natural uranium metal fuel with magnox(short for magnesium non-oxidizing) cladding. Maximum thermal output of the 5 MWe reactor is reportedly 25 MWth [1]. The reactor can load about 8,000 fuel rods containing about 50 tonnes of uranium [1].

Using the ORIGEN-ARP code [2] with the irradiation mode for magnox reactor, the total amounts of plutonium and compositions of major plutonium isotopes are obtained for different fuel average burnups in Table I. Here, the unit of burnup was given in MWd/MTU (megawatt-days per metric ton of uranium metal).

Table I: The total amounts of Pu and compositions of Pu isotopes for different fuel average burnups for the magnox reactor

| Fuel Average Burnup (MWd/MTU) | Pu (g/MTU) | Pu-239 (%) | Pu-240 (%) | Pu-241 (%) |
|---|---|---|---|---|
| 100 | 104 | 99.0 | 0.99 | 0.01 |
| 150 | 154 | 98.5 | 1.47 | 0.02 |
| 200 | 203 | 98.0 | 1.94 | 0.04 |
| 400 | 389 | 96.2 | 3.66 | 0.14% |

As the fuel burnup increases, the total amount of plutonium generated in the fuel increases but the abundance of Pu-240 in plutonium increases. The nuclear proliferators are expected to prefer the increase of the total amount of plutonium, while the increase of the Pu-240 content is undesirable because of its increasing the risk of predetonation. Thus, optimum range of the fuel burnup suitable to be used in plutonium bomb should exist and depends on the nuclear weapon design. According to the Table, the 5 MWe reactor is estimated to have the capability to produce roughly maximum 25 g of plutonium per day, assuming that it is operated continuously with its maximum thermal output.

The most recent North Korea's spent fuel rods discharged from the 5 MWe reactor reportedly contain roughly 7.5 kilograms of plutonium (corresponding to the declared amount of the plutonium production in our example) [3]. In order to produce 7.5 kilograms of plutonium (corresponding to 150 g/MTU), the average burnup should be roughly 150 MWd/MTU, according to Table I. Thus, the average burnup of the spent fuel is estimated to be roughly 150 MWd/MTU. This estimated value of the average burnup should be compared with the declaration data for the verification of the declared amount of the plutonium production.

There is also an alternative way to verify the declared thermal output history. When the structural components of the nuclear reactor are exposed to high flux neutrons during the operation, activation products are generated by capturing neutrons. By sampling the structural components of the reactor and analyzing the content of activation products in it, the cumulative burnup may be able to be deduced. The details are beyond the scope of this paper.

It also implies that the abundances of Pu-239, Pu-240, and Pu-241 of the separated plutonium are estimated to be 98.5, 1.47, and 0.02 %, respectively, according to Table I. However, because of the radioactive decay of plutonium isotopes, the abundances are changed depending on the elapsed time. Using the ORIGEN-ARP code [2] with the decay mode, the nuclide abundances of the separated plutonium are obtained in Fig. 1. The Pu-239 (half-life of 24,000 years) content is almost unchanged while the Pu-241 content (relatively short half-life of 14 years) and the Am-241 (decay product of Pu-241) content are relatively much changed. After sampling the separated plutonium, the data from the analysis of the sample should be compared with our abundance estimation results. The content of Pu-239 and/or Pu-240 can be used to verify the declared amount of the plutonium production and the declared thermal output history. In addition, the ratio of Am-241 to Am-241 can be used to verify the discharge time of the spent fuel.

*2.3 Verification of North Korea's Plutonium Separation in the Reprocessing Plant*

In addition to the verification of the plutonium production, that of the plutonium separation is also required since the amount of the plutonium separated in the reprocessing of the spent fuel is not the same as that of the plutonium produced in the reactor due to the loss in the extraction of the plutonium.

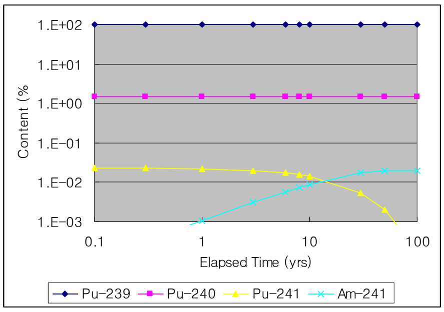


Fig. 1. The estimated nuclide abundances of recently separated North Korea's plutonium as a function of the elapsed time.

Since the plutonium lost in the extraction process remains in the high-level waste, the high-level waste from the reprocessing of the spent fuel should also be sampled and analyzed. The amount of the plutonium contained in the high-level waste should be compared with the difference of the amount of the plutonium production above and the amount of the declared separated plutonium.

## 3. Conclusions

As a preliminary research for the possible future verification of North Korea's declared plutonium stockpile, the data for the comparison and samples required for the analysis have been listed as summarized in the Table II. Our future works will include the broader and more detailed planning for the verification task as well as the refinement of the current work.

Table II: Summary of the data and samples to verify North Korea's plutonium declaration

| Verification | Data to be compared | Samples to be taken and analyzed |
|---|---|---|
| Plutonium Production | • Thermal output history of reactor (fuel average burnup)<br>• Amount and composition of produced Pu | • Structural components of the reactor<br>• Separated Pu |
| Plutonium Separation | • Amount and composition of separated and lost Pu | • Separated Pu<br>• Pu contained in high-level waste |

## REFERENCES

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