Reassessing radioactive waste inventories at North Korean nuclear facilities: updated estimates and sensitivity bounds

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1. Introduction

Whang and Baldwin [1] estimated waste volumes from the 5 MWe graphite reactor and the Radiochemical Laboratory (RCL) at Yongbyon, assuming two reprocessing campaigns totaling 100 tU. Their figures (500,000 L of HLW, 300,000 L of chemical decladding waste, and 600 t of irradiated graphite) have been cited for two decades without revision. Chesser and Witspitz [2] later assessed dismantlement timelines and costs. Both studies predate the reprocessing episodes reported after 2009 and the accumulation of milling waste at Pyongsan. This paper updates the 2005 baseline using information available through mid-2025 and evaluates whether a substantially increased waste-management burden remains robust under uncertainty. The resulting quantities constitute an uncertainty-bounded planning envelope rather than measured inventories.

2. Waste inventory re-estimation

The subsections below detail each component of the revised inventory, the assumptions involved, and a parametric sensitivity test of the principal unit factors.

2.1 Reprocessing waste

Open-source reporting identifies multiple episodes of RCL operation between 1989 and 2025 [3,4]. This study does not equate every reported episode with one complete core discharge. The inventory calculation uses an estimated cumulative throughput of 300–350 tU, corresponding to approximately six to seven 50-tU full-core equivalents. Applying unit factors from Whang and Baldwin [1], approximately 5,000 L/tU for HLW (Wick [5]) and 3,000 L/tU for decladding waste (Wolff [6]), gives the estimates in Table I. Because the 1992 IAEA inspection found the RCL denitration unit incomplete [4], no liquid volume reduction is assumed.

2.2 Sensitivity of unit factors

The 5,000 L/tU and 3,000 L/tU factors originate from Eurochemic PUREX experience in the 1960s–70s. North Korea's actual process is not known. Table I includes a ±50% parametric sensitivity band. This is not a statistical confidence interval but a test of whether the several-fold increase over 2005 depends on the unit factors. At 2,500 L/tU (HLW lower bound), volume falls to 750–875 m³; at 7,500 L/tU, it rises to 2,250–2,625 m³. The approximately threefold increase holds across this range.

2.3 Pyongsan milling tailings

No prior study quantified the milling waste at Pyongsan. Hecker and Braun [7] estimate annual ore throughput at roughly 360,000 t. At approximately 1,000 ppm ore grade, this ore contains about 360 t of uranium. The bulk of the ore mass becomes tailings. Under central assumptions of 360,000 t/yr and 20 years of operation, cumulative tailings reach approximately 7 Mt (scenario estimate, not a measured inventory). At half throughput the total is 3.5 Mt; at 25 years of operation, approximately 9 Mt. The tailings contain Ra-226 (t½ 1,600 yr), Rn-222, Pb-210, and Po-210. Satellite imagery shows them piped into an open settling pond [8]. A ROK government survey (July 2025) found no above-limit radioactivity in adjacent waters [9]'.

2.4 Decommissioning solid waste and analytical gaps

Whang and Baldwin [1] estimated the 5 MWe reactor would produce about 300 t of activated steel, 600 t of graphite (C-14, Cl-36), and several thousand tons of concrete; the RCL would yield 500–1,000 t of steel and 16,000–24,000 t of concrete. Post-2005 facilities [8] would add to these totals. The radioactivity inventory (Ci), decay heat (W per container), and chemical composition of liquid waste are not estimated in this or any prior work. These parameters determine vitrification plant throughput, canister count, and storage duration. Identifying these gaps is itself a contribution of this study.

Table I: Updated cumulative waste estimates at Yongbyon, 2025

Category	W&B [1]	This study	±50% range
Full-core equiv.	2	6–7	—
Throughput (tU)	100	300–350	—
HLW (m³)	500	1,500–1,750	750–2,625
Decladding (m³)	300	900–1,050	450–1,575
Graphite (t)	600	600	—
Pyongsan (Mt)	—	~7	3.5–9

±50% range: parametric sensitivity test, not a statistical confidence interval. Pyongsan range: scenario envelope based on throughput and operating-period variations.

2.5 Waste management and verification

The revised HLW volume would make direct overseas shipment substantially more demanding than assumed in 2005. Vitrification remains plausible, though canister count depends on waste composition data that do not yet exist. For Pyongsan tailings, a phased approach (hydraulic containment, dewatering, capping, groundwater monitoring) is consistent with IAEA-TECDOC-1403. Isotopic analysis of HLW samples could potentially reconstruct reactor operating histories through nuclear archaeology [10], providing a cross-check on any future fissile material declaration. This dual use of waste characterization warrants further investigation.

3. Conclusions

This paper updates the Whang–Baldwin (2005) baseline using 300–350 tU cumulative throughput (six to seven full-core equivalents). Central HLW estimate: 1,500–1,750 m³; decladding waste: 900–1,050 m³ (approximately three times the 2005 figures). A ±50% parametric sensitivity test confirms the several-fold increase is robust. Pyongsan tailings: approximately 7 Mt (scenario envelope: 3.5–9 Mt). Remaining gaps: radioactivity, decay heat, and chemical characteristics are unknown; the tailings estimate relies on a limited source base. These estimates define a planning envelope, not a measured or statistically bounded inventory, for the waste-management workload that any denuclearization scenario would face.

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