An Analysis of Magnox Type Gas-cooled Reactors Using Calder Hall Reactor and YongByon Reactor

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I. Introduction

According to the IAEA Director General's report on the application of safeguards in the Democratic People's Republic of Korea(DPRK), issued on 20 August 2018, changes to the cooling system for the Light Water Reactor(LWR) and 5MW(e) Experimental Nuclear Power Plant(Yongbyon reactor) were observed near the Kuryong River during the period September to November 2018. DPRK intends to re-operate the Yongbyon reactor, and this reactor is worth to be monitored consistently from the perspective of nuclear non-proliferation. The reason is that, even though it is one of the disclosed nuclear facilities to the IAEA by DPRK in 1992 and disablement activities were taken, it still can produce some amount of plutonium per year and divert it into a nuclear weapon upon re-operated.

On the other hand, effective blocking of the inflow of strategic items, which are used, using or will be used in Yongbyon reactor, into the DPRK can be conducted by understanding why the DPRK design the Yongbyon reactor based on UK's Calder Hall reactor and by comparing how the two reactors are similar and different in terms of design specifications. Also, through mutual comparison of the two reactor, it is possible to contribute to preventing DPRK's nuclear proliferation by identifying strategic items for the Yongbyon reactor and predicting the amount of plutonium produced.

II. Background of Magnox reactor development in the UK & DPRK

1. Advantageous to acquire plutonium

Unlike the LWR, the Magnox type Gas Cooled Reactor(GCR) was easier to obtain weapon-grades plutonium as fuel that could be replaced and reloaded during operation. On the other hand, since natural uranium was depleted for only short period of time and was frequently replaced after use, fuel efficiency was rather low. Also, as carbon dioxide gas is used for cooling instead of water, it was not cost effective. In this regard, the UK's Magnox design was superseded by the Advanced Gas-cooled Reactor(AGR), which is similarly cooled but includes changes to improve its economic performance. DPRK still rely on GCR to acquire plutonium because there are no other alternatives so far.

2. Usage of materials free from export control

The reason that the Magnox type GCR was built firstly in the world as a commercial scale is related to the materials which are relatively free from strategic items. Specifically, since natural uranium was used as nuclear fuel, the uranium enrichment process was not necessary, and carbon dioxide gas was used as a coolant, helium, which was mainly supplied by the United States, was not required. In addition, since graphite was used as a moderator, a heavy water manufacturing process was not needed. Also, Magnox cladding and other structural materials were easy to achieve industrially, and their physical properties were well known globally.[1] In other words, by using materials that are relatively easy to obtain, and well-known in physical properties, in the 1950s nuclear arms race era, the UK first built a GCR capable of generating electricity and plutonium with a large capacity, and DPRK was able to build GCR in the 1980s by taking advantage of unclassified information of the Magnox type reactor.

III. Result

1. Comparison of the Magnox type reactors appearance

The exterior of the Yongbyon reactor resembles Japan's Tokai-1 reactor, an improved version of the Calder Hall reactor. In the Calder Hall reactor, the reactor building and Auxiliary building which contains heat exchangers are connected in an X-shaped manner, whereas they connected in parallel in the Yongbyon reactor, like the Tokai-1 reactor.[2] The Tokai-1 reactor was improved to adjust Japan's seismic environment and was the first GCR built outside of Europe, so it would have been easy for DPRK to model GCR design when construction.

Fig. 1. Top view images of Three Magnox type reactors, Calder Hall reactor, Tokai-1 reactor, Yongbyon reactor(Left to Right).

Apart from reactor building, the presence of cooling tower is different. In case of Calder Hall reactor, four cooling towers are present, one for each reactor. The cooling tower for reactor no.1 and the cooling tower for reactor no.2 are back-up for each other, as is the case for reactor no.3 and no.4. Meanwhile, there was only one cooling tower in the Yongbyon reactor without a backup cooling tower and this was blown up in June 2008, according to the Six-Party Talks meeting. After that, cooling tower was not rebuilt, instead, direct water intake and drainage method was used for years and additional substitutional cooling system was built in July 2018.[3]

Table I. Overview of Calder Hall and Yongbyon reactors

	First grid connection	Shut down	No. of reactor units	No. of cooling tower
Calder Hall reactor	1956	2003	4	4
Yongbyon reactor	1986	N/A	1	1→0

2. Comparison of Two Magnox reactor specifications

Since the thermal power of the Calder Hall reactor is 7.3 times that of the Yongbyon reactor, but the amount of nuclear fuel used is only 2.4 times, the fact that DPRK operates with low uranium depletion to obtain high-purity plutonium rather than the purpose of electricity generation. It can be estimated that operation efficiency of Yongbyon reactor is quite low.

Table II. Summary of design data for Calder Hall and Yongbyon reactors[4][5]

	Calder Hall reactor	Yongbyon reactor
Station Design		
Reactor type	MAGNOX Gas Cooled	MAGNOX Gas Cooled
Thermal output (gross), MW	182	25
Electrical output (gross), MW	46	5
Efficiency, %	23	20
Reactor Core		
Active core length	9.45m(D), 6.4m(H)	0.6m(D), 0.8m(H)
Mass of uranium	120 ton-U	50 ton-U
Dimension of fuel rods	2.9cm(D),101.6cm(L), 11.8kg	3cm(D),52cm(L), 6.2kg
Number of fuel rods	10,176	8,010
Number of fuel channels	1696	801
Uranium enrichment	Natural Uranium	Natural Uranium
Uranium fuel type	Metal Fuel (Magnox Cladding)	Metal Fuel (Magnox Cladding)
Mass of Moderator	1150 ton	600 ton
Operation		
U Depletion	400-600 MWD/MTU[6]	600 MWD/tHM (200-300 MWD/tHM in real)
Pu production	*30~42 kg-Pu/yr	*5~7 kg-Pu/yr

*Estimates of GCR's annual plutonium production assume that 1g plutonium is produced per 1 MWth-day

*$Pu_{yearly\ total} = P_{thermal\ power} \times CF_{(Capacity\ Factor)} \times 365\ days \times PF_{(Plutonium\ conversion\ factor)}$

IV. Conclusion

Magnox type GCRs were built in the nuclear arms race era because they are advantageous in producing high-purity plutonium since GCR can replace nuclear fuel during operation and are used materials that are relatively easy to obtain, and well-known in physical properties. However, due to their high nuclear proliferation and low operation efficiency, they have been no longer built and replaced by next generation reactors such as AGR. Since the Yongbyon reactor is a Magnox type GCR, the operating principle is the same, but the electrical power is different, so there is a difference in the amount of nuclear fuel to be loaded and so is the moderator.

The Yongbyon reactor, which refer to the Calder Hall reactor, is still being improved and is preparing for reoperation. It is necessary to obtain proved information and verify it beyond the estimated strategic items. From the perspective of export control, the number of Yongbyon reactor's controlled item is similar to Calder Hall's but smaller and simpler than the LWR's, but unlike the typical magnox reactor, the localized design changes by DPRK requires additional further research through comparison with another magnox reactor such as Tokai-1 reactor.

Reference

[1] 차종희, 흑연감속 탄산가스냉각형 원자로(GCR), 2000.
[2] Joshua Pollack, Why does north korea have a gas-graphite reactor?, 2009.
[3] 38 North, "North Korea finished work on secondary cooling system at nuclear research center", 2018.
[4] S.E.Jensen and E. Nonbol, Description of the Magnox Type of Gas Cooled Reator(MAGNOX), 1999.
[5] David Albright and Kevin O'Neill, Solving the North Korean Nuclear Puzzle, 2000.
[6] World Nuclear Assciation (https://www.world-nuclear.org/)

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