Science & Global Security, 2000, Volume 8, pp.273–286
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How Much Plutonium Could Have been Produced in the DPRK IRT Reactor?

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In a previous study[1] the author estimated the maximum quantity of plutonium that could be produced in thermal research reactors in the potential nuclear weapon states (including North Korea), based on their declared power levels. Several follow-up studies[2,3] focused on estimating and revising upper bounds on the aggregate quantity of plutonium that could have been produced in the North Korean research reactor. Albright independently estimated the amount of plutonium the North Koreans may have produced since 1986 in the 5-megawatt-electric “power” reactor at Yongbyon and provided an upper-bound estimate of weapon-grade plutonium produced cumulatively if the gas-graphite (magnox) reactor had achieved a load factor of 0.80. Albright’s cumulative estimate did not include the potential plutonium production in the 8-megawatt-thermal research reactor, called the IRT-DPRK by the International Atomic Energy Agency (IAEA). To better quantify the possible cumulative North Korean production, this paper estimates the plutonium content in the irradiated material (PCIM). The estimates are based on what could have been produced in the IRT-DPRK research reactor operating at the declared power level during the entire period it has operated, including a period during which it was not safeguarded.

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INTRODUCTION

David Albright published his estimate and assumptions regarding North Korean plutonium production in the October 1994 *Bulletin* article "How Much Plutonium Does North Korea Have?"[4] Albright provided estimates of the plutonium content of the removed 1989 irradiated fuel (not separated) from the "power" reactor at 7 to 14 kilograms.[5] Albright's estimate addressed the question of how much plutonium could have been produced in the 5-megawatt-electric (MW_e) power reactor since 1986.[6]

North Korea (Democratic People's Republic of Korea, DPRK) also has had another potential source of plutonium, which was not considered by Albright. This is the IRT-DPRK research reactor. The DPRK may not have had the technical capabilities and facilities necessary to utilize the IRT-DPRK for plutonium production during the entire thirty-one year period it operated. However, in the early 1990s the DPRK admitted that the IRT-DPRK research reactor was the source for a minor quantity of plutonium separated in 1975. Despite this history, published estimates of DPRK plutonium production have only accounted for the 5-MW_e "power" reactor production and have not taken into account the IRT-DPRK. In order to determine how much plutonium North Korea may have produced it is also necessary to estimate the quantity of plutonium content in the irradiated material, potentially produced in the 8-megawatt-thermal (MW_t) IRT research reactor. Since the IRT-DPRK was the source of plutonium for the 1975 separation, it is necessary to raise the following question: *What quantity of plutonium could be contained in the irradiated material that had been in the IRT-DPRK during the period it has operated?* Undertaking this study was a natural follow-up to an earlier paper.[7]

If the DPRK had attempted to produce plutonium in the IRT-DPRK, about 4 kilograms of plutonium content in the irradiated material (PCIM -- not separated) could have been produced cumulatively in the research reactor. This is based on the assumptions that the IRT-DPRK was operated at the declared power levels with a load factor of 0.22[8] during the entire period it operated, including the 12-year period it was not safeguarded. This estimate assumes that the DPRK had a sufficient supply of fuel and target material for utilization. This potential plutonium production would require storage for the irradiated material.

BACKGROUND

Starting in the 1960s, DPRK scientists were trained by the Soviet experts at the Dubna nuclear research facilities and also by the Chinese. The DPRK technicians probably obtained knowledge about reprocessing chemistry and related technology during this training. The Soviet Union provided the DPRK an IRT research reactor (IRT-DPRK) and laboratory-scale processing equipment ("hot cells") in the 1960s. The IRT-DPRK is located in Yongbyon and the laboratory-scale hot cells are located in Pyongyang. Additionally, a small-lab 0.1-MW critical facility,[9] which included hot cells, was constructed at Yongbyon. The pool-type IRT-DPRK, with an initial power of 2 MW_t first went critical in August 1965 but was not placed under safeguards until 1977. The IRT-DPRK was placed under IAEA safeguards when an INFCIRC/66 trilateral (USSR, DPRK, and IAEA) safeguards agreement was initiated on July 20, 1977. INFCIRC/66 agreements are facility, material, or equipment specific. This agreement was initiated essentially twelve years after the IRT-DPRK first went critical.

The DPRK signed the Nuclear Non-Proliferation Treaty in 1985, but did not ratify an INFCIRC/153 type comprehensive safeguards agreement associated with the regime until April 9, 1992. As part of their safeguards declaration in May 1992, the DPRK provided the IAEA with nuclear material and facility declarations. As a result of the IAEA's verification process, discrepancies were discovered in the DPRK's declaration of plutonium production. Subsequently, the DPRK admitted utilizing the hot cells at Pyongyang and Yongbyon for plutonium separation[10,11,12] as early as 1975,[13,14] prior to the 1977[15] INFCIRC/66 safeguards agreement. The DPRK also admitted that the IRT-DPRK research reactor was the source for the minor quantity of plutonium separated in 1975. The DPRK has reprocessed plutonium at least four different times. They admitted separating plutonium in 1975 and 1990[16] and the IAEA obtained samples containing americium-241[17] indicating that plutonium was also separated in 1989 and 1991. It is obvious that the DPRK had extensive understanding of this process and technology by the 1990s.

As early as 1965, the DPRK had an indigenous nuclear infrastructure, including technically capable scientists and technicians, the IRT-DPRK research reactor, critical and subcritical facilities, and a quality source of natural uranium at Pyongsan.

PLUTONIUM PRODUCTION IN THE IRT-DPRK RESEARCH REACTOR

The actual rate of plutonium production in a reactor is dependent on a number of specific production factors including fuel enrichment, target configurations, and reactor operation. Very accurate neutronic calculations are possible when detailed information is known. Production factor data for the IRT-DPRK is not readily available, making accurate neutronic calculations impossible. The plutonium production rate in a reactor corresponds to the power level that is proportional to the flux. Since the plutonium production rate corresponds to the power level, it is possible to *estimate* the quantity of plutonium produced based solely on the reactor power level and load factor during a period of time. Basing a plutonium production estimate on power level and load factor only requires knowledge of the operating thermal power level and the megawatt days per year utilization for the reactor. The IAEA maintains a *Directory of Nuclear Research Reactors*,[8] where the declared maximum operating power level and the megawatt days per year utilization for research reactors are reported.

The calculations presented are estimates of the maximum PCIM production (EMPu) potential based on the declared power level and both the declared and possible load factors. An analytic expression[18] to estimate the quantity of plutonium that could be produced in a one-year period using fertile targets (^{238}U or natural uranium) can be used. The analytic equation utilized[19] is based on the assumption that the DPRK had sufficient fuel and target material, operated the research reactor at a specified load factor, and that the potential plutonium production rate is 0.30 – 0.40 g Pu/MW_t-d.[20]

In 1988 the IRT-DPRK was declared as having an 8-MW_t power level[8]; however, it was initially constructed for 2-MW_t and was subsequently upgraded in 1974 to a 4-MW_t power level.[21] The estimates assume that the reactor was operated for roughly nine years at 2-MW_t, fourteen years at 4-MW_t, and eight years at 8-MW_t. The duration of operation at the three different declared power levels reflects the information dates associated with the power level declared to the IAEA.

Table I summarizes the estimated maximum PCIM production ($EMPu_D$) in the IRT-DPRK for one year, based on the declared reactor power level, a declared load factor of 0.22, and the time required to produce 8 kilograms of PCIM. For example, at a declared power level of 8 MW_t, the $EMPu_D$ is 0.23 kilograms/year, and it would take 34.8 years to produce 8 kilograms of PCIM.

Table 1: Table 1: Estimated Maximum Plutonium Content in Irradiated Fuel for the Declared Power Level at Load Factor of 0.22 ($EMPu_D$).

Declared Power Level (MW)	$EMPu_D$ (kg/yr)	Years to Produce 8 kg PCIM (yr/8 kg)
2	0.06	133.3
4	0.11	72.7
8	0.23	34.8

The cumulative maximum PCIM production (CMPu) reflects the total quantity of plutonium that could have been produced in irradiated material, based on the number of years that the IRT-DPRK operated at the three declared power levels, from August 1965 to August 1996. There are two possible combinations for operation of the IRT-DPRK at the declared operating power level, either with safeguards starting in August 1977 or without safeguards. Because of the IRT-DPRK's low-power rating relative to IAEA safeguards criteria,[22] which do not require an analysis for reactors with a thermal power of 25 MW_t or less,[7,22] it is unclear whether or not the safeguards were adequate after it was placed under safeguards in 1977.

Declared Operating Power Level—No Safeguards

In the first two columns of Table 2 is the declared operating power and the number of years of operation at that power level. The third column ($CMPu_D$ [kg/years-operating] values) in Table 2 assumes no safeguards were implemented during the entire period of operation for the IRT-DPRK. These $CMPu_D$ values assume *unrestricted* plutonium production in irradiated material at the declared power level. The IRT-DPRK could have produced 3.8 kilograms of PCIM, assuming a load factor of 0.22 during the entire thirty-one year period of operation.

Declared Operating Power Level and Duration Of Safeguards

The last two columns of Table 2 summarize the number of years the IRT-DPRK actually operated at the particular power level without safeguards implemented and the resulting $CMPu_D$ (without safeguards for 12 years and with safeguards for 19 years). These two columns utilize the declared operating power and assume safeguards were applied on August 1977. The $CMPu_D$ values assume *restricted* plutonium production opportunity after safeguards were applied. At most the IRT-DPRK could have produced 0.8 kilograms of

PCIM during those twelve years, assuming that it operated at 2 MW_t for nine years and at 4 MW_t for three years at the declared load factor of 0.22.

Table 2: Cumulative Maximum Plutonium Content in Irradiated Fuel ($CMPu_D$) for Declared Power Level and 0.22 Load Factor with No Safeguards During Period of Operation and Accounting for Duration of Safeguards Implementation for IRT-DPRK

Declared Power Level (MW_t)	# Years Operate to 8/96	$CMPu_D$, No Safeguards (kg/yr-oper)	# Years Operate, No Safeguards	CMP_{uD} with Safeguards (kg/yr-oper)
2	9.0	.5	9.0	0.5
4	14.0	1.5	3.0	0.3
8	8.0	1.8	0.0	0.0
Total	31.0	3.8	12.0	0.8

Over-Power Plutonium Production Estimations

Heat dissipation is the dominant reactor design consideration. Consequently, the primary thermal criterion of this type of reactor is the requirement to prevent nucleate boiling in any of the fuel, which is considered the region of safe operation. Prevention of nucleate boiling requires that the fuel surface temperature not surpass the saturation temperature by more than 10°C on average. The power level at which this type of reactor can operate due to the correlated heat load is limited by this thermal principle. Sufficient heat dissipation keeps the fuel's surface temperature slightly above the saturation temperature at the maximum flux produced by the power level. These reactors have been designed and engineered not to exceed the thermal criteria for safety. Operation can occur with nucleate boiling but must not extend beyond. Thus, the declared maximum operating power level is often significantly lower than that permitted by the maximum heat dissipation rate. This results in a fundamental problem from the nonproliferation perspective: that the specified threshold only refers to the *declared* operating power of the reactor, not the feasible *over-power* maximum power level. With minor or no engineering modifications, it is possible to operate a reactor at up to 50% greater power, since as a rule the reactors have been conservatively designed from a thermal perspective. Some of the variables that can be exploited to impact the power level include: coolant velocity, secondary cooling system capacity, primary coolant temperature, target material, and reactor pressure. Decreasing the temperature of the primary coolant prior to inlet, increasing the heat transfer area of the target material, increasing the velocity of coolant flow, or increasing the capacity of the secondary cooling system permit an increase in the reactor power level due to the greater heat dissipation. Raising the reactor pressure increases the target material saturation temperature (for tank-type reactors that have a closed primary-coolant system) allowing an increased power level. The IAEA reported level only refers to the *declared* operating power of the reactor.

The plutonium production using over-power (50% greater than declared) levels has been estimated. The resulting reactor power levels are 3, 6, and 12 MW_t. Table 3 summarizes the over-power EMPu ($EMPu_{OP}$) in the IRT-DPRK for one year, based on the reactor power level, using a load factor of 0.22, and the time required to produce 8 kilograms of PCIM. For example, at over-power level of 12 MW_t (50% greater than the declared 8 MW_t), the $EMPu_{OP}$ is 0.34 kilograms/year and it would take 23.5 years to produce 8 kilograms of plutonium in the irradiated fuel.

Table 3: Estimated Maximum Plutonium Content in Irradiated Fuel Using the Over-Power Level ($EMPu_{OP}$) and Declared 0.22 Load Factor for the IRT-DPRK. Over-Power is 50% Greater than Declared.

Over-Power Level (MW_t)	$EMPu_{OP}$ (kg/yr)	Years to Produce 8 kg PCIM (yr/8 kg)
3	0.08	100.0
6	0.17	47.1
12	0.34	23.5

Operating Over-Power Level—No Safeguards

The first two columns of Table 4 present the operating over-power level and the number of years of operation at that power level. The third column $CMPu_{OP}$ values in Table 4 assume no safeguards were implemented during the entire period of operation for the IRT-DPRK. These $CMPu_{OP}$ values assume the *unrestricted* plutonium production opportunity. This would have resulted in the DPRK having produced less than 6 kilograms PCIM. If the IRT-DPRK had operated without safeguards at 3 MW_t for nine years, 6 MW_t for fourteen years, and then 12 MW_t for the remaining eight years 5.8 kilograms of PCIM could have been produced cumulatively.

Table 4: Cumulative Maximum Plutonium Content in Irradiated Fuel ($CMPu_{OP}$) for Over-Power Level and Declared 0.22 Load Factor with No Safeguards During Entire Period of Operation and Accounting for Duration of Safeguards Implementation for IRT-DPRK.

Over-Power Level (MW_t)	# Years Operate to 8/96	$CMPu_{OP}$ No Safeguards (kg/yr-oper)	# Years Operate, No Safeguards	$CMPu_{OP}$ with Safeguards (kg/yr-oper)
3	9.0	0.7	9.0	0.7
6	14.0	2.4	3.0	0.5
12	8.0	2.7	0.0	0.0
Total	31.0	5.8	12.0	1.2

Operating Over-Power Level and Duration Of Safeguards

The last two columns of Table 4 summarize the number of years the IRT-DPRK could have operated at over-power level without safeguards implemented and the resulting $CMPu_{OP}$ (without safeguards for 12 years and with safeguards for 19 years). These two columns utilize the operating over-power level and assume safeguards were applied in August 1977. The $CMPu_{OP}$ values assume *restricted* plutonium production opportunity after safeguards were applied. At most, the IRT-DPRK could have produced about 1.2 kilograms of PCIM during those twelve years, assuming that it operated at 3 MW_t for nine years and at 6 MW_t for three years.

Potential Plutonium Production In The IRT-DPRK

The reactor load factor and power level modifications from 2 to 4 MW_t and then 8 MW_t of the IRT-DPRK impact the maximum possible plutonium production. Since there could have been variations in the actual load factor during the thirty-one year operating period, this study has estimated the production depending on the period of operation at a specific declared power level for various load factors. The IAEA *Directory of Nuclear Research Reactors* reports the declared maximum operating power level and the megawatt days per year utilization for five IRT research reactors similar to the IRT-DPRK, this information is summarized in Table 5. The load factors for these five IRT research reactors reflect a realistic range of possible load factors from 0.1 to 0.55.

Table 5: IAEA Reactor Name, Declared Power Level, Declared Utilization, and Resulting Load Factor for IRT Research Reactors Similar to the IRT-DPRK.

IAEA Reactor Name	Declared Power Level	Declared Utilization (MWd/yr)	Load Factor (%)
IRT-DPRK	8	640	.22
IRT-M Tbilisi	8	400	.14
IRT-5000 (Iraq)	5	480	.26
IRT-8 Moscow	8	800	.27
IRT-C Riga	5	585	.32
IRT-M Minsk	4	800	.55
Avg. w/o DPRK	6		.31
Avg. w/ DPRK	6.3		.29

Figure 1 illustrates the potential cumulative PCIM ($CMPu_D$) that could be produced in irradiated fuel assuming the IRT-DPRK operated at the declared power levels of 2 MW_t for nine years, 4 MW_t for fourteen years and then 8 MW_t for the remaining eight years, using load factors ranging from 0.1 to 0.55. The $CMPu_D$ produced for the declared power levels at a load factor of 0.22 is slightly less than 4 kilo-grams of PCIM. An *upper* bound $CMPu_D$ of 9.7 kilograms is found at the 0.55 load factor.

Figure 2 illustrates the potential cumulative PCIM ($CMPu_{OP}$) that could be produced assuming the IRT-DPRK operated at over-power levels of 3 MW_t for nine years, 6 MW_t for fourteen years and then 12 MW_t for the remaining eight years, using load factors ranging from 0.1 to 0.55. The $CMPu_{OP}$ produced at over-power levels with a load factor of 0.22 is about 5.8 kilo-grams of PCIM. An *upper* bound $CMPu_{OP}$ of 14.6 kilograms is found at the 0.55 load factor.

Figure 3 presents production scenarios over the range of load factors. The first assumes operation at the declared power level. The second assumes operation at over-power levels until safeguards were initiated in August 1977 and then operation at declared levels for the remaining nineteen years. The third assumes over-power operation for the full thirty-one years. The potential cumulative PCIM ($CMPu_M$) assumes that the IRT-DPRK operated at mixed levels (3 MW_t for nine years, 6 MW_t for three years, 4 MW_t for eleven years and then 8 MW_t for the remaining eight years). The $CMPu_M$ with a load factor of 0.22 is about 4.3 kilograms of PCIM. An *upper* bound $CMPu_M$ of 10.8 kilo-grams is found at the 0.55 load factor.

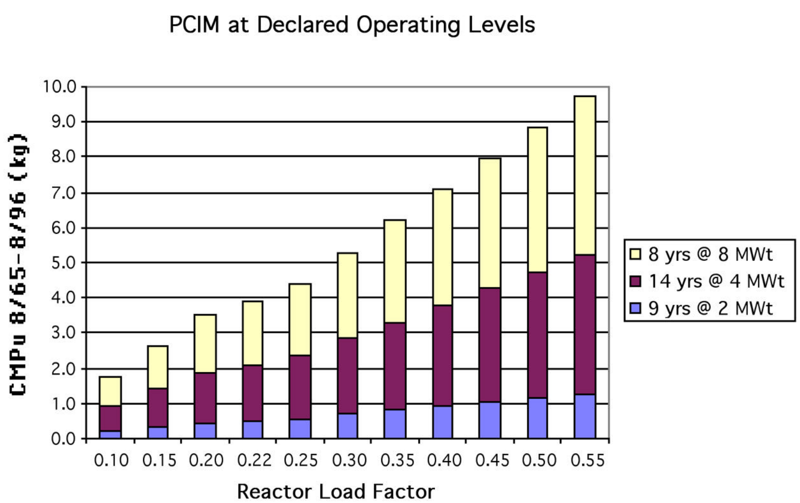

Figure 1: IRT-DPRK cumulative maximum PCIM production for declared ($CMPu_D$) power levels, assuming reactor load factors ranging from 0.1 to 0.55, including 0.22 for entire 31 years.

CONCLUSIONS

The DPRK may not have had the technical capability and desire to utilize the IRT-DPRK for plutonium production as early as 1965; indeed, the reactor may have not been utilized for such a purpose for the entire period of operation. However, the DPRK separated plutonium in 1975, had a source of fertile material, and had other required technical infrastructure. It is thus necessary

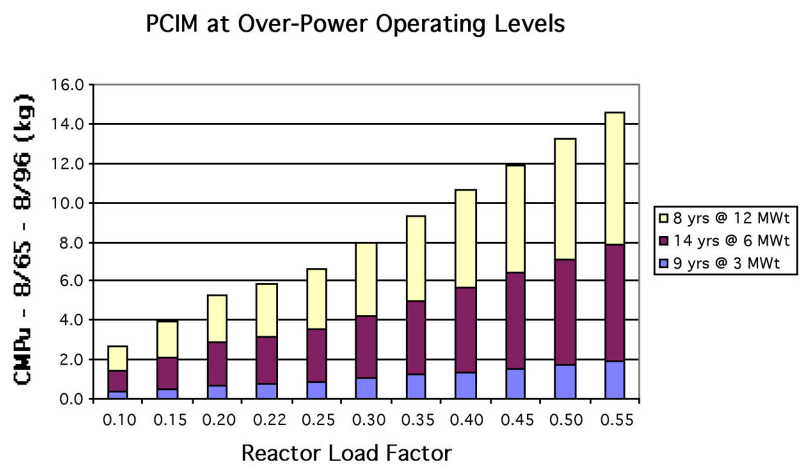

Figure 2: IRT-DPRK cumulative maximum PCIM production for over-power ($CMPu_{OP}$) levels, assuming reactor load factors ranging from 0.1 to 0.55, including 0.22 for entire 31 years.

to understand 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. Reiterating, these calculations represent estimates of the maximum PCIM produced in target material assuming that the DPRK had sufficient fuel and target material and that the potential plutonium production rate is 0.30 – 0.40 g Pu/MW_t-d.

A reasonable upper bound of cumulative PCIM production that the IRT-DPRK could have produced can be estimated by using the load factor of 0.55, assuming the declared power level had been achieved and that a load factor

CMPu - 8/65 - 8/96 (kg)

Figure 3: Production scenarios using declared, mixed, and over-power levels, assuming load factors ranging from 0.1 to 0.55 for operating period of 31 years

reached by the IRT-M Minsk was achievable by the IRT-DPRK. That was unlikely since it would have required consistent operation of the IRT-DPRK at this load factor for thirty-one years. It is possible, although unlikely, that the DPRK could have produced about 5.8 kilograms PCIM cumulatively based on the assumed periods of operation at the *over-power* levels and a load factor of 0.22. To achieve this would have required over-power operation of the IRT-DPRK for the entire thirty-one year period. More realistically about 4 kilograms of PCIM *at most* could have been produced in the IRT-DPRK reactor operating at the declared power levels and load factor.

The efficiency of operation of the IRT-DPRK has a significant impact on the quantity of plutonium produced; this was investigated by assuming various load factors. The effectiveness of the safeguards during the period that the IRT-DPRK operated also affects the quantity of plutonium that could have been produced. The IRT-DPRK was not safeguarded from 1965 to 1977 and then was placed under an INFCIRC/66 agreement. Since the IAEA safeguards criteria prior to 1996 did not stringently cover research reactors smaller than 25 MW_t, it is possible that the safeguards were insufficient from 1977 to 1996 from an over-power operation perspective. It is not clear that the IRT-DPRK was ever operated in over-power mode. However, if the IRT-DPRK was operated in over-power fashion, as much as 14.6 kilograms could have been produced.

To better quantify the total potential plutonium produced by North Korea it is necessary to combine the estimate of plutonium produced in the IRT-DPRK research reactor with that from the 5 MWe "power" reactor.

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