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ESTIMATED FEASIBLE PLUTONIUM PRODUCTION IN NORTH KOREA'S RESEARCH REACTOR, IRT-DPRK

by

Jared S. Dreicer

ABSTRACT

In a previous study,[1] as part of the Global Nuclear Material Control Model effort, we estimated that in one year an upper bound maximum of roughly 9 kg of plutonium combined could be produced in thermal research reactors in the potential nuclear weapon states* based on their declared power level. Also in that study we determined that in the worst case† a little less than a quarter metric ton (235.611 kg) of plutonium could have been produced cumulatively (over entire operating period). In a 1994 article in *The Bulletin of the Atomic Scientists*, D. Albright[3] estimated the amount of plutonium the North Korean's may have produced since 1986 in the 5 MW_e "power" reactor at Yongbyon. Albright provided an upper bound estimate of 53 kg of weapon-grade plutonium produced cumulatively, if the gas-graphite (magnox) reactor had achieved a load factor of 0.80. The plutonium content of the removed 1989 irradiated fuel from the 5 MW_e "power" reactor is placed at 7–14 kg. However, the cumulative estimate of 53 kg ignores the potential plutonium production in the 8 MW_{th} research reactor IRT-DPRK. We estimate that in addition to the 53 kg cumulative, it is possible that 5.35–21.40 kg (8.02–32.09 kg) of plutonium could have been produced in the IRT-DPRK reactor operating at the declared (feasible) power level during the entire period it has operated, including a period in which it was not safeguarded.‡

I. INTRODUCTION

The North Korean's received an IRT research reactor and laboratory-scale processing equipment ("hot cells") from the Soviet Union in the 1960s, the International Atomic Energy Agency's (IAEA) name for the research reactor is IRT-DPRK. The IRT-DPRK is located in Yongbyon and first went critical on August 15, 1965. The IRT-DPRK was not placed under IAEA safeguards until July 20, 1977, essentially 12 years after it first went critical, when a trilateral (USSR, DPRK, and IAEA) Type 66 safeguards agreement was initiated, which is facility-, material-, or equipment-specific. This information is summarized in Table 1. The laboratory-scale hot cells are

*Potential nuclear weapon states are defined to be Algeria, Iran, Iraq, Libya, North Korea, and Syria, since they are perceived to desire, or have openly demonstrated or expressed a desire for, a nuclear weapons capability.

†This assumes unimpeded plutonium production (no safeguards) during the entire period of research reactor operation and a feasible reactor power level 50% greater than declared, see Refs. 1 and 2 for details.

‡Technical and inspection measures for verifying that nuclear materials are not being diverted from civil to weapons uses, including material control and accounting. See Appendix A of Ref. 1. for more details.

located in Pyongyang. Also constructed at Yongbyon as part of the research reactor agreement was a small lab, a "0.1 MW nuclear research lab called a critical facility,"[4] which included hot cells.

TABLE 1. NPT Signatory Status of North Korea, Initiation of Safeguards, and Number of Years IRT-DPRK Research Reactor Unsafeguarded

Reactor	NPT Signatory	Safeguards Agreement	Criticality Date	Safeguards Initiated	Unsafeguarded (yrs)
IRT-DPRK	Joined NPT on 12/12/85	FSS[a] Type 153 4/10/92	08/15/65	Type 66 07/20/77	11.94

[a]Full-Scope Safeguards.

The North Koreans have admitted utilizing the hot cells at Pyongyang for plutonium separation[3,5-7] as early as 1975,[5] prior to the 1977[3] Type 66 safeguards. Starting in the 1960s North Korean scientists were trained by the Soviets at the Dubna nuclear research facilities and also by the Chinese. The North Korean technicians probably gained knowledge about reprocessing chemistry and technology during these exchanges. Clearly, by the early 1990s they appear to have extensive understanding of this process and technology, having separated plutonium at least four different times. They admitted separating plutonium in 1975 and 1990[3] and the IAEA discovered americium-241,* indicating that plutonium was also separated in 1989 and 1991.

As early as 1965, the North Koreans had an indigenous nuclear infrastructure. This infrastructure included the IRT-DPRK research reactor, critical and sub-critical facilities (which included hot cells), several sources of natural uranium (one at Pyongsan), and technically capable scientists and technicians. See the Korean Peninsula map (Fig. 1) for the geographic location of these sites. They admitted to having the technical and physical capability to separate plutonium by 1975. This advancement indicates a degree of sophistication and interest in plutonium dating to the early 1970s. Since the 5 MW_e "power" magnox reactor did not start operating until 1986, we are led to speculate as to the source of the material that was separated in 1975. If the IRT-DPRK was the source of plutonium for the 1975 separation, the question becomes: What quantity of plutonium could have been produced during its period of operation?

II. PLUTONIUM PRODUCTION IN THE IRT-DPRK RESEARCH REACTOR

In two previous studies[1,2] the methodology utilized for these estimates was explained in depth. We will provide a brief description of this methodology and the assumptions upon which it is based. These calculations represent an upper bound estimate (the Binford line) on the plutonium production potential; more accurate neutronic calculations require specific knowledge concerning reactor operation, fuel, and target configurations. The Binford line is based on confirmation studies on the unreported plutonium production at six research reactors; it represents an upper bound on the maximum possible quantity of plutonium that can be produced by a thermal research reactor. The Binford line established that the potential plutonium production rate is approximately 0.65–0.70 g Pu/MW(th)d. This relationship is modified by utilizing a 0.90 load

*Americium-241 is a decay product of plutonium-241; it dates the time that the plutonium was separated.

Source: Over the Internet from www.lib.utexas.edu

Fig. 1. Korean Peninsula map showing the location of Pyongbyon, Yongbyon, and Pyongsan (P'yonggang) in North Korea.

factor and converting to kilograms to obtain the following expression for our estimated maximum plutonium production (EMPu) calculations:

$$\text{EMPu [kg/yr]} \approx 0.224 \frac{\text{kg}}{\text{MW(th) yr}} \times \text{Operating Power Level [MW(th)]} \; .$$

The following assumptions are built into this expression: a one-year period, a reactor load factor (LF) of 0.90, and fertile targets (^{238}U or natural uranium). Additionally, in early studies we have only been interested in research reactors with a thermal power of 1 MW or more and the application of the declared or the feasible 50% greater operating power. This expression has not been verified to be applicable to fast reactors or critical assemblies.

The actual rate of plutonium production in a reactor is ultimately dependent on a number of production factors including the target material and the reactor operation. For a more complete discussion of these production factors, see Refs. 1 and 2. These factors impact the production of plutonium but of concern in this study is the power level. The plutonium production rate corresponds to the power level.

The IRT-DPRK has been identified as having an initial 2–4 MW_{th} power level[8]and then having been increased to a 8 MW_{th} power level[8,9] sometime after 1974. The most recent IAEA source[10] reports that the IRT-DPRK has also been declared as always having a 5 MW_{th} power level. Because of the declared power level discrepancy, all estimates will utilize the following declared power levels 4, 5, and 8 MW_{th} and report results based on each. These declared power levels will also be the basis for the feasible (50% greater than declared) power levels. The corresponding feasible reactor power levels are 6, 7.5, and 12 MW_{th}.

Table 2 summarizes the estimated plutonium production in the IRT-DPRK depending on the declared and feasible reactor power levels and the time required to produce a significant quantity (SQ), 8 kg, of fissile plutonium as defined by the IAEA. For example, at a declared power level of 5 MW_{th} the EMPu is 1.12 kg/yr and it would take 7.14 years to produce an SQ, and the feasible power level is 7.5 MW_{th}, which gives an EMPu of 1.68 kg/yr and decreases the time to produce an SQ to 4.76 years.

TABLE 2. Estimated Plutonium Production (EMPu) Using the Declared Power Level and the Feasible Power Level (50% Greater than Declared) for the IRT-DPRK

Declared Power Level (MW_{th})	EMPu Declared Power Level @ LF = 0.90 (kg/yr)	Years to Produce 1 SQ (8 kg) Declared Power (yr/SQ)	Feasible Power Level (MW_{th})	EMPu Feasible Power Level @ LF = 0.90 (kg/yr)	Years to Produce 1 SQ (8 kg) Feasible Power (yr/SQ)
2	0.448	17.86	3	0.672	11.90
4	0.896	8.93	6	1.344	5.95
5	1.120	7.14	7.5	1.680	4.76
8	1.792	4.46	12	2.688	2.97

III. FEASIBLE PRODUCTION ESTIMATIONS

For safety reasons, reactors have been thermally over-designed and engineered. The main design criterion is to engineer the reactor such that the heat generated by the operating power level can be dissipated. Heat dissipation keeps the reactor's fuel surface temperature from surpassing the saturation temperature at the maximum flux produced by the power level. Thus, the declared maximum operating power level is typically significantly lower than the required heat dissipation rate. From the nonproliferation perspective this creates a fundamental problem; without any (perhaps minor) engineering modifications it is possible to operate a reactor at up to 50% greater power and the plutonium production rate corresponds to the power level. The specified threshold only refers to the declared operating power of the reactor, not the feasible maximum power level. For a more complete discussion of this issue see Ref. 1.

Four cases will be presented that report the cumulative maximum plutonium production (CMPu). The CMPu (kg/years-operating) reflects the total quantity of plutonium that could have been produced based on the number of years that the IRT-DPRK operated for the possible power levels. The cases are defined by the four possible combinations of the declared operating power level, the feasible (50% greater) operating power level, the presence of safeguards, or the lack of safeguards for the IRT-DPRK research reactor. There was a period of 11.94 years from August 1965 to July 1977 that the IRT-DPRK definitely operated without IAEA safeguards. Even after the IRT-DPRK was placed under IAEA safeguards, it is unclear whether or not the safeguards were adequate. This is because of the research reactor's low power rating (even assuming 8 MW_{th}) relative to IAEA safeguards criteria, which do not require an analysis for reactors with a thermal power of 25 MW_{th} or less (see Refs. 1 and 2 for more details). Assuming that the safeguards were adequate, the IRT-DPRK operated from 1965 when it first went critical until 1977 with no safeguards.

Case 1 reports the CMPu for the IRT-DPRK operating at the declared power level with (A) no safeguards during the entire period of operation and (B) taking into account the duration of safeguards. Case 2 reports the CMPu for the IRT-DPRK operating at the feasible power level with (A) no safeguards during the entire period of operation and (B) taking into account the duration of safeguards.

CASE 1A: Declared Operating Power Level with No Safeguards

Summarized in the first five columns of Table 3 are the declared operating power, the EMPu, the number of years that would be required to produce an SQ of plutonium, the number of years of operation, and the cumulative maximum plutonium production. The first CMPu (kg/years-operating) column values in Table 3 assume no safeguards were implemented during the entire period of operation for the IRT-DPRK. The CMPu reflects the cumulative quantity of plutonium that could have been produced given the number of years the IRT-DPRK operated, applying the same assumptions previously mentioned and assuming unimpeded plutonium production opportunity.

Without the difficulties related to hiding illegitimate operation of the research reactor because of the lack of safeguards and the desire to produce plutonium, the North Koreans could have produced more than an SQ in the IRT-DPRK. A load factor of 0.90 could be achievable without the need to mask plutonium production activity and conceal fertile materials. Over the entire period of operation, assuming that the North Koreans understood the technical requirements, 27.78 kg could have been produced if the IRT-DPRK operated at 4 MW_{th}.

TABLE 3. Cumulative Maximum Plutonium Production (CMPu) for Declared Power Level with No Safeguards During Entire Period of Operation and Accounting for Duration of Safeguards Implementation for IRT-DPRK

Declared Operating Power Level (MW_{th})	EMPu (kg/yr)	Years to SQ (8 kg)	# Years Oper. to 8/96	CMPu No Safeguards (kg/yr-oper)	# Years Oper. No Safeguards	CMPu With Safeguards (kg/yr-oper)
2	0.448	17.86	31.00	13.89	11.94	5.35
4	0.896	8.93	31.00	27.78	11.94	10.70
5	1.120	7.14	31.00	34.72	11.94	13.37
8	1.792	4.46	31.00	55.55	11.94	21.40

CASE 1B: Declared Operating Power Level and Duration of Safeguards

The last two columns of Table 3 summarize the number of years the IRT-DPRK actually operated without safeguards implemented and the cumulative maximum plutonium production during operation without safeguards. These two columns again utilize the declared operating power and assume safeguards were applied on 8/77. The CMPu indicates the cumulative quantity of plutonium that could have been produced given the number of years that the IRT-DPRK operated under safeguards, applying the same assumptions previously mentioned and assuming impeded plutonium production opportunity.

The IRT-DPRK went critical on 08/65 and did not have international safeguards implemented until essentially 08/77 for a total period of 11.94 years unsafeguarded. At most the IRT-DPRK could have produced 10.70 kg of plutonium during those 11.94 years, assuming that it operated at 4 MW_{th} from the date it first went critical.

CASE 2A: Feasible Operating Power Level with No Safeguards

Summarized in the first five columns of Table 4 is the feasible (50% greater than declared) operating power, the EMPu, the number of years that would be required to produce an SQ of plutonium, the number of years of operation, and the CMPu. The first CMPu column values in Table 4 assume no safeguards were implemented during the entire period of operation for the IRT-DPRK. The CMPu reflects the cumulative quantity of plutonium that could have been produced given the number of years that the IRT-DPRK operated, applying the same assumptions previously mentioned and assuming unimpeded plutonium production opportunity.

Again, and more pertinent in this case, the North Koreans could have possibly operated their research reactor at up to 50% greater than declared power. This is possible without the difficulties related to hiding illegitimate operation of the IRT-DPRK due to the lack of safeguards and their desire to produce plutonium. This would have resulted in the North Koreans having produced significantly more than an SQ, 20.83 kg, during the period of operation if a power level of 3 MW_{th} was achieved.

TABLE 4. Cumulative Maximum Plutonium Production (CMPu) for Feasible Power Level with No Safeguards During Entire Period of Operation and Accounting for Duration of Safeguards Implementation for IRT-DPRK

Feasible Operating Power Level (MW_{th})	EMPu (kg/yr)	Years to SQ (8 kg)	# Years Oper. to 8/96	CMPu No Safeguards (kg/yr-oper)	# Years Oper. No Safeguards	CMPu With Safeguards (kg/yr-oper)
3	0.672	11.90	31.00	20.83	11.94	8.02
6	1.344	5.95	31.00	41.66	11.94	16.05
7.5	1.680	4.76	31.00	52.08	11.94	20.06
12	2.688	2.97	31.00	83.33	11.94	32.09

CASE 2B: Feasible Operating Power Level and Duration of Safeguards

The last two columns of Table 4 summarize the number of years the IRT-DPRK actually operated without safeguards implemented and the cumulative maximum plutonium production during operation without safeguards. These two columns again utilize the feasible operating power and assume safeguards were applied on 8/77. The CMPu reflects the cumulative quantity of plutonium that could have been produced given the number of years that the IRT-DPRK operated under safeguards, applying the same assumptions previously mentioned and assuming <u>impeded</u> plutonium production opportunity.

Assuming that the international safeguards were effective from the point in time that the IRT-DPRK was placed under safeguards, 8.02 kg of plutonium could have been produced during the 11.94 years of unsafeguarded operation at a power level of 3 MW_{th}.

Summing up Possible Plutonium Production in the IRT-DPRK

The discrepancy regarding the declared power level of the IRT-DPRK impacts the maximum possible plutonium production; we have estimated the quantity that could be produced depending on the period of operation at a specific declared power level. The IRT-DPRK was initially declared as having a 2–4 MW_{th} power level, which was increased to 8 MW_{th}; we will ignore the 5 MW_{th} power level. Based on the IAEA data and the desire to establish an upper bound estimate, we have assumed a 4 MW_{th} power level for the period 8/65–8/74 (9 years) and the 8 MW_{th} power level for the period 9/74–9/96 (22 years). If the actual date that the IRT-DPRK reached 8 MW_{th} is determined, appropriate adjustment of the following estimations are possible. Table 5 gives the plutonium production estimate for the period of operation at a specific declared power level and also the corresponding feasible power level estimates. Assuming the IRT-DPRK operated at 4 MW_{th} for the first 9 years and 8 MW_{th} for the remaining 22 years, 47.487 kg of plutonium cumulative could have been produced. The 47.487 kg cumulative assumes that the IRT-DPRK operated only at the declared power level but had unimpeded plutonium production opportunity (no or ineffective safeguards). The upper bound estimate for the production of plutonium assumes that the IRT-DPRK operated at the feasible 6 MW_{th} for the first 9 years and 12 MW_{th} for the remaining 22 years power levels during operation, resulting in 71.232 kg cumulative. The 71.232 kg cumulative assumes no or ineffective safeguards, resulting in unimpeded plutonium production opportunity.

TABLE 5. Cumulative Maximum Plutonium Production (CMPu) for Declared and Feasible Power Levels with No Safeguards During 8/65–8/77 Period of Operation and With Safeguards During 8/77–9/96 Period of Operation for IRT-DPRK

Power Level (MW_{th})	Assumed Period of Oper. at Power Level	# of Years	CMPu No Safeguards (kg/yr-oper)	CMPu No Safeguards (kg/yr-oper)	CMPu No Safeguards (kg/yr-oper)	CMPu With Safeguards (kg/yr-oper)
Dec.: 4	8/65 - 8/74	9.00	8.064	-	-	8.064
Feas.: 6	8/65 - 8/74	9.00	12.096	-	-	12.096
Dec.: 8	8/74 - 8/77	2.83	-	5.071	-	5.071
Feas.:12	8/74 - 8/77	2.83	-	7.607	-	7.607
Dec.: 8	8/77 - 9/96	19.17	-	-	34.352	-
Feas.:12	8/77 - 9/96	19.17	-	-	51.529	-
Total Declared	8/65 - 9/96	31.00			47.487	13.135
Total Feasible	8/65 - 9/96	31.00			71.232	19.703

IV. CONCLUSIONS

The North Koreans may not have had the desire and technical capability to utilize the IRT-DPRK for plutonium production as early as 1965; indeed, they might not have ever employed it for such purposes. But if the North Koreans had the desire and technical knowledge, they certainly had a source of fertile material (natural uranium) and other required technical infrastructure to be able to do so. In either case, in order to establish an upper bound estimate on plutonium production, it is necessary to account for what could have been produced in the IRT-DPRK research reactor in addition to what could have been or was produced in the 5 MW_e “power” reactor. Additionally, the fact that the North Koreans separated plutonium in 1975 provides increased interest in such an estimate.

In the worst case (remote possibility) from a proliferation perspective, the IRT-DPRK could have produced an upper bound of 71.232 kg of plutonium based on the previously mentioned assumptions. This is unlikely since it would have required an advanced degree of technological development, capability, and understanding prior to the time the IRT-DPRK started operation. It is also theoretically possible (unlikely) that the North Koreans produced 47.487 kg of plutonium cumulatively based on the assumed periods of operation at the declared power levels; this would also have required technical capability and sophistication prior to 1965. From a more practical perspective, it is possible that between 5.35–21.40 kg (8.02–32.09 kg) of plutonium could have been produced in the IRT-DPRK reactor operating at the declared (feasible) power level during the entire period it has operated, including a period it was not safeguarded. These quantities combined with the plutonium content of the removed 1989 irradiated fuel from the 5 MW_e “power” reactor placed at 7–14 kg,[3] results in possibly 12.35–35.40 kg (15.02–46.09 kg) of plutonium.

If North Korea has become (or becomes) a nuclear weapon state, the impact on the Non-Proliferation Treaty (NPT) and the response of other nonnuclear weapon member states may be significant. At the least, the NPT has lost substance and become hollowed. The NPT framework would suffer. Further, the current trends toward decreasing vertical and horizontal proliferation and the international stigma regarding nuclear weaponization may reverse. The implications for regional security is concerning. South Korea and Japan would receive the direct burden of any North Korean nuclear weaponization. By default the US would be affected because of its close economic and security ties with both states and the resulting need to establish a strong nuclear deterrent/security umbrella.

REFERENCES

1. J. S. Dreicer, “Estimation of Feasible Unreported Plutonium Production in Thermal Research Reactors in the Potential Nuclear Weapon States,” Los Alamos National Laboratory LA-13209-MS.
2. J. S. Dreicer and D. A. Rutherford, “Global Estimation of Potential Unreported Plutonium Production in Thermal Research Reactors,” *Nucl. Mater. Manage*. **XXX** (1996).
3. D. Albright, “How Much Plutonium Does North Korea Have?” *The Bulletin of the Atomic Scientists*, 46-53 (September/October 1994).
4. M. Mazarr, *North Korea and The Bomb - A Case Study in Nonproliferation (*St. Martin’s Press, New York, New York, 1995).
5. ACT editor, “North Korea at the Crossroads: Nuclear Renegade or Regional Partner?” *Arms Control Today,* 3-9 (May 1993).
6. D. Albright and M. Hibbs, “What’s North Korea Up To, Anyway?” *The Bulletin of the Atomic Scientists*, 10-11 (December 1991).
7. D. Albright and M. Hibbs, “North Korea’s Plutonium Puzzle,” *The Bulletin of the Atomic Scientists*, 36-40 (November 1992).
8. Directory of Nuclear Research Reactors, IAEA, STI/PUB/853 (IAEA, Vienna, 1989).
9. Nuclear Research Reactors In the World, Reference Data Series #3, IAEA-RDS-3/09 (IAEA, Vienna, 1993).
10. Nuclear Research Reactors In the World, Reference Data Series #3, IAEA-RDS-3/09 (IAEA, Vienna, 1995).

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