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

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1. 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 reactors, 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

2. Background of Magnox reactor development in the UK and DPRK

2-1. Advantageous to acquire plutonium

Unlike the light water reactor, the Magnox type GCR was easier to obtain weapon grade plutonium as fuel 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 quite low. Also, as carbon dioxide gas is used for cooling instead of water, it was not economical. In this regard, the UK's Magnox design was superseded by the Advanced Gas-cooled Reactor(AGR), which is similarly cooled but includes changes to improve its economic performance.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.

2-2. Usage of materials free from export control restriction

The reason that the Magnox type GCR was built firstly in the world as a commercial scale is related to the materials which are free from strategic items. Specifically, since natural uranium was used as nuclear fuel, the uranium enrichment process was not necessary, and because 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.[1] In other words, by using materials that are relatively safe, 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.

3. Result

3.1. 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 the heat exchanger are connected in an X-shaped manner, whereas the Yongbyon reactor is connected in parallel, 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 refer to GCR when construction.

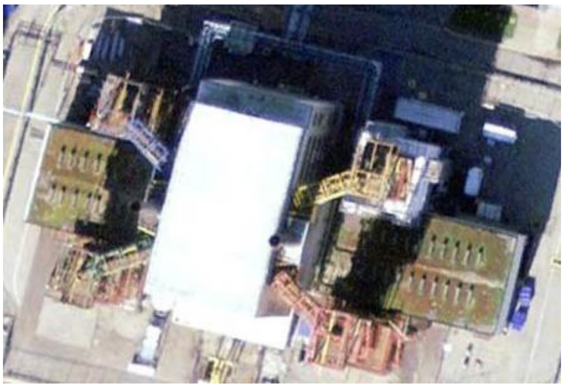

Fig. 1. Top view images of Three Magnox type reactors, Calder Hall(Top), Tokai-1(Bottom Left), Yongbyon(Bottom Right)

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 following 10.3 Agreement. After that, cooling tower was not rebuilt, instead, direct water intake and drainage method was used for years and additional secondary cooling system was built in July 2018.[3]

3.2 Comparison of Two Magnox reactor design 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 depletion to obtain high-purity plutonium rather than the purpose of power generation. It can be estimated that operation efficiency of Yongbyon reactor is quite low.

Table 1. Summary of design data for Calder Hall and Yongbyon reactors[4][5][6]

	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
Number of Gas circulators	4	4
Number of Steam generators	4	4
Number of generators	2	2
Reactor Core		
Active core length	9.45m(D), 6.4m(H)	0.6m(D), 0.8m(H)
Mass of uranium in tonnes	120 ton-U	50 ton-U
Length of fuel rod	2.9cm(D),101.6cm(L), 11.8kg	3cm(D),52cm(L), 6.2kg
Number of fuel rod	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
Reactor Pressure Vessel		
Material	Lowtem A-kill mild Steel	Steel
Length of Reactor pressure vessel	11.28m(D), 21.3m(H)	0.8m(D), 1.7m(H)
Operation		
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 1 g of Pu is produced per 1 MWt-day

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

4. 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.

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