AUGUST 2026

Nuclear Safety Under Strain:

Ageing Infrastructure, Governance and Environmental Risk in North Korea

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ACKNOWLEDGEMENTS

The authors would like to thank Marcy R. Fowler and Andreas Persbo for their roles in project conception and counsel, Man-Sung Yim and Tatsujiro Suzuki for their roles as project advisors, and the additional current and former ONN staff members who supported this work, including Yudian Tao.

We are particularly grateful to experts we consulted, including Jargal Chimedbazaryn, M.N. Fisher, Jungmin Kang, Mark Pellechi and Man-Sung Yim, other participants in a March 2026 expert workshop, and others who prefer to remain unnamed, for generously sharing their expertise and for the discussions, challenges and insights that informed and strengthened this report. We are also grateful to the IAEA Archives for its assistance in identifying and facilitating access to archive materials used in this research. The authors are also grateful to Wendy Lu Maxwell-Barton and Emily Ambash for their assistance with the layout and design.

Participation in the workshop, consultation, or provision of research assistance does not imply endorsement of the analysis or conclusions presented in this report. Any errors or omissions are solely the authors' responsibility.

The authors gratefully acknowledge funding support by the Korea Foundation (KF). KF grant support was provided for the project Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Program. The authors gratefully acknowledge the support of PAX *sapiens*, including their assistance with layout and design of this report.

Executive Summary

Nuclear facilities in the Democratic People's Republic of Korea (DPRK) have operated and expanded for years with almost no independent access. The resulting knowledge gaps are substantial.

Current inventories, equipment condition, maintenance practice and emergency arrangements are poorly documented outside the country. Open-source evidence can nevertheless identify where hazardous material is generated or stored, how it could be released, and which environmental pathways deserve closer attention.

This report examines uranium mining and milling, conversion and enrichment, reactor operations, reprocessing, spent fuel and radioactive waste. It draws on satellite imagery, DPRK legislation, International Atomic Energy Agency (IAEA) and Korean Peninsula Energy Development Organization (KEDO) records, technical literature, former inspectors and other specialists, including participants in an expert workshop convened by the Open Nuclear Network in March 2026. While the available material is sufficient to identify credible vulnerabilities, it is generally insufficient for accident-frequency estimates, site-specific source terms or reliable forecasts of geographic consequences.

The likeliest scenarios arise from problems that can develop gradually and remain close to the facilities where they originate. Pyongsan continuously produces large volumes of uranium-mill tailings and process water. Open-source analysis has identified spillage around the tailings-transfer system and wastewater drainage from the site. These observations establish plausible routes into nearby soil and surface water, although they do not establish contaminant concentrations or resulting exposure. Workers face additional risks from radon, uranium-bearing dust and the chemicals used in ore processing. A large tailings failure would carry greater consequences, but there is no evidence in the material reviewed for this study that such a breach has occurred.

At Yongbyon, long-term management of spent fuel and radioactive waste presents a different problem. Magnox fuel from the 5 MWe reactor is susceptible to corrosion during wet storage. Historical experience at the site shows that poor pond-water chemistry can cause serious degradation and generate contaminated water and sludge. The condition of fuel from later operating cycles is not known. Reprocessing has also left liquid and solid radioactive wastes whose inventories, chemistry and present storage conditions cannot be established from open sources. Ageing tanks, transfer systems and legacy waste stores create credible routes for localised contamination if containment deteriorates or material is disturbed during retrieval and handling. Fires, explosions and other major releases remain technically possible, though the DPRK-specific evidence for such sequences is limited.

Conversion and uranium enrichment bring significant chemical hazards. A loss of uranium-hexafluoride confinement can generate hydrogen fluoride and uranium-bearing compounds when the material contacts moisture in air. The immediate danger would fall most heavily on workers and others nearby. Deposited uranium could create a longer-lived contamination problem. Yongbyon combines conversion with enrichment and has recently refurbished older conversion infrastructure while expanding enrichment capacity. Kangson is assessed as an enrichment facility, but no conversion line has been established there.

Reactor safety is harder to judge from the present open record. The 5 MWe reactor has operated since the 1980s, while much less is known about the design and safety arrangements of the newer Experimental Light Water Reactor. Both depend on water-control infrastructure associated with the Kuryong River. Flooding, ice and subsequent repair have repeatedly affected the reservoir dam and related infrastructure. These events demonstrate an exposed supporting system; they do not establish that reactor cooling has been lost as a result. A more complete assessment depends on information about system condition, redundancy, electrical supply and emergency cooling that is not available externally.

Historical evidence from Yongbyon does not support assumptions of technical incompetence. DPRK personnel used written procedures, kept operating records and made technically conservative adjustments in a number of documented cases. They also worked effectively with foreign specialists during periods of international engagement. The record is less reassuring on whether these practices became embedded across the programme. Regulatory independence has long been uncertain, some important corrective measures followed significant deterioration, and much of the practical training planned under KEDO ended before it could be completed. Regular international technical contact has been absent since 2010, limiting external review and exchange of operating experience.

Environmental consequences would depend heavily on the release mechanism. Slow leakage from spent fuel or waste systems would be expected to appear first in buildings, nearby soil, drainage or groundwater. Material entering a connected river could move downstream, with some contaminants accumulating in sediment. Atmospheric releases could travel farther. The distance at which a radionuclide can be detected is not an indicator of the distance at which harmful exposure has occurred. For the same reason, monitoring farther downstream or across the border cannot by itself exclude contamination close to a DPRK facility.

Climate change leading to more severe weather adds pressure to systems already important for safe operation. Yongbyon's cooling-water infrastructure has experienced repeated flooding and dam damage. Storms and high water have damaged infrastructure around Pyongsan. Future changes in rainfall, flooding, drought and temperature could make repair, drainage and cooling more difficult during an unrelated equipment problem.

The immediate policy tasks do not depend on renewed access to the DPRK. Historical knowledge from former inspectors, KEDO personnel and other specialists can still be preserved. Satellite and environmental monitoring can be maintained on a consistent basis and reported with clearer limits on what the measurements show. Technical organisations can retain the expertise needed to assess an incident or support future cooperation. Nuclear safety may also provide a practical subject for engagement if political conditions change. Authorities, particularly in the Republic of Korea, should communicate nuclear-safety and environmental risks in technically grounded terms, making clear what monitoring results do and do not establish. Credible concerns should be taken seriously without treating isolated detections, infrastructure damage or unverified reports as evidence of a cross-border radiological threat.

Preserving that knowledge and technical capacity now will determine how useful the next period of access can be.

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CHAPTER 1

Introduction: Why Nuclear Safety in the DPRK Matters

The Democratic People's Republic of Korea's (DPRK) nuclear programme is most often examined through the lens of nuclear weapons production and proliferation risks. The safety of the facilities and activities that sustain the nuclear fuel cycle (NFC) has received less systematic attention.

Existing research frequently addresses individual sites or potential transboundary emergencies, while giving comparatively limited consideration to environmental pathways, and the interaction between technical vulnerabilities, governance and external stressors.

This report examines nuclear safety and environmental risks across the DPRK's nuclear programme. It considers uranium mining and milling, conversion and enrichment, reactor operations, reprocessing, spent fuel and radioactive waste. These activities involve different combinations of radiological, chemical, industrial and conventional hazards. Their consequences may arise through acute accidents, but also through chronic leakage, gradual degradation or repeated smaller releases that accumulate over time.

The project seeks to provide a structured assessment of plausible failure modes, environmental pathways and systemic vulnerabilities under conditions of limited technical information. The analysis was developed through multilingual open-source research, technical and environmental assessment, imagery analysis, interviews and expert elicitation, including an expert workshop held in Vienna in March 2026. The methodology, scope and limits of the evidence are set out in the following chapter.

The issue remains difficult to assess. There has been no regular external access to the DPRK's nuclear facilities for more than a decade and a half, and public information on current designs, inventories, safety systems, operating practices and emergency arrangements is incomplete. Some risks can be identified from observable infrastructure, historical reporting, imagery, legal texts and comparison with analogous facilities, but the probability and scale of specific events often cannot be estimated reliably.

The report moves from a focused inventory of sites and activities to the governance conditions that shape safety performance. It then assesses front-end processes; reactor operations; reprocessing, spent fuel and waste; environmental pathways and receptors; and climate and other external stressors. The report concludes by drawing out policy-relevant implications for the Republic of Korea (ROK), technical experts, international organisations and non-governmental actors and identifying areas for further research.

CHAPTER 2

Methodology, Scope and Limits of Evidence

This assessment applies an interdisciplinary open-source approach to identify plausible nuclear safety vulnerabilities, failure modes and environmental release pathways across the DPRK's nuclear programme.

Because detailed design, operational and monitoring data are rarely available, it does not attempt to reproduce a facility-level probabilistic safety assessment or assign precise accident frequencies or dose consequences. Instead, it combines several forms of evidence and distinguishes between what is observed, historically reported, technically inferred and explored as a plausible scenario.

2.1. Analytical Approach

The report is organised around functional stages of the nuclear fuel cycle, anchored in the principal known or suspected sites. For each activity, it considers the material at risk, credible technical or organisational failure modes, the possible release mechanism, environmental pathways, affected receptors and factors that may increase or reduce consequences.

The analysis is pathway-based. It traces how a problem at a facility or activity could generate a source term and move through air, surface water, groundwater, soil or food systems to workers, local communities, ecosystems and other receptors. Governance, safety culture, maintenance capacity, emergency preparedness and climate-related hazards are treated as cross-cutting conditions that may interrupt or amplify this sequence. The presence of radioactive material, ageing equipment or hazard exposure is not itself treated as evidence that an accident or release will occur.

2.2. Evidence Base and Methods

The research draws on a structured review of publicly available sources in English, Korean, Chinese and Russian. These include DPRK legal and official texts; archival records from the International Atomic Energy Agency (IAEA); reporting by international organisations, governments and the Korean Peninsula Energy Development Organization (KEDO); scientific and technical literature; historical travel and inspection-related records; and specialist open-source analysis. Sources were compared across languages and publication types to identify corroboration, disagreement and continuing uncertainty. Historical observations are used to establish conditions or practices at a particular time, not as evidence of current performance unless supported by more recent information.

Commercial satellite imagery and available ground-level imagery are used to examine facility layouts, construction and expansion, water-control and supporting infrastructure, visible waste-management areas, and evidence of damage, repair or renewed activity. Imagery cannot normally reveal internal equipment condition, material inventories, operating procedures or the performance of safety systems under abnormal conditions. It is therefore interpreted alongside technical and contextual reporting.

Technical analogues are used to identify credible failure mechanisms where DPRK-specific information is incomplete. Comparisons draw on related reactor and fuel-cycle technologies, waste-management experience, and documented external-hazard events. Environmental pathway mapping and climate-hazard screening then connect potential releases to transport routes and receptors.

Preliminary findings were reviewed through an expert workshop held in Vienna on 17–18 March 2026 and through interviews with former inspectors and other subject-matter experts. These inputs were used to test assumptions, identify blind spots, clarify historical practices and distinguish more credible pathways from speculative concerns. Workshop and interview evidence is treated as contextual or first-hand evidence according to its source and degree of corroboration, rather than as a substitute for documentary or technical evidence.

2.3. Scope, Uncertainty and Limits

The report assesses accidental releases, chronic contamination, equipment or containment degradation, and other risks associated with the operation, maintenance, ageing and expansion of the DPRK's nuclear programme. Nuclear security, deliberate attack, command and control, nuclear weapon use and the nuclear weapons programme beyond production of fissile material are outside scope.

The environmental assessment starts with the hazardous materials and release mechanisms identified in the technical assessments. It then considers how released material could move or persist, which human or ecological receptors could be exposed and the potential geographic extent. Transboundary consequences are considered where a technically plausible pathway exists but impacts within the DPRK are not treated as less significant.

The principal limitation is the absence of regular, independent access to DPRK nuclear facilities. Information on internal system condition, material inventories, maintenance, backup systems, waste composition, environmental monitoring and emergency arrangements remains incomplete and uneven across sites. Analogues and inference can identify plausible mechanisms and relative areas of concern, but they cannot provide definitive site-specific source terms, accident frequencies or consequence estimates. Less public information about a facility or activity should not be interpreted as evidence of lower risk.

CHAPTER 3

DPRK Nuclear Sites and Activities: A Focused Inventory

This chapter provides a concise inventory of the principal sites and activities examined in the report. Its purpose is to define the physical and functional scope of the subsequent assessment of nuclear safety and environmental risks.

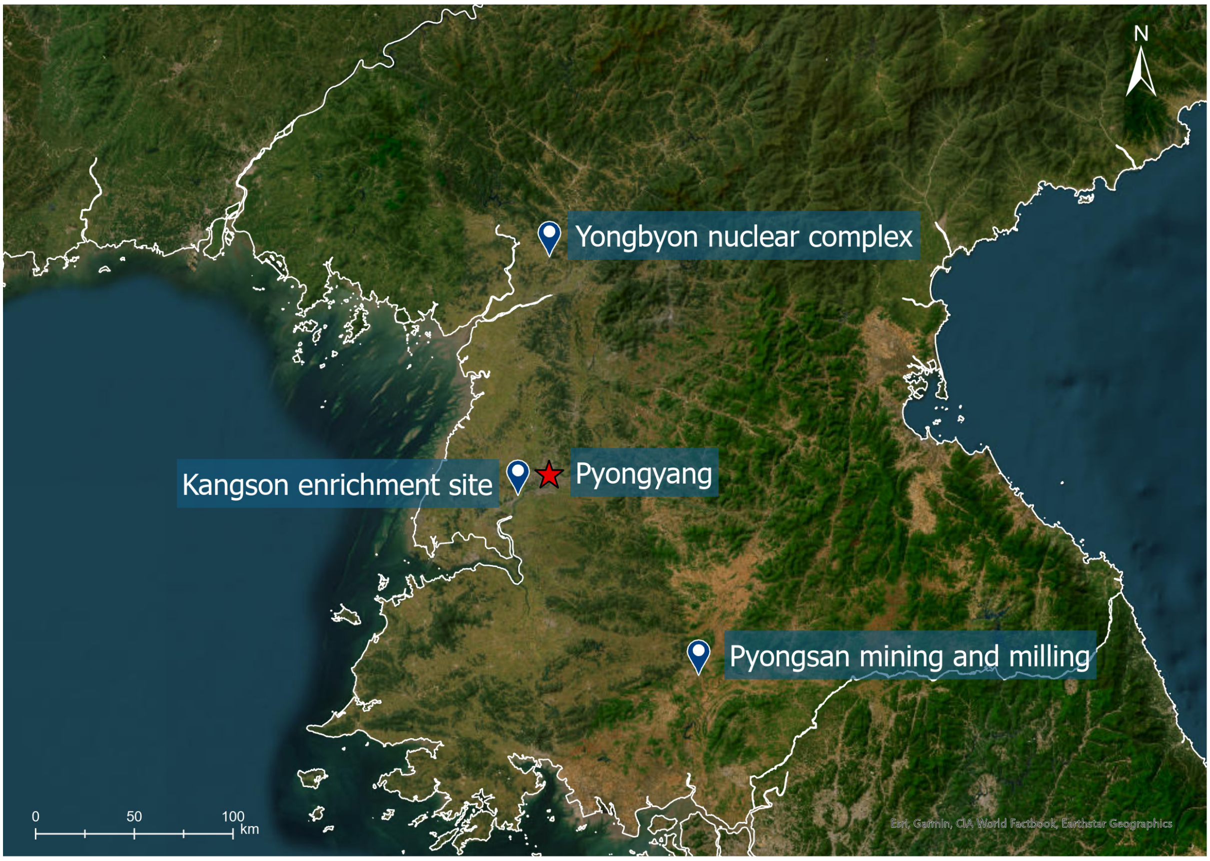

Figure 1: DPRK nuclear sites overview. Image: Esri, Vantor, Earthstar Geographics, and the GIS User Community

3.1. Pyongsan Uranium Mining and Milling Complex

The Pyongsan complex in North Hwanghae Province (38.318 N, 126.434 E) is the DPRK's only confirmed active uranium mining and milling complex. It includes five visible mines, which supply ore to the crushing and grinding mill. The processed ore slurry is transported by pipeline to the Uranium Ore Concentration Plant, where it is processed into uranium concentrate (U3O8, or "yellowcake") for subsequent use within the DPRK's NFC, including at the Yongbyon complex, where it can undergo further conversion and fuel fabrication for use in reactors or as feedstock for uranium enrichment.

Waste tailings generated during the process are transported via pipeline to an artificial tailings pond located south of the Concentration Plant, across the Namchon River. Although the tailings pond appears physically separated from the Namchon River, excess wastewater is discharged through a small outflow on its western side into the Ryesong River.

3.2. Yongbyon Nuclear Complex

The Yongbyon Nuclear Research Centre (39.796 N, 125.755 E) constitutes the core of the DPRK's fissile material production infrastructure and remains central to its NFC and nuclear weapons programme. It contains facilities associated with reactor operations, uranium conversion and enrichment, fuel fabrication, reprocessing, spent-fuel management and radioactive-waste storage.

Figure 2: Yongbyon nuclear complex. 1 – IRT research reactor; 2 – 5 MWe reactor and the ELWR; 3 – unfinished 50 MWe reactor; 4 – New Enrichment Facility; 5 – Radiochemical Laboratory; 6 – Radiochemical Laboratory thermal power plant; 7 – Uranium Fuel Fabrication Plant. 39.796 N, 125.755 E. 27 June 2026. Image: © 2026 Planet

3.2.1. Reactor facilities

The principal reactor facilities are:

- the 5 MWe graphite-moderated, gas-cooled reactor (39.797 N, 125.754 E);
- the Experimental Light Water Reactor (ELWR) (39.795 N, 125.755 E); and
- the IRT research reactor (39.807 N, 125.751 E).

The 5 MWe reactor has operated since the 1980s and is considered to be intended for plutonium production. The ELWR is a newer and larger reactor[1] whose detailed design and safety arrangements are not publicly known.[2] Indications of initial operations and commissioning have been observed since 2023.[3] The IRT research reactor, supplied by the Soviet Union in the 1960s, appears to be inactive.

The 5 MWe and the ELWR are located close to the Kuryong River and draw cooling water through infrastructure associated with a common reservoir and overflow dam. Each reactor has separate pump-house arrangements, while the reservoir, channels and intake structures form part of the wider cooling-water system.

The never-completed 50 MWe reactor is also situated at Yongbyon. The reactor complex is being gradually demolished, with demolition efforts intensifying in 2025 based on satellite imagery analysis.[4]

3.2.2. Fuel fabrication, conversion and enrichment

Yongbyon houses a Uranium Fuel Fabrication Plant (39.769 N, 125.750 E), where uranium conversion, enrichment and fuel fabrication activities take place.

An additional building south-west of the 50 MWe reactor building, externally completed by May 2025, has been assessed as a possible uranium-enrichment facility (Building-J; 39.785 N, 125.759 E).

1 The newer reactor at Yongbyon is generally identified as ELWR based on information provided by DPRK officials during a 2010 site visit, when a Stanford delegation was shown the reactor under construction and told that it was a 25–30 MWe ELWR. Siegfried S. Hecker, 'North Korea's Yongbyon Nuclear Complex: A Report by Siegfried S. Hecker', CISAC, Policy Briefs, 20 November 2010, https://cisac.fsi.stanford.edu/publications/north_koreas_yongbyon_nuclear_complex_a_report_by_siegfried_s_hecker.

2 IAEA, Application of Safeguards in the Democratic People's Republic of Korea, GOV/2025/51-GC(69)/13 (IAEA, 2025), https://www.iaea.org/sites/default/files/gc/gc69-13.pdf.

3 Cecilia Gustavsson et al., 'Modeling Plutonium Production in the Experimental Light Water Reactor of North Korea', Science & Global Security 33, nos 1–3 (2025): 68–88, https://doi.org/10.1080/08929882.2025.2583613.

4 Peter Makowsky, Jack Liu, and Iliana Ragnone, Yongbyon Nuclear Scientific Research Center: A Suspected New Enrichment Facility and Dismantlement of 50 MWe Reactor, 38 North, 13 June 2025, https://www.38north.org/2025/06/yongbyon-nuclear-research-center-a-suspected-new-enrichment-facility-dismantlement-50mwe-reactor/.

3.2.3. Reprocessing

The Radiochemical Laboratory (39.780 N, 125.752 E) is used to reprocess irradiated fuel from the 5 MWe reactor and recover plutonium. Associated activities include the receipt, handling, and reprocessing of irradiated fuel, as well as handling and storage of radioactive waste generated during reprocessing.[5]

3.2.4. Radioactive-waste facilities

Yongbyon contains several known or reported radioactive-waste areas:

- waste storage buildings (Building 500; 39.780 N, 125.756 E) connected to the Radiochemical Laboratory;
- a buried waste site declared to the IAEA (39.780 N, 125.756 E); and
- an undeclared, currently semi-buried waste site (39.787 N, 125.756 E).

Historical observations also identify several Radiochemical Laboratory buildings associated with the storage and treatment of different categories of liquid radioactive waste, including low- and intermediate-level waste storage, high-level waste storage, concentrated high-level waste storage and waste-treatment facilities.[6]

3.3. Kangson Suspected Enrichment Facility

Kangson (38.957 N, 125.612 E) is assessed in open-source analysis as a suspected uranium-enrichment facility and is located near the town of Chollima in South Pyongan Province, close to the Taedong River. No uranium-conversion line is known to be present at this facility.

5 There is no publicly available information on whether any ELWR fuel has yet been discharged or reprocessed, or confirmation on where such reprocessing would take place.

6 Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

CHAPTER 4

Governance, Safety Culture and Institutional Capacity

Nuclear safety and the potential environmental consequences of a nuclear incident depend not only on facility design, waste-storage integrity and equipment condition, but also on the quality of governance.

Relevant factors include the adequacy of the legal and regulatory framework, the implementation of technical requirements, organisational safety culture, access to international operating experience and peer learning and the capacity to prepare for and respond to emergencies.

Governance weaknesses can increase both the likelihood that a technical problem remains unaddressed and the consequences if an incident occurs. Limited regulatory authority or inadequate response arrangements may impede the detection of abnormal conditions, constrain independent risk assessment or prevent concerns from being reported and corrected without political interference. Following a release, delays in notification, containment, protective action and remediation could prolong exposure and allow contamination to spread through air, water, soil and agricultural systems, even where the initial event is technically limited.

Available evidence suggests that the DPRK has developed a relatively extensive formal framework for nuclear safety and possesses personnel with meaningful scientific, engineering and operational expertise. The principal uncertainty is whether these elements function together as a coherent, consistently applied and independently supervised safety system. Across the historical record, formal safety provisions reportedly coexist with indications of uneven implementation, uncertain regulatory independence, political influence over some technical decisions and periodic reliance on external assistance. Prolonged gaps in international inspections and technical exchange, combined with limited transparency, leave substantial uncertainty regarding current implementation and safety culture.

For analytical purposes, this chapter therefore attempts to distinguish between two categories of evidence: formal alignment with international nuclear-safety frameworks and the reported implementation of the corresponding practices. This distinction is important because the existence of laws, regulatory bodies and technical procedures indicates recognition of the principal components of a nuclear-safety system but does not in itself demonstrate their consistent application or effective enforcement.

4.1. Institutional Architecture and Control of the Nuclear Programme

The DPRK has historically maintained a formal distinction between the administration of its nuclear programme and the regulation of nuclear safety. A historical organisational chart reproduced in a 2001 KEDO-era legal compilation places the General Bureau of Atomic Energy (GBAE) and the State Nuclear Safety Regulatory Commission (SNSRC) as separate bodies within the executive structure.[7] It further states that the SNSRC was established in November 1994 and supported by specialised units responsible for nuclear-facility safety, radiation protection, nuclear-material control and regulatory affairs. The SNSRC has reportedly issued licences and permits, conducted inspections, participated in regulatory training and exercised oversight over reactor construction.

The 2021 Atomic Energy Law[8] continues to assign extensive responsibilities to a state nuclear-safety regulatory body but does not identify the body by name or clarify its present institutional position. It indicates continuity of the regulatory function but does not establish that the historical SNSRC continues to operate in the same organisational form.

The GBAE, by contrast, has reportedly administered major parts of the DPRK's nuclear programme from 1994 onwards. The UN Security Council 1718 Committee's narrative summary for the GBAE has described it as the principal government agency overseeing nuclear activities, including the operation of the Yongbyon Nuclear Research Centre, the 5 MWe reactor and associated fuel-fabrication and reprocessing facilities.[9] It also served as a principal counterpart in nuclear-related discussions with the IAEA and reportedly supported the visits of US experts to the Yongbyon complex in 2010.[10] This broad administrative and operational role is formally distinct from the licensing, inspection and enforcement functions attributed to the SNSRC.

More recent open-source institutional mapping presents the wider nuclear programme as involving the GBAE, the Ministry of Atomic Energy Industry (MAEI) and the Munitions Industry Department (MID).[11] The MAEI was reportedly established in 2013 to modernise the nuclear industry, expand the production of nuclear materials and improve the quality of nuclear-related products. A 2024 amendment to the UN sanctions list states that GBAE changed its name to MAEI in 2013, although other reporting does not conclusively establish whether subsequent references to both bodies indicate separate organisations operating concurrently or continued use of the

7 북한 원자력체제 및 법률 [North Korea's Nuclear System and Law] (경수로사업지원기획단 [Light Water Reactor Project Support Planning Team], 2001), Information Center on North Korea.

8 조선민주주의인민공화국원자력법 [Atomic Energy Law of the Democratic People's Republic of Korea], Pub. L. No. 15, 509 (2021), https://www.unilaw.go.kr/bbs/selectBoardArticle.do?bbsId=BBSMSTR_000000000021&nttId=176.

9 United Nations Security Council Committee established pursuant to resolution 1718 (2006), 'General Bureau of Atomic Energy (GBAE)', United Nations Security Council, 29 October 2014, https://main.un.org/securitycouncil/en/sanctions/1718/materials/summaries/entity/general-bureau-of-atomic-energy-%28gbae%29?

10 Siegfried Hecker, A Return Trip to North Korea's Yongbyon Nuclear Complex (Center for International Security and Cooperation, Stanford University, 2010), https://fsi9-prod.s3.us-west-1.amazonaws.com/s3fs-public/HeckerYongbyon.pdf.

11 Adriana Nazarko, 'Know Who's at the Negotiating Table: A Guide to the Ministries and Main Figures in North Korea's Nuclear Program', The Nuclear Threat Initiative, 26 August 2020, https://www.nti.org/risky-business/know-whos-at-the-negotiating-table-a-guide-to-the-ministries-and-main-figures-in-north-koreas-nuclear-program/.

former name.[12] The MID's reported subordinate institutions include bodies associated with the research, development and production of advanced weapons systems, and according to UNSC sanction list also the Nuclear Weapons Institute,[13] connecting the DPRK's nuclear programme to the wider defence-industrial system.

These bodies appear to perform distinguishable technical-administrative, industrial and weapons-related functions. However, their precise division of responsibilities and decision-making relationships remain unclear. Movement of senior personnel between nuclear-technical and defence-industrial roles has been observed, a notable example being Hong Seung Mu, a former chief engineer at Yongbyon who later became a vice minister in the Munitions Industry Department and a full member of the Workers' Party Central Committee.[14] These institutional boundaries are further complicated by the dual-use nature of much of the programme's material-production infrastructure, which may support scientific, energy-related and weapons objectives.

4.2. Legal and Regulatory Framework

The open-source record of the DPRK's nuclear and environmental legislation consists principally of a 2001 compilation prepared by the ROK's Light-Water Reactor Project Support Planning Group in connection with KEDO, which reproduces laws and regulations adopted between the 1970s and 1990s.[15] These include the Atomic Energy Law, regulations on radioactive materials and their transport, the Environmental Protection Law, the Nuclear Safety Supervision Regulation and detailed licensing rules. Later amendments and revised laws are available through ROK government sources, including legislation updated until 2021.

Taken together, the available texts entail many concepts associated with the IAEA's nuclear-safety framework, including state supervision, lifecycle licensing, safety analysis, environmental assessment, quality assurance, inspection, radiation protection, waste management and emergency planning. Their increasing detail over time may suggest continued attention to evolving international practice.

The most detailed publicly available implementing instrument is the 1996 Nuclear Safety Supervision Regulation. It applies across the full nuclear-facility lifecycle and to activities involving nuclear materials, radioactive materials and nuclear waste. It assigns licensing and oversight functions to a state nuclear-safety supervision body and gives that body broad powers to enter facilities, obtain information, require corrective action and suspend operations or material-related activities where safety cannot be assured. The Regulation also establishes extensive licensing

12 UN Security Council, 'Security Council 1718 Sanctions Committee Amends Two Entries on Its Sanctions List', 5 January 2024, https://press.un.org/en/2024/sc15555.doc.htm. A 2013 North Korea Leadership Watch post, citing KCNA, reported that the General Department of Atomic Energy, another translation of GBAE, was upgraded into the Cabinet-level MAEI. The original report cannot be verified because KCNA subsequently deleted almost all pre-October 2013 articles. Later news reporting also describes MAEI as a reorganisation of GBAE. However, the ROK Ministry of Unification continued to list GBAE personnel in 2016 and did not explain this succession in its account of the relevant 2013 developments, while UNSC Resolution 2321 attributed officials separately to GBAE and MAEI. It therefore remains unclear whether GBAE and MAEI are currently separate entities.

13 UN Security Council, 'United Nations Security Council Consolidated List', UN Security Council, 21 July 2023, https://main.un.org/securitycouncil/sites/default/files/en_all_21july.html.

14 Adriana Nazarko, 'Know Who's at the Negotiating Table'.

15 북한 원자력체제 및 법률 [North Korea's Nuclear System and Law].

requirements. Depending on the activity and stage of development, applicants must submit safety analyses, environmental-impact reports, quality-assurance arrangements, operating procedures, personnel qualifications, radiation-protection measures, physical-protection provisions and on-site and off-site emergency plans. It further requires site inspection, periodic monitoring and maintenance, defined safety limits and emergency planning, and provides for administrative or criminal responsibility in cases of non-compliance. The wider environmental framework complements these provisions through controls on radioactive releases, environmental monitoring and the management of radioactive materials and waste. The available legal texts do not, however, provide sufficient evidence to determine how these requirements are implemented across uranium mining and milling or how nuclear-safety regulation interacts in practice with the management of associated chemical and conventional industrial hazards.

4.3. Regulatory Effectiveness and Implementation

The formal framework incorporates many of the legal and institutional components of a nuclear-safety system but leaves central questions of regulatory effectiveness and implementation unresolved. During the 1992 visit led by IAEA Director General Hans Blix, the Ministry for Atomic Energy[16] served as the principal DPRK counterpart, and no separate safety organisation or regulatory commission was presented to the delegation.[17] This indicates that an institutionally distinct regulator was not visible at that time.

The reported establishment of the SNSRC in November 1994 therefore represented a significant formal development.[18] During the KEDO project, the SNSRC acted as the recognised DPRK counterpart for nuclear safety and radiation protection, issued the construction permit for the light-water-reactor (LWR) project, participated in inspections and received regulatory training.[19] However, the principal documented project-level safety assessment was conducted through KEDO and the Korea Institute of Nuclear Safety (KINS).[20] KEDO continued to treat the development of a competent and independent DPRK regulator as an outstanding requirement and assessed the DPRK as insufficiently prepared to regulate, operate and maintain commercial LWRs in accordance with international standards.[21] A contemporaneous US government statement similarly described the project as seeking to foster an independent regulator and a nuclear safety culture that would

16 During the 1992 IAEA visit led by Director General Hans Blix, the responsible body was referred to in English as the Ministry for Atomic Energy; a contemporary Korean record gives its name as 원자력공업부. UN documentation continued to use “Ministry of/for Atomic Energy” through December 1993, but a DPRK statement dated 18 March 1994 used “General Department of Atomic Energy”, subsequently more commonly rendered General Bureau of Atomic Energy (GBAE), indicating that the institution had been renamed or reorganised by then, although the exact date and form of the change remain unclear.

17 IAEA Archives, Democratic People's Republic of Korea (1992), Box 38783, Travel Report: Visit to the Democratic People’s Republic of Korea, 11–16 May 1992, 1040-01-03-05-000112546.

18 북한 원자력체제 및 법률 [North Korea’s Nuclear System and Law].

19 KEDO, ‘Nuclear Safety: Interaction with the DPRK’, KEDO, accessed 22 July 2026, http://www.kedo.org/ns_dprk.asp.

20 KEDO, KEDO Annual Report 2001 (KEDO, 2001), http://www.kedo.org/pdfs/KEDO_AR_2001.pdf.

21 John B. Mulligan and HanKwon Choi, ‘Redirection of DPRK Nuclear Talent to the LWR Project’, paper presented at U.S.–ROK Workshop on DPRK Nuclear Scientist Redirection, n.d.; KEDO, ‘Nuclear Safety: Nuclear Safety Policy’, KEDO, accessed 22 July 2026, http://www.kedo.org/ns_policy.asp.

otherwise not exist.[22] Questions regarding regulatory effectiveness remained after the KEDO period. During a 2010 visit to Yongbyon, the chief engineer of the ELWR stated that the National Nuclear Safety Commission[23] had approved the project plans, conducted inspections and maintained an oversight presence at the site to US visitor Hecker.[24] Hecker and other experts later expressed repeated concern that the regulatory authority might be technically weak and not independent.[25]

The available evidence therefore supports the existence of licensing and inspection activity, while remaining insufficient to determine whether regulatory requirements are applied independently and consistently across the full nuclear programme.

4.4. Observed Safety Culture and Operational Practice

Evidence concerning safety culture is derived mainly from IAEA inspectors, US technical teams and invited specialist delegations that visited DPRK nuclear facilities between the early 1990s and 2010. Most observations concern Yongbyon, and access was limited, managed and often undertaken for safeguards, freeze monitoring, disablement or diplomatic purposes rather than as part of a comprehensive safety assessment. Some practices were observed directly, while others were described by DPRK facility personnel. The evidence therefore cannot establish current conditions or be generalised confidently across the nuclear programme. This limitation is particularly acute for uranium mining and milling, which lay outside the application of safeguards under the DPRK's safeguards agreement and therefore did not receive the same degree of direct international inspection as facilities at Yongbyon. Evidence is likewise sparse for other front-end facilities to which international inspectors did not have access, including Kangson. Available sources consequently provide little direct evidence on occupational monitoring, tailings inspection and maintenance, chemical handling, ventilation or contamination-control practices at Pyongsan, or on comparable arrangements at Kangson. The quality and consistency of these arrangements therefore cannot be inferred from historical observations at Yongbyon. The historical record nevertheless provides indications of how personnel approached operation, maintenance and identified safety problems.

Several observations over the years suggest practical engineering competence and an ability to recognise and respond to operational problems. For example, at the 5 MWe reactor, operators reportedly reduced the outlet temperature from approximately 350°C to 300°C, despite the

22 U.S.-North Korea Agreed Framework and KEDO: Hearing before the Senate Foreign Relations Committee, Subcommittee on East Asian and Pacific Affairs, US Senate (1998), https://1997-2001.state.gov/policy_remarks/1998/980714_deming_north_korea.html.

23 During Hecker's 2010 visit, the reactor's chief engineer attributed oversight to what Hecker called the "National Nuclear Safety Commission." This may be an alternative translation of 국가핵안전감독위원회, rendered by KEDO as the State Nuclear Safety Regulatory Commission (SNSRC) but translated more literally as the "State Nuclear Safety Supervision Commission." However, the account does not confirm institutional continuity, while the 2021 Atomic Energy Law refers only to an unnamed state nuclear-safety regulatory body.

24 Siegfried S. Hecker et al., 'North Korea's Light-Water Reactor Ambitions', Journal of Nuclear Materials Management 39, no. 2 (2011), https://resources.inmm.org/system/files/jnmm/vol_39/V-39_3.pdf.

25 Chaim Braun et al., North Korean Nuclear Facilities After the Agreed Framework (Center for International Security and Cooperation, Stanford University, 2016), https://fsi-live.s3.us-west-1.amazonaws.com/s3fs-public/khucisacfinalreport_compressed.pdf.

resulting loss of efficiency, to reduce the likelihood of fuel-cladding failure.[26] Fuel rods were inspected before loading and during operation, damaged rods were removed, and an earlier fuel load was discharged after two years because operators were uncertain about the reliability of its pre-1994 cladding. Reactor personnel also demonstrated an ability to diagnose and adapt to operating problems. During early operation, the reactor reportedly experienced asymmetric neutron flux, excessive temperatures in the lower core and repeated fuel failures. Engineers responded by partially inserting control rods and replacing selected fuel rods with steel dummy rods; according to the chief engineer, these lessons were incorporated when the reactor restarted in 2003. These measures reduced technical and operational risk, but available evidence does not establish whether they were motivated principally by worker protection, production continuity or both.

A former IAEA inspector recalled that DPRK operators had written procedures and followed routine spent-fuel-pond practices, including daily water-level measurements, periodic sampling, cleaning and filtration.[27] In 2008, the DPRK provided the United States with approximately 18,000 pages of records concerning the 5 MWe reactor and the Radiochemical Laboratory.[28] The content available in open sources is insufficient to determine the quality of these records, but their existence indicates an established practice of operational recordkeeping.

A recurring feature of the historical record is that several substantial changes followed identified problems, visible deterioration or external engagement. DPRK officials told the 1992 IAEA delegation that the Chornobyl accident had prompted additional safety analyses and modifications to reactors then under construction, although the delegation could not verify the scope or adequacy of the resulting changes.[29] Fuel-management measures at the 5 MWe reactor similarly followed earlier cladding failures, abnormal core conditions and uncertainty regarding material reliability.[30] The management of the fuel discharged in 1994 provides a more consequential example. Inadequate control of the spent-fuel pond's water chemistry contributed to severe corrosion of the magnesium-alloy cladding.[31]The fuel was ultimately stabilised through a US-led programme in which individual rods were cleaned, sealed in inert-gas-filled canisters and placed under IAEA monitoring.[32] DPRK personnel acquired substantial practical experience through the operation, but the episode also demonstrates that corrective action followed significant deterioration and depended heavily on external technical support.

Radiation-protection and contamination-control practices also appear to have changed during periods of international engagement. Later visitors reported wider availability of protective clothing and portable monitoring equipment, although these improvements may have depended

26 Braun et al., North Korean Nuclear Facilities After the Agreed Framework.

27 Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

28 Bureau of Public Affairs Department of State. The Office of Electronic Information, 'Update on the Six-Party Talks', Department of State. The Office of Electronic Information, Bureau of Public Affairs., 10 May 2008, https://2001-2009.state.gov/r/pa/prs/ps/2008/may/104558.htm.

29 Hans Blix et al., Travel Report: Visit to the Democratic People's Republic of Korea, 11–16 May 1992 (International Atomic Energy Agency, 1992), IAEA Archive.

30 Braun et al., North Korean Nuclear Facilities After the Agreed Framework.

31 S. S. Hecker et al., A Technical and Political History of North Korea's Nuclear Program over the Past 26 Years (Center for International Security and Cooperation, Stanford University, 2018), https://fsi-live.s3.us-west-1.amazonaws.com/s3fs-public/narrativescombinedfinv2.pdf.

32 Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

on IAEA- or US-supplied materials and may not have persisted uniformly.[33] Other observations continued to identify inconsistent protective measures and contamination outside intended controlled areas.[34] The evidence therefore suggests improvement in some settings rather than a uniform transition to consistently applied contamination control.

Some of the strongest examples of controlled technical practice also occurred during international cooperation. DPRK personnel worked with IAEA and US teams on spent-fuel stabilisation, facility monitoring and the 2007–2008 disablement measures.[35] Hecker assessed cooperation between the DPRK and US technical teams as effective and considered that they had balanced timely implementation with safe working practices. This demonstrates an ability to work within externally agreed procedures and alongside international specialists. It is less clear whether the same practices were institutionalised after external access ended.

Human performance is a further cross-cutting factor. Some older facilities at Yongbyon reportedly rely on ageing electro-mechanical equipment and manual intervention. At the Radiochemical Laboratory, one assessment describes operation as requiring significant hands-on work and relying less on the advanced remote controls used in more modern facilities.[36] Specific components identified as ageing include the gas circulator, steam generator and parts of the reactor control system.[37] A former IAEA inspector also recalled that personnel measured spent-fuel-pond water levels daily and periodically sampled and filtered the water.[38] Because the pool reportedly lacked a dedicated leak-detection system, possible leakage was discussed on the basis of changes in measured water levels and visible traces on the pool wall. These examples suggest that safety at some older facilities may depend on operators detecting changes and intervening in a timely manner. Manual operation is not inherently unsafe, but it increases the importance of procedural discipline, reliable instrumentation and the retention of facility-specific knowledge.

Overall, the evidence indicates that DPRK nuclear personnel possessed meaningful technical competence, used written procedures, maintained records and could take conservative or technically informed action in particular circumstances. It also identifies some preventive practices, including routine monitoring and fuel inspection. However, several major improvements appear to have followed equipment failure, deterioration or external intervention, while maintenance and radiation protection were reportedly applied unevenly. The record suggests capable but facility-specific and often problem-responsive practice rather than a consistently institutionalised safety culture able to identify and address weaknesses before they develop into significant hazards.

33 Siegfried S. Hecker, Hinge Points: An Inside Look at North Korea's Nuclear Program (Stanford University Press, 2023).; Former inspector, email correspondence with Open Nuclear Network, August 2026. Identity withheld at source's request; Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

34 Former inspector, email correspondence with Open Nuclear Network, August 2026. Identity withheld at source's request; Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

35 Braun et al., North Korean Nuclear Facilities After the Agreed Framework; Hecker et al., A Technical and Political History of North Korea's Nuclear Program over the Past 26 Years.

36 Robert Alvarez, '2003: North Korea: No Bygones at Yongbyon', Bulletin of the Atomic Scientists, n.d., accessed 4 September 2025, https://thebulletin.org/premium/2020-12/2003-north-korea-no-bygones-at-yongbyon/.

37 Francesca Giovannini, 'A Disaster in Waiting or Simple Paranoia? Examining the Status of Nuclear Safety in North Korea and the Factors That Might Strengthen It', in Avoiding Meltdowns + Blackouts (The Wilson Center, 2023), https://www.wilsoncenter.org/publication/avoiding-meltdowns-and-blackouts.

38 Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

Figure 3: Yongbyon fuel fabrication facility. Siegfried Hecker examining machining lathes removed from machine shop. Source: W. Keith Luse, Senior Professional Staff Member, U.S. Senate.

4.5. External Training and Institutional Learning

By the outset of the KEDO project, the DPRK had already developed a domestic base of nuclear-scientific and engineering knowledge. This base was initially supported through several Soviet cooperation arrangements. A 1955 techno-scientific agreement enabled DPRK specialists to participate in the Soviet Peaceful Atoms programme, including through the Joint Institute for Nuclear Research at Dubna.[39] A separate agreement concluded on 7 September 1959 provided for Soviet technical assistance in the peaceful use of atomic energy and was followed by the provision of a research reactor, radiochemical laboratory and other equipment for the Yongbyon research centre.[40] These links did not disappear entirely, but the available historical record suggests that their role became more limited over time as DPRK policy placed greater emphasis on indigenous development and technological self-reliance under the principle of Juche.

KEDO therefore represents the most substantial structured nuclear-safety capacity-development programme visible in the public record. It did not begin with inexperienced personnel: selected DPRK candidates reportedly held engineering qualifications and had approximately 5–15 years of professional experience, including within the Atomic Energy Research Institute[41], technical ministries and industry.[42]

For regulatory personnel, KEDO provided both technical material and limited practical exposure. Between 1998 and 2002, KEDO and SNSRC held periodic meetings on safety review, licensing,

39 Donghyun Woo, 'The Peaceful Origins of North Korea's Nuclear Programme in the Cold War Period, 1945–1965', The Historical Journal 66, no. 2 (2023): 459–79, https://doi.org/10.1017/S0018246X22000140.

40 Woo, 'The Peaceful Origins of North Korea's Nuclear Programme in the Cold War Period, 1945–1965'; Hecker et al., 'North Korea's Light-Water Reactor Ambitions'.

41 The Atomic Energy Research Institute (원자력연구소) is a DPRK nuclear research body under the Yongbyon Nuclear Research Center.

42 Mulligan and Choi, 'Redirection of DPRK Nuclear Talent to the LWR Project'.

inspection arrangements and the strengthening of regulatory infrastructure.[43] The SNSRC received approximately 660 codes, standards and technical documents intended to support its review and inspection of the project.[44] It participated in reviews of the preliminary safety and environmental documentation, submitted questions, attended technical meetings and joined KINS personnel in inspections of the foundations and construction site.[45]

From 3 to 26 July 2002, 25 DPRK regulatory officials attended an orientation programme at KINS in the ROK. The programme introduced the fundamentals of nuclear-safety regulation, licensing, safety assessment, inspection and quality assurance through classroom instruction and visits to the Ulchin reference plant.[46] This was the first course in a broader programme that was intended to include 18 classroom and on-the-job components over the construction period, but the available record indicates that only the initial orientation was completed.[47]

Training for prospective operators and maintenance personnel was organised separately. Initial familiarisation included visits by senior DPRK officials to nuclear facilities in Spain and Sweden and to the project's reference plant.[48] Formal instruction began at the Kumho Nuclear Training Centre in June 2002, with an initial group of 129 personnel from a planned total of 529.[49] The classroom programme covered subjects ranging from basic reactor theory to plant design and structure, operational management and the safe operation and maintenance of light-water reactors.

The most important practical stages were not completed. Prospective operators were intended to undertake extended placements at operating ROK reactors, while licensed personnel would have received full-scope simulator training, participated in commissioning and start-up, and applied and validated plant-specific procedures.[50] The suspension of the project reportedly prevented these phases from proceeding. The available record therefore does not show that DPRK personnel acquired sustained operating-LWR experience, repeated training under abnormal conditions, practical commissioning experience or extended on-the-job instruction under established commercial operators.

KEDO consequently provided exposure to international codes, documented safety assessment, formal licensing, inspection practice and commercial-reactor operations, but its scope and completion were limited. The documented training was designed specifically for the planned Kumho LWRs rather than the existing 5 MWe graphite-moderated reactor, which remained frozen

43 KEDO, 'Nuclear Safety: Interaction with the DPRK'; KEDO, KEDO Annual Report 2001; KEDO, KEDO Annual Report 2002 (KEDO, 2002), http://www.kedo.org/pdfs/KEDO_AR_2002.pdf.

44 KEDO, KEDO Annual Report 2002.

45 KEDO, KEDO Annual Report 2002; KEDO, KEDO Annual Report 2001.

46 KEDO, KEDO Annual Report 2002; Mulligan and Choi, 'Redirection of DPRK Nuclear Talent to the LWR Project'.

47 KEDO, KEDO Annual Report 2002; Mulligan and Choi, 'Redirection of DPRK Nuclear Talent to the LWR Project'; Kayla Orta et al., Avoiding Meltdowns and Blackouts: Confidence-Building in Inter-Korean Engagement on Nuclear Safety and Energy Development (The Wilson Center, 2023), https://www.wilsoncenter.org/publication/avoiding-meltdowns-and-blackouts.

48 KEDO, KEDO Annual Report 2001.

49 KEDO, KEDO Annual Report 2002.

50 Mulligan and Choi, 'Redirection of DPRK Nuclear Talent to the LWR Project'.

under the Agreed Framework. Moreover, during the 2010 Yongbyon visit, the delegation was told that no members of the former DPRK KEDO LWR team had yet been brought into the ELWR project, although they might be involved during its operational phase.[51] The KEDO experience therefore cannot be assumed to have informed safety practices at the 5 MWe reactor or to have been transferred systematically into the construction and operation of the indigenous LWR. Its contribution is best understood as introductory and partially implemented capacity development, rather than a completed or demonstrably institutionalised transfer of regulatory and operational competence.

KEDO provided the DPRK with a temporary channel for regulatory exchange, technical documentation, training and exposure to international commercial-reactor practice. That channel ended with the termination of the project in 2006.[52] IAEA inspectors and the official US technical team were subsequently expelled from Yongbyon in April 2009, and the most recent direct external access identified in the reviewed sources was a managed Stanford delegation visit in November 2010.[53] For approximately the past 15 years, the DPRK therefore appears to have had little or no regular access to international peer review, regulator-to-regulator exchange, exchanges with commercial vendors, simulator-based training or operating experience disseminated through bodies such as World Association of Nuclear Operators[54] and Institute of Nuclear Power Operations.[55] This limits opportunities to compare domestic practices with evolving international standards, identify failure modes observed elsewhere and incorporate lessons from incidents and near misses. Safety knowledge may consequently become increasingly dependent on internally available experience and on training received during earlier periods of cooperation, much of which is now more than two decades old.

Renewed bilateral cooperation could provide an alternative channel for technical exchange, although the extent to which this is occurring remains unclear. The Russia–DPRK Comprehensive Strategic Partnership Treaty, signed on 19 June 2024, commits both parties to expand scientific and technical exchanges and promote joint research in several areas, including the peaceful use of nuclear energy. However, no further practical detail has been identified in open sources, and there is currently no publicly available evidence that nuclear-related cooperation has been initiated under this provision.

51 Hecker, A Return Trip to North Korea's Yongbyon Nuclear Complex.

52 KEDO, 'About Us: Our History', KEDO, accessed 2 August 2026, http://www.kedo.org/au_history.asp.

53 Braun et al., North Korean Nuclear Facilities After the Agreed Framework; Hecker et al., A Technical and Political History of North Korea's Nuclear Program over the Past 26 Years.

54 WANO, 'Who We Are', World Association of Nuclear Operators, accessed 2 August 2026, https://www.wano.info/about-wano/who-we-are/.

55 Institute of Nuclear Power Operations, 'Our History', INPO, accessed 2 August 2026, https://www.inpo.info/history.

4.6. Operational Resilience: Emergency Preparedness and Material Constraints

Open-source evidence remains insufficient to assess the DPRK's emergency-response capacity in practice. The available legislation requires on-site and off-site emergency plans, evacuation arrangements, environmental monitoring and measures to manage accident consequences.[56] However, little is publicly known about the frequency or scope of exercises, inter-agency coordination, public-warning arrangements, medical preparedness or the availability of equipment for monitoring, containment and remediation.

The DPRK signed both principal international emergency-response instruments on 29 September 1986: the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.[57] The first establishes arrangements for promptly notifying the IAEA and potentially affected States of an accident with possible transboundary radiological consequences and for providing relevant information about its development.[58] The second establishes a framework through which States cooperate with the IAEA and one another to request, offer and coordinate assistance during a nuclear or radiological emergency.[59] However, the DPRK has not ratified either convention, and neither is in force for the DPRK.[60] It is therefore not bound by the full notification and assistance obligations applicable to States Parties.

Emergency preparedness was included within KEDO's overall nuclear-safety policy. KEDO also provided instruction relevant to accident prevention, including safe plant operation and maintenance and regulatory orientation covering safety review, licensing, inspection and quality assurance.[61] The available descriptions of completed training do not, however, identify emergency preparedness or accident response as distinct components. Moreover, the practical stages most directly relevant to managing abnormal conditions – including simulator training, operating-reactor placements, commissioning and procedure validation – were not completed.[62] A later assessment identified on-site and off-site emergency-response procedures among the arrangements that would still have needed to be established before the DPRK could assume responsibility for the KEDO reactors.

No subsequent international training or exercise involving DPRK nuclear-emergency personnel was identified in the open sources reviewed for this study. Public Chinese accounts describe nuclear-emergency cooperation with several named regional partners; they do not identify the

56 북한 원자력체제 및 법률 [North Korea's Nuclear System and Law].

57 Statement on Signing the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986).

58 INFCIRC/335 - Convention on Early Notification of a Nuclear Accident (1986), https://www.iaea.org/sites/default/files/infcirc335.pdf.

59 INFCIRC/336 - Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986), https://www.iaea.org/sites/default/files/infcirc336.pdf.

60 IAEA, 'Country List: Office of Legal Affairs : IAEA', IAEA, accessed 27 July 2026, https://ola.iaea.org/Applications/FactSheets/Country/Detail?code=KP&utm.

61 KEDO, KEDO Annual Report 2002; KEDO, KEDO Annual Report 2001; KEDO, 'About Us: Our History'.

62 Mulligan and Choi, 'Redirection of DPRK Nuclear Talent to the LWR Project'.

DPRK in these activities.[63] DPRK participation therefore cannot be confirmed, but unpublicised technical exchanges cannot be excluded.

The absence of public evidence does not establish that emergency plans, training or external support are absent. It does, however, prevent assessment of whether the DPRK's formal arrangements are regularly exercised, supported by current technical guidance and capable of coordinating facility, national and international action under accident conditions.

Similar uncertainty applies to the procurement and replacement of nuclear-related equipment or materials. Open sources provide little insight into how the DPRK procures, manufactures, stockpiles or replaces such items. Historical records occasionally identify potentially relevant material stocks, but rarely establish their subsequent condition or use.[64] Assessments of the 5 MWe reactor identify ageing systems and components that may fail, but replacing some major components could be technically and economically difficult.[65] The sanctions regime constrains legal access to listed nuclear-related and dual-use items and applies a broader prohibition to goods that could contribute to the DPRK's nuclear programme.[66] Separate measures prohibit the transfer to the DPRK of industrial machinery, iron, steel and other metals. At the same time, there is insufficient public information to determine the level of informal procurement and indigenous production capabilities. The DPRK has nevertheless constructed and begun operation of an ELWR. Separately, during the 2010 visit to Yongbyon, Hecker described the control room of the newly completed uranium-enrichment workshop as modern and digitally equipped. This indicates some ability to manufacture, adapt or obtain complex equipment.

The principal concern is therefore not a demonstrated inability to obtain equipment, but uncertainty over how ageing or damaged parts are repaired and replaced. Continued operation may require life extension, local fabrication, substitution or modification. Open sources do not permit assessment of whether such measures preserve reliability and needed redundancy. The resulting concern is cumulative or piecemeal adaptation: individual interventions may keep particular systems functioning, while their combined effect on facility safety remains independently unverifiable. These uncertainties become particularly consequential during abnormal conditions, when power, instrumentation, communications, equipment and trained personnel must function together. Even where material constraints do not initiate an accident, they could reduce redundancy, delay stabilisation and complicate recovery.

63 China's Nuclear Emergency Preparedness (2016), https://english.www.gov.cn/archive/white_paper/2016/01/27/content_281475279484672.htm.

64 One example concerns graphite reportedly manufactured for the unfinished 50 MWe reactor. Historical IAEA reporting records that the DPRK presented approximately half of the reported graphite-block inventory for monitoring, with additional blocks presented in 1998. Because the DPRK did not permit sampling, the IAEA could not confirm that the material was nuclear grade. A later technical assessment noted that the reported quantity would have been sufficient to replace the graphite in the 5 MWe reactor, but there is no evidence that such a replacement occurred. International Atomic Energy Agency (IAEA), Implementation of the Agreement Between the Agency and the Democratic People's Republic of Korea for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, Report by the Director General to the General Conference, GC(42)/16, 26 August 1998, para. 13, p. 4; Julien de Troullioud de Lanversin and Moritz Kütt, "Verifying North Korea's Plutonium Production with Nuclear Archaeology", Science & Global Security, vol. 29, no. 3 (2021)

65 Orta et al., Avoiding Meltdowns and Blackouts.

66 UN Security Council, 'Lists of Items Prohibited for Export to and Import from The Democratic People's Republic Of Korea Pursuant to Security Council Resolution 1718 (2006)', UN Security Council, United Nations Security Council, accessed 2 August 2026, https://main.un.org/securitycouncil/en/sanctions/1718/prohibited-items; UN Security Council, 'Security Council Committee Established Pursuant to Resolution 1718', UN Security Council, accessed 2 August 2026, https://main.un.org/securitycouncil/en/sanctions/1718.

Taken together, the available evidence shows formal recognition of emergency planning and a demonstrated capacity to sustain and expand parts of the nuclear programme, but it does not establish system-level resilience.

4.7. Conclusion

The DPRK has developed a formal nuclear-safety framework, a specialised regulatory function and a substantial base of scientific and engineering expertise. Historical engagement with the IAEA, KEDO and US technical teams further exposed regulators and operators to international standards, structured procedures and practical safety methods. The available evidence indicates that the DPRK possesses awareness of nuclear-safety principles and the technical capacity to apply them in specific settings.

The principal observed weakness lies in institutionalisation. From the 1992 IAEA visit through the KEDO period and later access to Yongbyon, independent regulatory authority has remained uncertain. Operational practice has been uneven across facilities, safety improvements have often followed rather than preceded deterioration, and some of the strongest controls were implemented under temporary international arrangements. Political direction, institutional opacity, limited international operating-experience exchange and resource constraints may further reduce the ability of technical personnel to identify and correct problems consistently.

Governance therefore acts as a risk multiplier. Ageing equipment, waste-storage degradation or cooling-system failure do not inevitably result in environmental release. Their consequences depend on whether deterioration is detected, whether the release can be accurately characterised in time to guide protective action, whether information is reported, regulators can intervene, resources are available and emergency action is timely. The most important uncertainty is not whether the DPRK possesses individual experts or formal rules, but whether these components operate together as an independent, consistently enforced and self-correcting national safety system.

CHAPTER 5

Technical Risk Assessment I: Front-End Risks

5.1. Pyongsan Mining and Milling

5.1.1. Site profile

Pyongsan processes very low-grade ore, estimated at approximately 0.01–0.03% uranium by weight.[67] Due to the low-grade nature of the ore, more rock must be mined, crushed and chemically processed for each unit of uranium concentrate, increasing the volumes of waste rock, tailings, process water and dust requiring management. Open-source analysis indicates that milling probably uses an acid-leach process involving sulphuric acid and oxidants such as sodium chlorate and manganese dioxide.[68] Pyongsan's risk profile is therefore shaped primarily by the scale and persistence of its radiological and chemical waste streams rather than by the uranium-concentrate product itself.

67 Sulgiye Park et al., 'Assessing Uranium Ore Processing Activities Using Satellite Imagery at Pyongsan in the Democratic People's Republic of Korea', Science & Global Security 29, no. 3 (2021): 111–44, https://doi.org/10.1080/08929882.2021.1988258.

68 Park et al., 'Assessing Uranium Ore Processing Activities Using Satellite Imagery at Pyongsan in the Democratic People's Republic of Korea', 2021.

Figure 4: Pyongsan complex. 1 – mines; 2 – crushing and grinding mill; 3 – Concentration Plant; 4 – tailings pond. Green line – pipeline from milling to the Plant; yellow – pipeline to the tailings pond; orange – wastewater path to the river. 38.318 N, 126.434 E. 19 April 2026. Image: © 2026 Planet

5.1.2. Tailings, water management and loss of containment

The tailings pond is the central environmental-risk feature at Pyongsan because it concentrates process residues and contaminated water in a single storage system. Uranium-mill tailings can remain a source of radionuclides, metals, acidity, salinity and suspended solids after uranium recovery. The international experience identifies recurring release mechanisms: erosion and windblown dispersal of exposed tailings; seepage through the base or containment structures; and decant or overflow into natural waterways.[69] These mechanisms can produce chronic contamination without a dramatic structural failure.

At Pyongsan, surface water is the most directly evidenced potential off-site route. A 2019 analysis identified recurring spillage or leakage around both ends of the cross-river tailings pipeline during the 2010s,[70] while more recent imagery analysis reported wastewater discharge through a drainage channel towards streams connected with the Ryesong River system.[71] These observations establish

69 IAEA, The Long Term Stabilization of Uranium Mill Tailings: Final Report of a Co-Ordinated Research Project 2000–2004, IAEA-TECDOC-1403 (IAEA, 2004), https://www-pub.iaea.org/MTCD/Publications/PDF/te_1403_web.pdf.

70 38North, 'North Korea's Pyongsan Uranium Mill: Operations Produce Environmental Damage While Extracting Uranium for Its Nuclear Program', 38 North, 27 August 2019, https://www.38north.org/2019/08/pyongsan082719/.

71 SI Analytics, North Korea Situation Update: Pyongsan Wastewater Will Be a Long-Term Hazard, nK Insight (SI Analytics, 2025), https://si-analytics.ai/en/pyongsan-wastewater-will-be-a-long-term-hazard-%e2%80%95-july-8-2025/.

recurrent release pathways, but not the chemical composition, activity concentration, discharge rate or downstream dose consequences of the material involved. Direct local environmental sampling would be required to quantify those consequences; downstream transport and monitoring evidence are considered in Chapter 8. Environmental Pathways and Receptors.

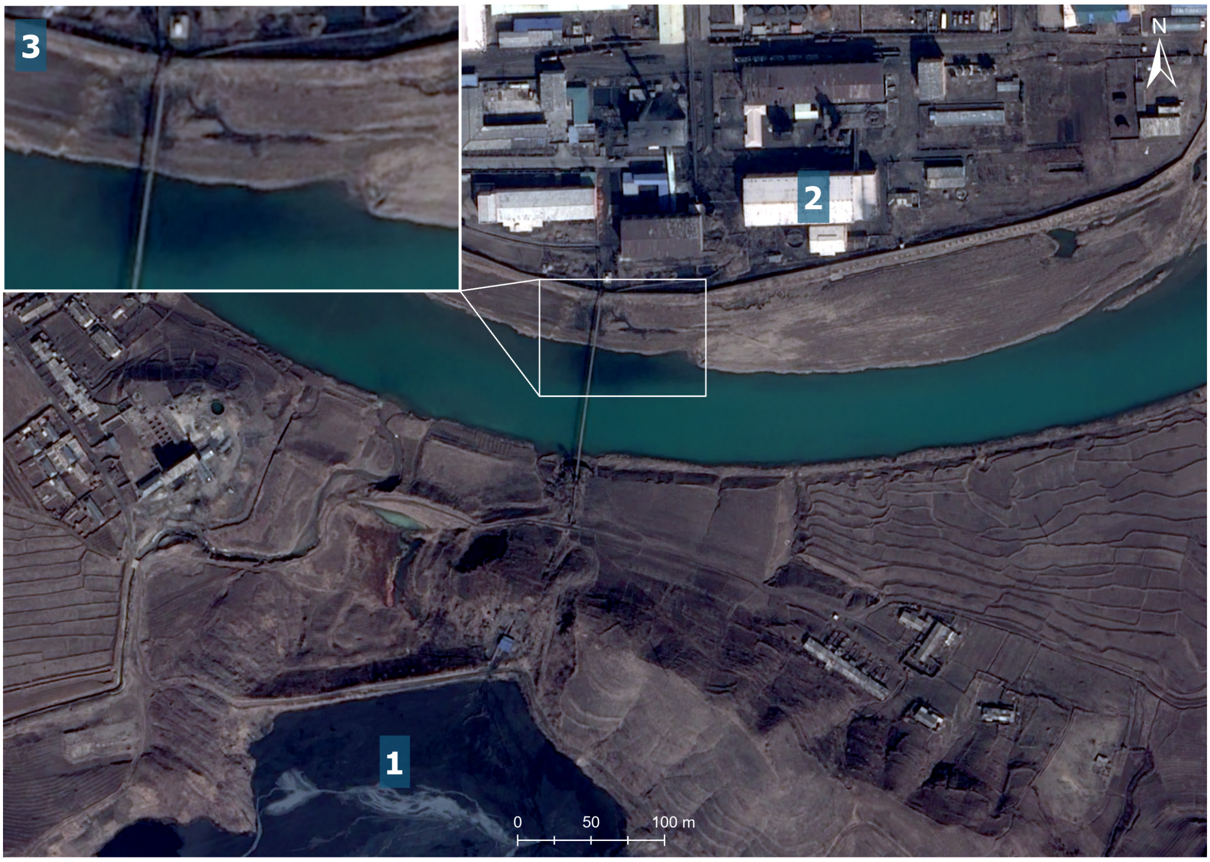

Figure 5: Probable pipeline leak at Pyongsan complex. 1 – tailings pond; 2 – wastewater treatment plant; 3 – zoomed-in area of leak. 38.315 N, 126.431 E. 5 March 2021. Image: © CNES (2026), Distribution Airbus DS

Seepage through or beneath the tailings pond is a possible chronic loss-of-containment mechanism, but groundwater conditions and the integrity of subsurface barriers are not publicly known. Pipeline failure is a separate, better-observed and real vulnerability.[72] The cross-river tailings line carries chemically processed residues to the pond, while a separate ore-slurry pipeline transfers uranium-bearing material within the mining and milling process. A rupture or chronic leak from either could affect nearby soil or water.

The available evidence points more clearly to a higher probability of chronic or recurrent localised loss of containment than to catastrophic failure of the tailings pond. Open-source analysis has identified spillage or leakage around the cross-river tailings pipeline and reported slow wastewater drainage from the pond. However, no open-source data reviewed identifies a full breach of the tailings pond. Such a breach remains a lower-probability but potentially higher-consequence scenario, since it could rapidly move large volumes of contaminated water and tailings into the adjacent river corridor.

72 38North, 'North Korea's Pyongsan Uranium Mill'.

5.1.3. Process hazards

Occupational exposure is important even where off-site effects are limited. In uranium mining, inhalation of radon progeny is a principal radiological exposure pathway, alongside long-lived alpha-emitting aerosols and external gamma radiation.[73] At Pyongsan, the adequacy of mine ventilation and workplace monitoring is unknown.

Crushing and grinding can also generate uranium-bearing dust, while dry tailings surfaces can become a source of fine particles. Inhalation is the most direct occupational pathway; radon emanation and dust from exposed tailings are also relevant to longer-term site management, although outdoor dispersion makes this less concentrated than in confined work areas.

The use of leaching agents also introduces chemical hazards that may be more acute for workers than the radiological consequences of many routine incidents. Possible failure modes include leaks from reagent storage, pumps and process tanks; corrosion or rupture of transfer lines; spills during handling; and inadequate ventilation. Some external experts identified corrosion around the probable leach tank house and noted that if sulphuric-acid leaching is used, gases or vapours such as hydrogen sulphide, sulphur dioxide and acidic mist could be present.[74]

5.1.4. Overall assessment

The strongest evidence at Pyongsan points to a higher likelihood of chronic and recurrent risk rather than a single catastrophic event. Tailings and wastewater are continuously generated; reported spillage and drainage provide credible release routes; and radon, dust and chemical hazards arise through routine mining and milling. Small releases could therefore accumulate in the near-site environment over time even if no major accident occurs. The lower probability but higher consequence scenarios are a major tailings-containment failure, a large pipeline rupture and a serious chemical storage or process accident. The first two could rapidly release larger quantities of contaminated water and solids to adjacent ground and surface water, potentially increasing downstream transport, while a serious chemical accident could produce acute local contamination or toxic exposure through spills or vapours.

73 IAEA, 'Information System on Uranium Mining Exposures (UMEX)', IAEA, accessed 7 August 2026, https://nucleus.iaea.org/sites/orpnet/worldwide/umex/SitePages/Home.aspx.

74 Park et al., 'Assessing Uranium Ore Processing Activities Using Satellite Imagery at Pyongsan in the Democratic People's Republic of Korea', 2021.

5.2. Conversion and Uranium Enrichment at Yongbyon and Kangson

5.2.1. Site profiles

Conversion and uranium enrichment are less directly observable than mining and milling. Satellite imagery can identify construction, expansion, cooling infrastructure and some external operating signatures, while DPRK media and historical visits provide limited information on selected internal facilities. The presence of any small uranium-hexafluoride (UF_6) releases, hydrogen fluoride (HF) exposure, internal corrosion, failures of confinement or contaminated liquid discharges remain unknown.

Figure 6: Uranium fuel fabrication plant. 1 – uranium enrichment halls; 2 – railhead. 39.769 N, 125.750 E. 27 June 2026. Image: © 2026 Planet

At Yongbyon, a centrifuge-enrichment plant was publicly demonstrated during a November 2010 visit. The building was expanded in 2013, and a further annex was constructed between September 2021 and May 2022. The IAEA continued to observe indications of operation through its 2025 reporting period. A further building south-west of the Yongbyon 50 MWe reactor was constructed between December 2024 and May 2025 and assessed by IAEA as a possible enrichment facility;[75] subsequent open-source analysis has referred to it as "Yongbyon-J."[76] If this analysis is correct, the environmental implication arises from the additional inventory of UF_6 process equipment, cylinders and supporting systems concentrated at Yongbyon.

Figure 7: New enrichment building at Yongbyon. 1 – probable ventilation stack; 2 – support building. 39.785 N, 125.759 E. 27 June 2026. Image: © 2026 Planet

Kangson is assessed as a suspected uranium-enrichment site. An annex constructed in 2024 increased the main building's floor space, and the IAEA reported continued activity and additional cooling cell deliveries through 2025.[77] In September 2024, DPRK media released photographs of Kim Jong Un visiting what it described as a "production base of weapon-grade nuclear materials."[78] By comparing those photographs with commercial satellite imagery of the Kangson buildings, the IAEA identified the photographed facility as the Kangson complex. The visible cascades were consistent with low-enriched uranium operation, although the IAEA could not exclude cascades configured for higher enrichment elsewhere in the building.[79] Evidence from open sources does not establish an on-site conversion line at Kangson. Conversion-specific hazards should therefore not automatically be transferred from Yongbyon, although enrichment still entails the handling and storage of UF_6, enriched product and depleted tails.

75 IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025).

76 Hailey Wingo, 'Analysis of a New DPRK Enrichment Facility', VERTIC, 11 June 2026, https://www.vertic.org/2026/06/analysis-of-a-new-dprk-enrichment-facility/.

77 IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025).

78 IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025).

79 IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025).

Figure 8: Kim Jong Un's visit to Kangson enrichment plant. Image: KCNA

At Yongbyon, conversion activities add a separate chemical-processing risk chain. The IAEA reported that a major renovation began in July 2022 on the previously derelict UF4 Production Process Building at the Nuclear Fuel Rod Fabrication Plant, with indications that the renovated facility was operational by October 2024. It also reported continuing activity in other buildings with features consistent with chemical processing.[80] Reuse of a legacy process building does not itself demonstrate unsafe operation, but the increased age of the facilities could negatively affect the condition of structures, piping, ventilation and associated support systems, which may increase risks at this site.

For both sites, the principal safety variables remain largely unobservable: the quantities and physical condition of UF_6 cylinders; the integrity of process piping and other confinement boundaries; ventilation performance; maintenance and inspection; emergency arrangements; and the design and condition of drainage and waste-management systems.

5.2.2. UF_6 loss of confinement and chemical hazards

The most immediate accident hazards associated with uranium conversion and gas-centrifuge enrichment are often chemical rather than radiological. IAEA safety guidance identifies loss of confinement involving UF_6, HF and fluorine as important hazards,[81] while the US Nuclear Regulatory Commission similarly treats UF_6 releases and associated chemical, fire and explosion hazards as central accident concerns.[82] A release involving uranium therefore does not necessarily mean that radiation dose would be the dominant negative consequence.

UF_6 reacts rapidly with moisture in air to form HF and uranyl fluoride (UO_2F_2).[83] A substantial release would consequently be a combined chemical-radiological event: HF and airborne uranium compounds would drive the immediate near-field hazard, while deposited UO_2F_2

80 IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025).

81 IAEA, Safety of Conversion Facilities and Uranium Enrichment Facilities, Safety Standards Series SSG-5 (Rev. 1) (IAEA, 2023), http://www.iaea.org/publications/15077/safety-of-conversion-facilities-and-uranium-enrichment-facilities.

82 US Nuclear Regulatory Commission, 'Uranium Conversion', US Nuclear Regulatory Commission, 2 December 2020, https://www.nrc.gov/materials/fuel-cycle-fac/ur-conversion; US Nuclear Regulatory Commission, 'Frequently Asked Questions About Gas Centrifuge Enrichment Plants', US Nuclear Regulatory Commission, 12 March 2015, https://www.nrc.gov/materials/fuel-cycle-fac/faq.

83 IAEA, Safety of Conversion Facilities and Uranium Enrichment Facilities.

could contaminate surfaces, soil and water and create a subsequent decontamination and waste-management burden. Consequences would depend on the quantity and conditions of release, meteorology, proximity of workers and the public, confinement performance and the speed of protective action. Credible initiators include corrosion or failure of process piping; damage to or overheating of cylinders; loss of ventilation or cooling; fire or explosion; and operator error. Other chemical hazards depend on the conversion route and may include fluorine, nitric acid, ammonia, hydrogen and solvents.

Mechanical failure of centrifuge components is also a plant-safety concern,[84] but its environmental significance lies mainly in whether it damages process piping or other confinement boundaries and causes a UF_6 release. Confinement and ventilation are therefore common safety functions across several initiating events. Nuclear criticality remains a potentially severe hazard for workers and the facility, but the likelihood and severity of a criticality event depend on enrichment, mass, moderation, geometry and the effectiveness of process controls.[85] Based on available open-source information, hazards are less directly connected to routine environmental release pathways than UF_6 handling, uranium-bearing residues and conversion chemicals.

5.2.3. Chronic material management and ageing risks

Enrichment also produces a depleted tails stream, shifting part of the risk from active processing to storage, handling and long-term material management.[86] The quantity, age and condition of tails inventories at Yongbyon and Kangson are not publicly known. Leakage from stored material or repeated small losses of confinement could create localised contamination and an accumulating remediation burden even in the absence of a major accident.

Ageing can increase these risks through corrosion, material degradation and obsolescence of instrumentation and safety systems. IAEA guidance emphasises ageing management, inspection and surveillance of structures, systems and components with safety functions.[87] At Yongbyon, the refurbishment of legacy conversion infrastructure alongside newer enrichment construction creates a mixed-age facility profile in which long-term reliability depends on maintenance and compatible support systems. Flooding, severe rainfall, heat and loss of power could challenge ventilation, monitoring, drainage and other support functions.

5.2.4. Overall assessment

The principal acute front-end risk at Yongbyon and Kangson is loss of confinement of UF_6, or hazardous chemicals used in the conversion process. A substantial release could produce severe near-field chemical effects over a short period and leave deposited uranium compounds requiring longer-term management. A broader set of potential risk scenarios is present at Yongbyon because it combines conversion and enrichment; at Kangson, the strongest supported concern is enrichment-related UF_6 handling and storage.

Chronic risks at both facilities could arise from degraded cylinders and equipment, repeated small leaks, contaminated ventilation or drainage systems, uranium-bearing residues and tails management.

84 Open Nuclear Network expert workshop, Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Programme, Vienna, 17–18 March 2026, https://opennuclear.org/en/open-nuclear-network/news/onn-convened-expert-workshop-evaluating-and-mitigating-environmental.

85 IAEA, Safety of Conversion Facilities and Uranium Enrichment Facilities.

86 IAEA, Safety of Conversion Facilities and Uranium Enrichment Facilities.

87 IAEA, Safety of Conversion Facilities and Uranium Enrichment Facilities.

CHAPTER 6

Technical Risk Assessment II: Reactor Operations

This chapter focuses on the 5 MWe reactor and ELWR, the two reactors at Yongbyon for which recent open-source evidence indicates operation.

The IRT research reactor appears inactive, while the unfinished 50 MWe reactor is being dismantled, and neither is assessed here as an active reactor-operation hazard. The analysis considers the principal reactor safety functions of reactivity control, heat removal and confinement; environmental transport following a release is addressed in Chapter 8 and climate and external hazards in Chapter 9.

Figure 9: Reactors area. 1 – 5 MWe reactor; 2 – spent-fuel storage; 3 – ELWR; 4 – ELWR support facility; 5 – water pump houses. 39.796 N, 125.755 E. 27 June 2026. Image: © 2026 Planet

6.1. The 5 MWe Reactor

The 5 MWe reactor is a gas-cooled, graphite-moderated reactor using natural uranium fuel and carbon dioxide as coolant. As a Magnox-type reactor, it is generally understood to have been modelled on the UK's Calder Hall reactor,[88] although details of its design and later modifications remain limited. By contemporary nuclear power standards, the reactor has a relatively low electrical generating capacity and is based on an ageing reactor design, with a nominal electrical output of 5 MWe and an estimated thermal output of about 20–25 MWth.[89]

6.1.1. Operational risks

From a risk perspective, the reactor raises several concerns. Its age and intermittent operating history create uncertainty about the condition of safety-relevant components, including the graphite moderator, fuel and control-rod channels, cooling systems and spent-fuel handling facilities.

Graphite-moderated gas-cooled reactors can experience ageing mechanisms such as graphite dimensional changes, irradiation-induced cracking, oxidation, and changes in core geometry. These could become safety-significant where they impair coolant flow, fuel-channel geometry, neutron behaviour, and control-rod movement. However, publicly available information is insufficient to determine whether such degradation has occurred at Yongbyon or whether safety margins have been materially reduced.[90]

The lack of continuous international inspection and detailed operational data also makes it difficult to assess the reactor against modern safety standards. Little is publicly known about the condition and reliability of safety systems, maintenance practices, coolant-system integrity, or procedures for detecting and managing degradation.

The 5 MWe reactor has operated intermittently since the mid-1980s, with several multi-year irradiation periods separated by refuelling outages and extended shutdowns. Later campaigns are better documented, including operation in 2003–2005, 2005–2007, 2013–2015 and 2016–2018. After a further shutdown, operation resumed in July 2021. The IAEA subsequently referred to

88 Stephan Haggard and Tai Ming Cheung, 'North Korea's Nuclear and Missile Programs: Foreign Absorption and Domestic Innovation', Journal of Strategic Studies 44, no. 6 (2021): 802–29, https://doi.org/10.1080/01402390.2021.1993828.

89 David von Hippel and Peter Hayes, POTENTIAL IMPACTS OF ACCIDENT AT OR ATTACK ON THE DPRK'S YONGBYON NUCLEAR REACTORS, NAPSNet Special Report (Nautilus Institute for Security and Sustainability, 2017), https://nautilus.org/napsnet/napsnet-special-reports/potential-impacts-of-accident-at-or-attack-on-the-dprks-yongbyon-nuclear-reactors/. For a detailed table of possible design parameters see: Jungmin Kang, 'Using the Graphite Isotope Ratio Method to Verify the DPRK's Plutonium-Production Declaration', Science & Global Security 19, no. 2 (2011): 121–29, https://doi.org/0.1080/08929882.2011.586309; Dokyun Kim et al., 'Evaluation of Tritium Production Capability of the 5 MWe Gas-Cooled Graphite-Moderated Reactor at Yongbyon Using Tritium-Producing Burnable Absorber Rods', Nuclear Engineering and Technology 57, no. 2 (2025), https://doi.org/10.1016/j.net.2024.09.010; Jooho Whang and George T. Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities, Cooperative Monitoring Center Occasional Paper SAND 2005-1981P, 957471 (Sandia National Laboratories, 2005), SAND 2005-1981P, 957471, https://doi.org/10.2172/957471.

90 Cristian I. Contescu and Ryan M. Paul, Oxidation Behavior and Property Degradation of Nuclear Graphites, ORNL/TM-2022/1839 (Oak Ridge National Laboratory (ORNL), 2022), https://doi.org/10.2172/1860566; Martin Metcalfe, 'Damage Tolerance in the Graphite Cores of UK Power Reactors and Implications for New Build', Nuclear Engineering and Design 406 (May 2023), https://doi.org/10.1016/j.nucengdes.2023.112237.

this as the reactor's sixth operational cycle. A roughly 60-day shutdown in August–October 2024 was long enough to permit refuelling, and the IAEA later assessed that the reactor had likely entered a seventh cycle.[91]

This intermittent history complicates assessment of the reactor's long-term condition. Operation, shutdown, refuelling, maintenance, restart, and spent-fuel handling each involve different safety considerations. That history also shows that the DPRK has managed to keep the reactor in service and carry out refurbishment despite its age, sanctions and prolonged international isolation. This suggests some capacity to obtain, produce or adapt replacement equipment, although how far that capacity extends is unclear. More difficult to judge is whether safety-critical components are being inspected, tested and replaced in ways that preserve adequate safety margins.

6.1.2. Radiological-release risk

The long-term operation of the 5 MWe reactor at Yongbyon raises safety concerns, particularly because information on the facility's design, ageing condition, inspection history, and safety systems is limited.

A severe accident involving core damage or a release of radioactive material could produce radiological consequences in the area surrounding Yongbyon. Depending on the quantity released and atmospheric conditions, radioactive material could also be transported beyond the immediate site.

The duration and pattern of reactor operation are also relevant to accident-consequence assessments. Longer operating periods can increase the inventory of radioactive material in the reactor core and spent-fuel storage pool, potentially increasing the consequences of a severe accident.[92] Beyond the uncertainty surrounding core inventory and release amounts, a major challenge is quantifying how ageing of individual reactor components affects the probability of an accident. Consequently, both the likelihood of an accident and the extent to which ageing may influence that likelihood remain uncertain.

91 Grant Christopher et al., North Korea's Plutonium Infrastructure (VERTIC, 2023), https://storymaps.arcgis.com/stories/8ccf63a7408743ec8929df8ea489020a; IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025); IAEA, IAEA Director General's Introductory Statement to the Board of Governors, 8 June 2026, https://www.iaea.org/newscenter/statements/iaea-director-generals-introductory-statement-to-the-board-of-gover nors-8-june-2026; Julien De Troullioud De Lanversin and Moritz Kütt, 'Verifying North Korea's Plutonium Production with Nuclear Archaeology', Science & Global Security 29, no. 3 (2021): 145–66, https://doi.org/10.1080/08929882.2021.1999054.

92 Taewook Kang and Moosung Jae, 'Consequence Analysis for Nuclear Reactors, Yongbyon', Journal of Nuclear Science and Technology, 1 February 2017, https://www.tandfonline.com/doi/full/10.1080/00223131.2016.1255572.

6.2. The ELWR

The ELWR at Yongbyon is generally assessed to be a small pressurised-water reactor (PWR).[93] Under the conventional interpretation, the reactor uses a pressurised primary water loop to transfer heat from the reactor core to a steam generator, where heat is transferred to a separate secondary loop. The resulting steam drives a turbine to generate electricity, while a third cooling circuit, ultimately drawing on river or reservoir water, condenses the turbine exhaust and returns the condensate to the steam system. During the 2010 Stanford delegation visit, DPRK officials described a 100 MWth reactor using uranium-dioxide fuel enriched to approximately 3.5% U-235, with a full fuel load of about four tonnes. Based on the stated thermal output and expected conversion efficiency, Hecker estimated an electrical output of approximately 25–30 MWe. The containment structure was reportedly approximately 22 metres in diameter, with reinforced-concrete walls around 0.9 metres thick and a height of approximately 40 metres; these dimensions were considered broadly consistent with satellite imagery.[94]

6.2.1. Operational risks

The ELWR differs significantly from the older 5 MWe reactor in terms of its physical configuration and safety-related infrastructure. The reinforced-concrete containment structure represents a significant difference from the older gas-graphite reactor, which does not possess a comparable modern containment structure. The presence of containment does not, however, establish that the ELWR meets contemporary international safety standards, since the quality of construction, containment integrity, pressure resistance, penetrations, isolation systems, and associated safety systems cannot be independently verified from publicly available information.

The principal accident pathway would involve loss of cooling, potentially resulting in fuel overheating and damage to fuel cladding. This could release radioactive fission products into the reactor coolant and, in a severe accident, potentially into the containment and depending on the accident progression also to the environment. Loss of electrical power, failure of pumps or other safety-critical components, or disruption of cooling-water supplies could contribute to such an accident. Observed flooding and repeated damage to the reservoir dam demonstrate exposure of this supporting infrastructure to hydrological stress, although no reviewed event establishes an actual loss of reactor cooling; this issue is assessed in detail in Chapter 9.

93 Despite this relatively well-established general interpretation, important uncertainties remain regarding the ELWR's precise design. The prevailing assessment is that it is a water-moderated, water-cooled reactor using enriched uranium-oxide fuel. However, it has been reported that some European intelligence assessments considered an alternative design involving light-water cooling combined with graphite moderation and a larger reactor vessel. This possibility has not been independently confirmed. Consequently, descriptions of the ELWR as a 100 MWth PWR should be understood as the leading open-source assessment rather than as a fully verified description of the reactor. See David Albright et al., North Korea's ELWR: Finally Operational After a Long Delay (Institute for Science and International Security, 2024), https://isis-online.org/isis-reports/north-koreas-elwr-finally-operational-after-a-long-delay.

94 Hecker, 'North Korea's Yongbyon Nuclear Complex'; IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025); IAEA, Application of Safeguards in the Democratic People's Republic of Korea, GOV/2024/42-GC(68)/15 (IAEA, 2024); IAEA, Application of Safeguards in the Democratic People's Republic of Korea, GOV/2023/41-GC(67)/20 (IAEA, 2023); IAEA, Application of Safeguards in the Democratic People's Republic of Korea, GOV/2022/40-GC(66)/16 (IAEA, 2022); IAEA, Application of Safeguards in the Democratic People's Republic of Korea, GOV/2021/40-GC(65)/22 (IAEA, 2021).

6.2.2. Radiological-release risk

The reactor's relatively small size would generally imply a smaller radioactive inventory than that of a large commercial PWR, potentially limiting the scale of a severe release. Nevertheless, a significant local release could still have serious radiological consequences for personnel, nearby facilities, agricultural land and surrounding communities. Compared with the 5 MWe Magnox-type reactor, however, the ELWR potentially produces a larger radioactive inventory and therefore a greater release to the environment in case of a severe accident.

The principal difficulty in assessing the ELWR is therefore uncertainty rather than evidence of a high accident probability. A reliable quantitative assessment would require information on fuel inventory and burnup, reactor operating power, containment performance, emergency cooling, electrical redundancy and maintenance practices.[95] Such information is not publicly available and cannot be established through remote monitoring alone. The ELWR should therefore be regarded as presenting a potentially significant but poorly quantifiable radiological-release risk, with the greatest uncertainties surrounding the reliability of its cooling and safety systems and the effectiveness of its containment.

6.3. Conclusion

The two operating reactors at Yongbyon present different but similarly difficult safety-assessment problems. For the 5 MWe reactor, approximately four decades of intermittent operation make ageing of the graphite core and other safety-relevant systems an important concern, while current inspection, maintenance and component condition remain unknown. For the ELWR, the central uncertainties concern the as-built design, limited externally observable operating history, emergency heat-removal capability, electrical supply and containment performance.

Both reactors also depend on supporting water-control infrastructure that has been exposed to repeated hydrological stress, although available evidence does not establish that these events have caused a loss of reactor cooling. Severe accidents are technically plausible at either reactor, but open sources do not support credible accident-frequency estimates or site-specific source terms.

95 Niko Milonopoulos and Edward D. Blandford, '"Safety First—Not One Accident Can Occur": Nuclear Safety and North Korea's Quest to Build a Light', 38North, 3 April 2014, https://www.38north.org/2014/04/milonbland040314.

CHAPTER 7

Technical Risk Assessment III: Reprocessing, Spent Fuel and Waste

7.1. Spent Fuel Storage and Handling

7.1.1. Current conditions and evidence gaps

Spent fuel discharged from the 5 MWe graphite-moderated reactor is stored initially in the adjacent spent-fuel pond building before it is transferred for reprocessing. The fuel is metallic uranium clad in a magnesium alloy (Magnox), which is vulnerable to corrosion during prolonged wet storage. Historical DPRK measures, like lowering reactor operating temperatures,[96] if implemented consistently, would slow rather than eliminate degradation. The present condition of spent fuel is unknown. Information on fuel inventories, pond integrity, water-treatment equipment, maintenance and backup arrangements would be needed for an assessment of present storage conditions.

Satellite imagery in September–December 2024 showed excavation and construction near the spent-fuel building.[97] Jargal Chimedbazaryn, a former IAEA inspector, assessed that the activity was more likely associated with the adjoining "waste solution treatment building" wing than with direct spent-fuel handling.[98] The construction purpose remains uncertain, but it may suggest continued operational relevance of the pond and its support systems rather than evidence of a new storage configuration or a safety problem.

7.1.2. Corrosion, sludge and accident scenarios

Corrosion is a likely chronic hazard. Breach of the magnesium-alloy cladding can release fission products and corrosion products into pond water, while continued corrosion and fuel handling generate radioactive sludge. The pond must also maintain sufficient water depth to provide radiation shielding.[99] Experts have highlighted contaminated pond water, sludge accumulation and

96 Braun et al., North Korean Nuclear Facilities After the Agreed Framework; Orta et al., Avoiding Meltdowns and Blackouts.

97 Peter Makowsky, Jack Liu, Martyn Williams, et al., 'Yongbyon Nuclear Scientific Research Center: Construction Nearing Completion at Radiochemical Laboratory', 38 North, 6 January 2025, https://www.38north.org/2025/01/yongbyon-nuclear-scientific-research-center-construction-nearing-completion-at-radiochemical-laboratory/.

98 The inspector described the adjacent water-treatment building, which is connected to the spent fuel pond building and effectively forms a second wing of the same structure, as containing water filtration and cleaning equipment and assessed the 2024 work as more likely related to those functions than to direct spent-fuel handling. Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

99 Whang and Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities.

possible leakage as related concerns;[100] deterioration increases contamination, sludge complicates inspection and retrieval, and loss of pond or structural integrity could create a pathway for contaminated water to escape.

A fire hazard involving Magnox spent fuel is credible only under more specific conditions. Uranium hydride can form as uranium metal corrodes and can be pyrophoric, but spontaneous ignition would not normally be expected while fuel remains submerged. The hazard becomes more significant if damaged fuel is exposed by severe loss of water, or is removed, dried and handled without adequate control. International experience confirms that hydride-related ignition can occur during fuel handling and repackaging.[101]

Drawing on the DPRK's 1994 first-core discharge, Jargal Chimedbazaryn described the underwater canning of approximately 8,000 spent-fuel rods, alongside the management of around 200 damaged rods, as an exemplary operation that limited further degradation. In their assessment, the canning also reduced ignition risk. They noted that DPRK personnel gained substantial practical experience through the joint DPRK–US operation.[102] However, fuel discharged during later operating cycles apparently was not subjected to the same canning process, which, in their view, increased the risk of accidental ignition during handling and transport to the reprocessing plant.[103] Information on subsequent fuel cycles remains very limited.

Historical accounts also indicate that the DPRK possessed equipment for pond-water purification and sludge removal before 2002. Sludge generated by corrosion and canning operations was collected, packaged and transferred to a designated waste-storage area, and pond water was filtered.[104] Historical accounts also describe pond clean-up and purification as a substantial undertaking during periods of international cooperation, indicating that management of contaminated water and accumulated sludge could require considerable equipment, labour and specialist support.[105] Whether comparable treatment capability remains available and effective is unknown.

For acute pool safety, the principal scenarios are loss of cooling and, more importantly, sustained

100 Open Nuclear Network expert workshop, Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Programme.

101 Hugh Godfrey and Robin Strange, Contractor Report to RWM: Knowledge Status on Uranium Hydride, RWM/Contr/20/003 (2020), https://assets.publishing.service.gov.uk/media/61e6d273e90e0703731d3ade/RWM_Contr_20_003_-_Knowledge_Status_on_Uranium_Hydride_-_Nov_2020.pdf; Whang and Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities; David Albright, 'North Korea's Corroding Fuel', Science & Global Security 5 (1994): 89–97. UK operational experience cited by Godfrey and Strange includes hydride-related thermal or ignition events during decanning, examination and repackaging, illustrating the mechanism rather than a Yongbyon-specific frequency.

102 Jargal Chimedbazaryn recalled daily pond-level measurements, periodic water sampling and cleaning, and did not observe the pond level approaching a critical condition during the period of access. Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

103 Jargal Chimedbazaryn assessed that spontaneous ignition would not normally be expected while Magnox spent fuel remained submerged under normal pond-storage conditions. He considered the fire hazard to become more significant following severe loss of water or during removal and drying of degraded fuel, particularly where uranium hydride had formed beneath breached cladding. He noted that the likelihood would depend on factors including fuel burn-up, time since discharge, storage geometry, degree of oxidation, ventilation and heat removal. Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

104 Jargal Chimedbazaryn recalled collection of sludge in drums, use of submersible pumps and filters to clean pond water, and transfer of sludge drums and used filters to a designated storage pit before 2002. Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

105 Former inspector, in-person discussion with Open Nuclear Network, August 2026. Identity withheld at source's request.

loss of water inventory. A large pool water inventory provides shielding and thermal inertia, so loss of normal cooling does not by itself imply rapid fuel damage. The more consequential sequence would involve loss of water coverage or an inability to restore cooling and make-up water before fuel became exposed.[106] DPRK-specific uncertainty concerns the condition and redundancy of pumps, piping, instrumentation, electrical supply and make-up water. Recollections from historical inspections indicate that operators measured pond level daily and periodically sampled and cleaned the water, but current operational practices are unknown.[107]

7.1.3. Handling and transfer

Transfer from the spent-fuel pond to the Radiochemical Laboratory creates an additional period of vulnerability because containment, shielding, heat control and criticality safety must be maintained while potentially degraded fuel is lifted, packaged and transported.[108] A former IAEA inspector recalled that fuel rods were moved in baskets within a shielded cask carried by a large truck. They considered that the vehicle was a heavy-duty or military truck rather than a purpose-built nuclear-material transporter and assessed that the arrangement may not have matched international best practice, although numerous transfers were reportedly completed successfully.[109]

7.1.4. Overall assessment

The most plausible near- and medium-term concern is gradual degradation: Magnox-cladding corrosion, contamination of pond water, sludge accumulation and possible low-rate leakage. A major fire or release is considered a lower probability event and would require additional conditions, particularly severe loss of water or hazardous drying and handling of degraded fuel. The largest assessment gaps are current fuel inventory and condition, pond integrity, water-treatment capability, instrumentation, maintenance and emergency arrangements.

7.2. Radiochemical Laboratory Operations

7.2.1. Facility role and activities

The Radiochemical Laboratory receives irradiated fuel from the 5 MWe reactor and uses a PUREX-type process to separate and recover plutonium, generating high-, intermediate- and low-level radioactive waste as well as chemically hazardous process streams.[110] The process

106 OECD NEA, Status Report on Spent Fuel Pools under Loss-of-Cooling and Loss-of-Coolant Accident Conditions, NEA/CSNI/R(2015)2 (OECD NEA, 2015), https://www.oecd-nea.org/upload/docs/application/pdf/2021-02/csni-r2015-2.pdf; U.S. Nuclear Regulatory Commission, '9.1.3 Spent Fuel Pool Cooling and Cleanup System', Standard Review Plan, U.S. Nuclear Regulatory Commission, March 2007, https://www.nrc.gov/docs/ML0631/ML063190013.pdf.

107 Jargal Chimedbazaryn recalled daily pond-level measurements, periodic water sampling and cleaning, and did not observe the pond level approaching a critical condition during the period of access. Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

108 Whang and Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities; Godfrey and Strange, Contractor Report to RWM: Knowledge Status on Uranium Hydride.

109 Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

110 Whang and Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities; Olli Heinonen et al., 'North Korea's Yongbyon Nuclear Complex: Assessing Activity at the Radiochemical Laboratory', 38 North, 25 June 2021, https://www.38north.org/2021/06/north-koreas-yongbyon-nuclear-complex-assessing-activity-at-the-radiochemical-laboratory/.

consequently involves both highly radioactive fission-product streams and separated fissile material, which present different safety requirements and criticality considerations. Risk areas therefore extend beyond the reprocessing cells to liquid-waste storage, treatment, ventilation, transfer and supporting systems. Following renovation of the Laboratory's steam plant in 2024, the IAEA observed almost continuous steam plant operation from late January 2025, together with occasional chemical deliveries to the Laboratory, which is assessed to be consistent with a campaign to reprocess irradiated fuel from the 5 MWe reactor's sixth operational cycle.[111]

Figure 10: Radiochemical laboratory. 1 – fuel receiving building; 2 – main process building; 3 – metal processing; 4 – off-gas treatment; 5 – washing/decontamination; 6 – high level waste; 7 – low and intermediate level waste. 39.780 N, 125.752 E. 16 December 2025. Image: Airbus DS (2025)

The current inventory of waste generated from reprocessed material cannot be established from open sources. A 2005 technical assessment indicates that historical reprocessing campaigns could have generated substantial quantities of liquid high- and intermediate-level waste, uranyl nitrate and plutonium-bearing sludge, but the estimates were scenario-based rather than measurements of material currently stored at Yongbyon.[112] Current campaign history, tank inventories, waste chemistry, treatment status and the condition of supporting systems remain major uncertainties.

111 IAEA Director General, APPLICATION OF SAFEGUARDS IN THE DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA, Board of Governors General Conference GOV/2025/51-GC(69)/13 (IAEA, 2025), https://www.iaea.org/sites/default/files/gc/gc69-13.pdf.

112 Whang and Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities. A 2005 Sandia analysis modelled the waste arising from two assumed 50t U reprocessing campaigns and, assuming no waste-volume-reduction step, estimated approximately 500,000 litres of liquid high-level waste, 300,000 litres of intermediate-level waste and about 100 tonnes uranium equivalent of uranyl nitrate.

7.2.2. Treatment, storage and chronic degradation

Historical site-access evidence indicates that Yongbyon possessed several treatment and storage functions. A former IAEA inspector described treatment of lower-level waste through ion exchange, cementation and bituminisation, and reported that liquid high-level waste from earlier campaigns remained in interim storage. As of 2009, liquid high-level waste from the 1990 "hot test" and the concentrated waste from 2003 and 2005 campaigns remained in an interim high-level waste storage building. The inspector further stated that a concentrated high-level waste building was completed after 2009 to provide intermediate storage before solidification, increasing the site's capacity to accommodate further reprocessing campaigns.[113] This indicates that some waste-treatment and volume-reduction capability existed and was subsequently expanded, but available information does not establish the concentration method, resulting waste chemistry or implications for cooling and tank management.

Consulted experts further identified facilities for low- and intermediate-level waste storage, high-level waste storage, and concentrated high-level waste storage as areas of concern. They recalled very high radiation and contamination levels in parts of the area during 2007 visits but could not establish whether the system had robust secondary containment or other engineered barriers suitable for prolonged storage.[114] The current number and contents of tanks, their present condition and any post-2009 modifications remain unknown.

The most plausible chronic failure mode is thus gradual loss of containment through tank wall thinning, cracking, degraded seals or leakage from transfer lines. Even a small undetected release could contaminate structures, soil or groundwater over time. Poorly characterised sludge creates an additional management problem because the quantity, composition and fissile content of material at the bottom of tanks may be uncertain; disturbance during maintenance or retrieval could therefore introduce chemical, radiological, and, where sufficient fissile material has accumulated under unfavourable conditions, criticality hazards.[115]

Criticality is also a distinct process-safety hazard during reprocessing. Fissile material is handled in solution and may become more concentrated during separation, transfer or subsequent processing; criticality safety therefore depends on controls including material quantity, concentration, geometry, moderation and chemical conditions.[116] Historical descriptions of the Radiochemical Laboratory identify mixer-settlers and glove boxes for further plutonium processing, but open sources do not establish the current fissile inventories, process

113 Jargal Chimedbazaryn, former IAEA inspector, email correspondence with Open Nuclear Network, July 2026.

114 Open Nuclear Network expert workshop, Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Programme. Participants associated a building dedicated to low- and intermediate-level waste storage with approximately 25 liquid-waste tanks. Another building was associated with higher-level liquid waste, although the most contaminated areas were reportedly observed only from a gallery and not entered.

115 Whang and Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities. Open Nuclear Network expert workshop, Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Programme. Participants highlighted uncertainty over accumulated sludge and reported that criticality risks had not been systematically addressed in discussions during the site visits.

116 IAEA, Safety of Nuclear Fuel Reprocessing Facilities, text STI/PUB/2106 (IAEA, 2025), https://doi.org/10.61092/iaea.3egz-z7fy.

concentrations, equipment geometry, monitoring or criticality-control arrangements.[117] Consulted experts also noted that criticality risks were not systematically addressed in discussions during historical site visits.[118] This does not demonstrate inadequate controls, but leaves an important aspect of current process safety unresolved.

7.2.3. High-consequence accident scenarios

Separated plutonium also creates a particular contamination hazard because loss of confinement of plutonium-bearing solutions or other dispersible material can result in internal exposure, especially through inhalation. The relevant containment, ventilation, monitoring and plutonium-handling arrangements at Yongbyon are not publicly known.

Experts identified hydrogen or pressure build-up, resin fires, noble-gas releases and fire or explosion in high-level waste storage as potential higher-consequence scenarios, particularly if loss of power affected cooling, monitoring or pumping.[119] However, more information is needed about the specific waste chemistry, resin inventories, gas-generation mechanisms and control-system design to make specific determinations about the probability and magnitude of an event.

The 1957 Mayak accident, which occurred at the Soviet Union's first reprocessing plant near Kyshtym, illustrates the potential hazard posed by concentrated, liquid high-level waste. After an undetected cooling-system failure allowed a waste tank to boil dry, chemical reactions involving residual nitric acid and organic solvent caused an explosion that dispersed substantial radioactivity and contaminated a large downwind area. The case demonstrates how loss of cooling and adverse waste chemistry can produce a major release, but it is not directly comparable to Yongbyon, where tank design, inventories, chemistry and cooling arrangements remain insufficiently known.[120]

7.2.4. Overall assessment

The strongest evidence supports cumulative degradation rather than an imminent catastrophic event. Ageing tanks and transfer systems, poorly characterised sludge, uncertain inventories and possible loss of institutional knowledge could produce localised leakage that remains undetected for an extended period. A fire, explosion or substantial loss of radioactive liquid would have greater potential consequences but is less directly supported by site-specific evidence.

117 Whang and Baldwin, Dismantlement and Radioactive Waste Management of DPRK Nuclear Facilities.

118 Open Nuclear Network expert workshop, Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Programme.

119 Open Nuclear Network expert workshop, Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Programme.

120 G. Sh. Batorshin and Y. G. Mokrov, 'Experience in Eliminating the Consequences of the 1957 Accident at the Mayak Production Association', International Experts' Meeting on Decommissioning and Remediation After a Nuclear Accident, IAEA, Vienna, Austria, 28 February 2013, https://www-pub.iaea.org/iaeameetings/IEM4/Session2/Mokrov.pdf; Frank von Hippel et al., Plutonium - How Nuclear Power's Dream Fuel Became a Nightmare (Springer, 2019), 132–35, https://doi.org/10.1007/978-981-13-9901-5.

7.3. Waste Transfer, Buried Waste and Old Waste Sites

7.3.1. Site inventory and recent activity

Three waste locations are particularly relevant at Yongbyon: Building 500, the Old Waste Site and the Declared Waste Site. The evidence base differs across them, but all raise long-term questions about waste characterisation, package condition and stewardship. Recent observations from satellite imagery show renewed physical activity at Building 500 and the Old Waste Site, while historical inspection records provide the strongest information on the Declared Waste Site.

At Building 500, the principal concern is the combination of an ageing, partly buried structure, historically contaminated internal areas and uncertain package condition. At the Old Waste Site, re-exposure and new construction could represent inspection, retrieval, remediation or additional storage; imagery cannot determine which. The Declared Waste Site is better documented historically but still contains mixed legacy inventories for which present package condition is unknown.

Figure 11: Locations of the three main waste sites. 1 – Building 500; 2 – buried waste site declared to the IAEA; 3 – undeclared old waste site. 27 June 2026. Image: © 2026 Planet

7.3.2. Loss of containment, disturbance and transfer

Two common failure modes cut across the three sites. The first is gradual degradation of packages, tanks, pits or building barriers, potentially producing localised contamination over long periods. The second is disturbance during excavation, retrieval or transfer, when containment depends on package integrity, lifting and loading operations, temporary staging and transport. A dropped or damaged package, leaking tank or hose, or disturbance of contaminated soil could create a local release even where stored material had previously remained confined.

Figure 12: Undeclared waste site.
1 – unburied old waste site; 2 – newly constructed probable radioactive waste storage; 3 – ongoing excavation work.
39.787 N, 125.756 E. 16 December 2025. Image: Airbus DS (2025).

7.3.3. Overall assessment

The legacy waste sites constitute a long-term characterisation and stewardship problem rather than evidence of a current major release. Mixed waste forms, ageing structures, inconsistent records and recent construction or excavation create credible pathways for gradual loss of containment or disturbance-related releases. Consulted experts warned that any expansion of the DPRK's nuclear-energy activities would increase the waste-management burden and worsen the unresolved challenge of high-level waste.[121] The available evidence does not establish that major contamination is already occurring.

121 Open Nuclear Network expert workshop, Evaluating and Mitigating Environmental Risks Associated with the DPRK's Nuclear Programme.

CHAPTER 8

Environmental Pathways and Receptors

The preceding technical risk assessments examine which hazardous materials may be present, how releases could occur and which environmental medium might initially receive them.

This chapter considers what may happen next: how released material could move or persist, which human or ecological receptors could be exposed, and the possible geographic scale. It is a pathway-screening exercise rather than a quantitative assessment of consequences as information on inventories, release quantities, environmental conditions and monitoring data is insufficient from open sources.

The materials identified in the technical assessments include uranium-bearing liquids, slurries and particulates; radionuclides, metals, suspended solids and residual uranium-processing chemicals; UF_6 and its reaction products; contaminated spent-fuel water, corrosion products and radioactive sludge; and liquid or solid waste containing fission products, uranium, plutonium and other actinides. These categories identify materials potentially available for environmental transport rather than site-specific source terms.

Airborne releases may involve gases, vapours, aerosols or particulates transported by wind and subsequently inhaled or deposited onto soil, vegetation, surface water and other surfaces.[122] UF_6 presents both chemical and radiological considerations because it reacts with atmospheric moisture to form HF and uranium-bearing uranyl fluoride.[123] Noble gases may be transported over considerable distances and provide evidence of a release without producing significant deposition, whereas particulates can deposit and create more persistent surface contamination.[124] Detection at a distant location must therefore be distinguished from environmental consequence.

122 Prospective Radiological Environmental Impact Assessment for Facilities and Activities, text STI/PUB/1819 (IAEA, 2017), http://www.iaea.org/publications/12198/prospective-radiological-environmental-impact-assessment-for-facilities-and-activities.

123 Safety of Conversion Facilities and Uranium Enrichment Facilities, STI/PUB/2038, Safety Standards Series, No. SSG-5 (Rev. 1) (IAEA, 2022), http://www.iaea.org/publications/15077/safety-of-conversion-facilities-and-uranium-enrichment-facilities.

124 Sources and Measurements of Radon and Radon Progeny Applied to Climate and Air Quality Studies, text STI/PUB/1541, Proceedings Series 1541 (IAEA, 2016), http://www.iaea.org/publications/8573/sources-and-measurements-of-radon-and-radon-progeny-applied-to-climate-and-air-quality-studies; Prospective Radiological Environmental Impact Assessment for Facilities and Activities.

Contaminated liquids, slurries, runoff or drainage may enter surface water, where dissolved material can move downstream and particle-associated contaminants can accumulate in sediment.[125] Flooding and erosion may remobilise deposited material, while river flow influences downstream dispersion and dilution.[126] Soil may receive contamination through leakage, spills, atmospheric deposition, runoff or seepage. Groundwater is also relevant because soluble contaminants may migrate below the surface and potentially reach wells, rivers or other receptors.[127] However, assessing this pathway is particularly difficult in a constrained information environment because it requires knowledge of groundwater depth and direction, soil and rock permeability, fracture networks and connections with surface water. Proximity to a river therefore identifies a pathway requiring investigation rather than demonstrating that groundwater contamination would reach it.

Food-chain and ecological exposure may occur where contamination in air, water, sediment or soil intersects agricultural or aquatic systems, including through deposition onto crops, irrigation, livestock ingestion or uptake by aquatic organisms.[128] These pathways depend on contaminant form, environmental conditions, species and local practices, so the presence of farmland, rivers or fisheries identifies potential receptors rather than demonstrated exposure. Satellite imagery may reveal physical changes, drainage patterns or operational activity, while external monitoring may detect contaminants that have reached sampled locations. Neither generally characterises inaccessible soil, sediment or groundwater without direct sampling, leaving important local pathways and consequences unresolved.

8.1. Pyongsan

Pyongsan has a comparatively strong evidence base for identifying potential environmental release routes, but a substantially weaker basis for determining contaminant concentrations or resulting exposures. The technical assessment identifies uranium-bearing ore and particulates; tailings and process water that may contain radionuclides, ore-associated metals, suspended solids and residual chemicals; and radon as the principal materials of interest. Their precise composition and concentration remain unknown and depend on the ore and processing methods used.

8.1.1. Potential exposure pathways

Surface water is the most directly evidenced potential off-site pathway. The processing complex and tailings-storage system are separated by the Namchon River and connected by a tailings-transfer pipeline, while a separate ore-slurry pipeline carries crushed ore from the mine to the mill. Open-source analysis has reported recurring local spillage or leakage around the cross-river

125 Investigation of Site Characteristics and Evaluation of Radiation Risks to the Public and the Environment in Site Evaluation for Nuclear Installations, STI/PUB/2122, Safety Standards Series, No. SSG-92 (IAEA, 2025), https://doi.org/10.61092/iaea.4o4x-cn46; The Environmental Behaviour of Uranium, STI/DOC/010/488, Technical Reports Series, No. 488 (IAEA, 2020), http://www.iaea.org/publications/14688/the-environmental-behaviour-of-uranium.

126 Prospective Radiological Environmental Impact Assessment for Facilities and Activities.

127 Investigation of Site Characteristics and Evaluation of Radiation Risks to the Public and the Environment in Site Evaluation for Nuclear Installations.up

128 Prospective Radiological Environmental Impact Assessment for Facilities and Activities; The Environmental Behaviour of Uranium; Investigation of Site Characteristics and Evaluation of Radiation Risks to the Public and the Environment in Site Evaluation for Nuclear Installations.

transfer system, but the latest analysis suggests this has been addressed.[129] These observations identify routes by which material may leave intended parts of the waste-management system, but do not establish the composition, concentration or volume of the material involved.

The environmental behaviour of a pipeline release would depend on the material involved. Unprocessed ore slurry consists primarily of crushed uranium-bearing rock mixed with water, much of which could settle on nearby soil or river sediment, although finer particles could travel downstream.[130] Processed tailings may contain both fine residual solids and dissolved radionuclides, metals or processing chemicals. Dissolved contaminants could move with flowing water, while suspended material could be transported and subsequently deposited in sediment, potentially producing a wider aquatic impact.

Of the two streams, processed tailings are of greater potential relevance to groundwater because their dissolved constituents may infiltrate through the impoundment base or contaminated soil more readily than particulate ore slurry.[131] Contamination could persist underground and potentially reach wells, springs or the Namchon River.

Airborne exposure is most directly relevant within and around the mining and milling areas. Underground mine exhaust may contain radon, its progeny and ore dust, while crushing, grinding, leaching and concentrate drying can generate uranium-bearing dust or chemical aerosols.[132] These materials could be inhaled or deposited on nearby soil, vegetation and surface water, but no air monitoring, deposition sampling or dispersion modelling has been identified from which to establish an off-site footprint or resulting exposure.

Workers are the nearest potential receptors: miners could inhale radon, its progeny and ore dust, while milling and waste-management personnel could inhale processing emissions or come into direct contact with leaked ore slurry, tailings or wastewater.[133] Particulate or liquid contamination adhering to workers' skin, hair, clothing, footwear or equipment could be carried off site and transferred to households if workplace monitoring and decontamination were inadequate; radon exposure would not create this pathway. Soil, drainage channels and sediment around the pipelines and waste infrastructure could receive spilled or deposited material.[134] Farther downstream, aquatic organisms and communities using river water could be exposed if dissolved

129 38 North, 'North Korea's Pyongsan Uranium Mill: Operations Produce Environmental Damage While Extracting Uranium for Its Nuclear Program - 38 North: Informed Analysis of North Korea', 38 North, 27 August 2019, https://www.38north.org/2019/08/pyongsan082719/; Bryan Betts, 'No Signs That North Korea Dumping Uranium Waste into South's Waterways: Imagery', NK PRO, 2 July 2025, https://www.nknews.org/pro/no-signs-that-north-korea-dumping-uranium-waste-into-souths-waterways-imagery/.

130 The Environmental Behaviour of Uranium; Park et al., 'Assessing Uranium Ore Processing Activities Using Satellite Imagery at Pyongsan in the Democratic People's Republic of Korea', 2021.

131 Management of Residues Containing Naturally Occurring Radioactive Material from Uranium Production and Other Activities, text STI/PUB/1883, Safety Standards Series, No. SSG-60 (IAEA, 2019), http://www.iaea.org/publications/13515/management-of-residues-containing-naturally-occurring-radioactive-material-from-uranium-production-and-other-activities; The Environmental Behaviour of Uranium.

132 Occupational Radiation Protection in the Uranium Mining and Processing Industry, text STI/PUB/1890, Safety Reports Series, No. 100 (IAEA, 2018), http://www.iaea.org/publications/13401/occupational-radiation-protection-in-the-uranium-mining-and-processing-industry; Sulgiye Park et al., 'Assessing Uranium Ore Processing Activities Using Satellite Imagery at Pyongsan in the Democratic People's Republic of Korea', Science & Global Security 29, no. 3 (2021): 111–44, https://doi.org/10.1080/08929882.2021.1988258.

133 Occupational Radiation Protection in the Uranium Mining and Processing Industry.

134 Management of Residues Containing Naturally Occurring Radioactive Material from Uranium Production and Other Activities; The Environmental Behaviour of Uranium.

or suspended contaminants entered the Namchon and wider Ryesong systems, while agricultural systems could be affected through irrigation, livestock watering or sediment deposition. Seepage could affect groundwater and those using connected springs or wells. Nearby residents could also inhale windborne material, while vegetation, soil and surface water could receive deposition, if emissions dispersed beyond the site. These connections remain conditional because contaminant concentrations and local patterns of water and land use are not known.

8.1.2. Potential geographic extent and confidence

Available evidence supports the identification of potential occupational, near-site and local river-corridor pathways, but does not establish the presence or geographic extent of contamination. Material entering connected surface water could move through the Ryesong system, although the distance over which environmentally significant concentrations might persist would depend on the quantity, duration and composition of the release, river flow and sediment interactions.[135] No comparable basis exists for estimating the extent of groundwater or airborne transport.

ROK monitoring provides limited evidence concerning conditions farther downstream. In June 2026, uranium concentrations at seven downstream and coastal locations were reported as normal, following news reports on potential releases.[136] Intermittent releases, contaminants not included in the monitoring programme, or contamination retained closer to Pyongsan in the upper Ryesong system, sediment, soil or groundwater cannot be excluded.[137]

Determining actual consequences therefore requires sampling close to the facility and along the upper Namchon and Ryesong waterways.

8.2. Yongbyon

Yongbyon combines conversion and enrichment, reactor operation, spent-fuel management, reprocessing and radioactive-waste storage. This creates a wider range of potential airborne, surface-water, soil and groundwater pathways than at the other assessed sites.

8.2.1. Potential exposure pathways

The most directly evidenced physical connection with the Kuryong River is the engineered cooling-water infrastructure serving the reactors. Observed cooling-water discharges establish a route from the reactor area to the river, but do not indicate that the water contained radioactive material or establish that contaminated systems are connected to the outfalls.

135 The Environmental Behaviour of Uranium.

136 북한 평산 우라늄공장 폐수 우려 관련, '26년 2분기 정기모니터링 결과 '이상 없음' 확인 [Second-quarter 2026 monitoring concerning concerns over wastewater from the Pyongsan uranium facility finds no abnormalities], (Republic of Korea Ministry of Oceans and Fisheries), 19 June 2026.

137 The 1979 Church Rock incident provides context for the potential spatial scale of a major uranium-mill release. Failure of a tailings impoundment discharged approximately 94 million US gallons of tailings water and around 1,100 tons of solid tailings into the Rio Puerco, with abnormal concentrations of radionuclides and toxic elements recorded up to approximately 58 km downstream. However, this was a large, acute structural failure and differs substantially from the smaller or unquantified releases reported at Pyongsan.

For conversion and enrichment, loss of UF_6 confinement would principally create an airborne chemical-radiological pathway.[138] HF and uranium-bearing reaction products could disperse through the atmosphere, while deposited uranium could contaminate surfaces and soil and subsequently enter drainage.[139] Over time, deposited or leaked material could reach the Kuryong.

A reactor-derived release could create both atmospheric and waterborne pathways. A waterborne reactor pathway would require contaminated water to enter connected cooling-water or drainage systems, which open sources do not establish. Atmospheric transport would depend on the form of the released material, the release conditions, wind and precipitation.[140] Noble gases could travel considerable distances without producing persistent deposition, while radioiodine, radiocaesium and radioactive aerosols could be deposited onto soil, vegetation, surface water and buildings. Deposited material could subsequently enter terrestrial, food-chain and aquatic pathways. Iodine-131 could enter leafy vegetables, pasture and milk, while longer-lived radiocaesium could persist in soil and sediment. Material deposited within the Kuryong catchment could enter the river through runoff or erosion, with dissolved radionuclides moving downstream and particle-associated material accumulating in sediment and potentially being remobilised during later high-flow events.

Spent-fuel and waste-management activities create principally liquid and solid pathways. Reprocessing creates similar pathways but may also release radioactive noble gases and potentially volatile or particulate radionuclides through process off-gases or abnormal ventilation releases.[141] A reprocessing criticality accident would principally create an acute radiation hazard for workers and others close to the facility; it would create a contamination pathway only if radioactive material were also dispersed.[142] A fire involving plutonium-bearing solvents, resins or contaminated process material could carry radioactive particles in smoke or through abnormal ventilation, creating inhalation and deposition pathways on nearby soil, vegetation and surface water.[143] The potential extent cannot be estimated because the relevant inventories, material forms and confinement and filtration performance at Yongbyon are unknown.

Leakage of contaminated pond water or radioactive process and waste liquids could affect structures, adjacent soil or groundwater.[144] Sludge and other particle-associated material could become mobile if carried by water or disturbed during handling.[145] Conditioned solid waste is less mobile while contained, but degradation of packages or storage barriers, or disturbance during excavation, retrieval or transfer, could expose contaminated material to weathering, runoff or local airborne dispersion.[146] Outside the reactor cooling-water system, direct drainage and groundwater connections between these facilities and the Kuryong have not been established.

138 Safety of Conversion Facilities and Uranium Enrichment Facilities.

139 Prospective Radiological Environmental Impact Assessment for Facilities and Activities.

140 Prospective Radiological Environmental Impact Assessment for Facilities and Activities; IAEA, Environmental Sensitivity in Nuclear Emergencies in Rural and Semi-Natural Environments, IAEA-TECDOC-1719 (IAEA, 2013), http://www.iaea.org/publications/10507/environmental-sensitivity-in-nuclear-emergencies-in-rural-and-semi-natural-environments.

141 IAEA, Safety of Nuclear Fuel Reprocessing Facilities.

142 Criticality Safety in the Handling of Fissile Material, STI/PUB/1995, Safety Standards Series, No. SSG-27 (Rev. 1) (IAEA, 2021), http://www.iaea.org/publications/14883/criticality-safety-in-the-handling-of-fissile-material.

143 IAEA, Safety of Nuclear Fuel Reprocessing Facilities.

144 Storage of Spent Nuclear Fuel, STI/PUB/1882, Safety Standards Series, No. SSG-15 (Rev. 1) (IAEA, 2021), http://www.iaea.org/publications/13516/storage-of-spent-nuclear-fuel.

145 Prospective Radiological Environmental Impact Assessment for Facilities and Activities.

146 Storage of Radioactive Waste, STI/PUB/1254, Safety Standards Series, No. WS-G-6.1 (IAEA, 2017), http://www.iaea.org/publications/7441/storage-of-radioactive-waste.

Workers are the nearest potential receptors: conversion and enrichment personnel could inhale or come into contact with UF_6 reaction products, while reactor, spent-fuel, reprocessing and waste-management personnel could be exposed to airborne material, contaminated water, surfaces or waste.[147] Radioactive particulate or liquid contamination adhering to workers and their equipment could be carried off site and transferred to households if workplace monitoring and decontamination were inadequate; external irradiation and noble-gas exposure would not create this pathway. Soil and groundwater around the facilities, together with the Kuryong and its sediment, are the most relevant environmental receptors.[148] Nearby residents, agricultural systems and aquatic ecosystems could become exposed if airborne or waterborne contaminants reached areas of actual use. These connections remain conditional because environmental concentrations, groundwater movement and local patterns of water and land use are not known.

8.2.2. Potential geographic extent and confidence

The potential geographic extent of a release from Yongbyon would depend strongly on the pathway involved. Gradual leakage from spent-fuel, reprocessing or waste-management systems would most likely first affect buildings, adjacent soil or groundwater. The extent of any off-site movement cannot be estimated because direct drainage and groundwater connections between these facilities and the Kuryong River have not been established.

If contaminants reached Kuryong, the river could provide a route into the wider Chongchon system. The distance over which environmentally significant concentrations might persist would depend on the quantity, duration and form of the release, river flow, dilution and sediment interactions.[149] No local water, sediment or groundwater monitoring has been identified from which to determine whether such transport is occurring.

Available modelling provides limited context for atmospheric pathways. A 2014 safeguards-detectability study modelled assumed routine UF_6 losses from a hypothetical conversion facility near the enrichment plant.[150] Under its source-term and release-height assumptions, the highest uranium-particle concentrations occurred within approximately 0.4 km, while concentrations beyond 100 km fell below estimated natural background levels. Separate reactor-accident modelling placed the greatest modelled consequences close to and downwind of Yongbyon and indicated that rainfall could produce uneven deposition.[151] Neither study demonstrates an actual release or provides a reliable footprint for a future accident because the source terms, facility characteristics and meteorological conditions were assumed.

147 Safety of Conversion Facilities and Uranium Enrichment Facilities; Storage of Spent Nuclear Fuel; IAEA, Safety of Nuclear Fuel Reprocessing Facilities.

148 Prospective Radiological Environmental Impact Assessment for Facilities and Activities; IAEA, Environmental Sensitivity in Nuclear Emergencies in Rural and Semi-Natural Environments.

149 Prospective Radiological Environmental Impact Assessment for Facilities and Activities.

150 Sung-Woo Kwak et al., 'Estimation of Uranium Particle Concentration in the Korean Peninsula Caused by North Korea's Uranium Enrichment Facility', Journal of Radiation Protection 39, no. 3 (2014): 127–33, https://doi.org/10.14407/jrp.2014.39.3.127.

151 Taewook Kang and Moosung Jae, 'Consequence Analysis for Nuclear Reactors, Yongbyon', Journal of Nuclear Science and Technology 54, no. 2 (2017): 223–32, https://doi.org/10.1080/00223131.2016.1255572.

The 1957 Mayak accident illustrates the different spatial potential of an exceptional energetic waste release.[152] Loss of control of heat-generating liquid waste caused an explosion and an atmospheric contamination trace extending approximately 300 km. Mayak involved different waste chemistry, inventories, tank design and operating conditions and therefore provides no Yongbyon-specific distance. It demonstrates only that a sufficiently large and energetic radioactive-waste release could shift the principal pathway from local soil and groundwater contamination to wider atmospheric deposition.

Gaseous radionuclides have a different spatial significance. A 2026 peer-reviewed study associated anomalous radioxenon detections at several International Monitoring System stations with modelled emissions from Yongbyon and estimated that a facility there may be among the largest known radioxenon emitters globally.[153] The attribution and source term were model-derived and detecting radioxenon at considerable distance does not indicate persistent deposition or harmful exposure.

The central implication is that no single impact radius can be assigned to Yongbyon. Gradual liquid and solid-waste releases would most likely produce site-local or near-site contamination unless they reached connected groundwater or the Kuryong. Particle-bearing atmospheric releases could produce wider and uneven deposition during a severe event, while noble gases might be detected much farther away without creating a comparable contamination footprint.

8.3. Kangson

Kangson presents a more limited range of potential environmental hazards because this assessment considers only uranium-enrichment activities. UF_6, enriched uranium and depleted tails could create airborne, soil and water pathways following loss of confinement, but limited information on inventories, storage, drainage, groundwater and monitoring prevents determination of whether releases have occurred or how far they might extend.

8.3.1. Potential exposure pathways and receptors

The principal pathway is loss of confinement involving UF_6, enriched product or depleted tails. UF_6 reacts with atmospheric moisture to form hydrogen fluoride and uranyl fluoride, creating an immediate inhalation hazard and depositing uranium-bearing material on nearby surfaces and soil.[154] Rainfall could subsequently carry deposited material into drainage or groundwater.

The longer-term pathway depends partly on the form in which depleted tails are stored. Tails retained as UF_6 would preserve the same chemical-radiological pathway following loss of

152 G. Sh Batorshin et al., 'Experience in Eliminating the Consequences of the 1957 Accident at the Mayak Production Association', Meeting on Decommissioning and Remediation after a Nuclear Accident, 2013.

153 Daniel L. Chester et al., 'Investigating Anomalous Radioxenon Detections on the International Monitoring System Related to a Significant Source in East Asia', Journal of Environmental Radioactivity 291 (January 2026): 107836, https://doi.org/10.1016/j.jenvrad.2025.107836.

154 'Frequently Asked Questions About Gas Centrifuge Enrichment Plants', 12 March 2015, https://www.nrc.gov/materials/fuel-cycle-fac/faq?; IAEA, Application of Safeguards in the Democratic People's Republic of Korea (2025).

confinement.[155] Deconversion to uranium oxide produces a more stable, low-solubility solid, although a container breach or dispersal of the powder could still contaminate soil and, through waterborne transport, surface water or groundwater. The specific inventories, storage arrangements or waste-management systems are not known.

Workers and the immediate facility surroundings are potential receptors. Particulate contamination from uranyl fluoride or other uranium-bearing powders adhering to workers and their equipment could be carried off site and transferred to households if workplace monitoring and decontamination were inadequate; HF vapour exposure alone would not create this pathway. The Taedong River is also nearby, but uranium-bearing material could reach it only through connected surface drainage or groundwater. No such connectivity is observable in available satellite imagery.

8.3.2. Potential geographic extent

Available evidence supports principally site-local and near-site pathways. Smaller releases would be expected to produce local airborne exposure, deposition or drainage contamination unless material entered a connected watercourse.

The 1986 Sequoyah Fuels accident in Oklahoma, US, illustrates that a major UF_6 release can produce effects beyond a facility boundary.[156] Approximately 13.4 tonnes of UF_6 were released, with a plume containing hydrogen fluoride and uranyl fluoride reported to have travelled about 29 km downwind. The case demonstrates the potential for off-site transport but cannot be used to estimate a consequence distance at Kangson. Open sources do not establish Kangson's UF_6 inventory, cylinder types or storage arrangements, and plume extent would depend on the quantity and conditions of the release, meteorological conditions and local terrain.

No comparable basis exists for assigning a river-scale contamination distance. Such transport would require uranium-bearing material to enter drainage or groundwater connected to the Taedong, which available evidence does not demonstrate.

155 Final Supplemental Environmental Impact Statement for Disposition of Depleted Uranium Oxide Conversion Product Generated from DOE's Inventory of Depleted Uranium Hexafluoride - Summary (US Department of Energy Office of Environmental Management, 2020), https://www.energy.gov/documents/final-eis-0359-s1-and-eis-0360-s1-duf6-2020-2-chapterspdf-0?; 'Frequently Asked Questions About Gas Centrifuge Enrichment Plants'.

156 Doug Brugge et al., 'The Sequoyah Corporation Fuels Release and the Church Rock Spill: Unpublicized Nuclear Releases in American Indian Communities', American Journal of Public Health 97, no. 9 (2007): 1595–600, https://doi.org/10.2105/AJPH.2006.103044.

8.4. Conclusion

Across the three sites, the most probable environmental concern is local or near-site exposure. Pyongsan presents the clearest evidence of a surface-water release route, while Kangson's potential pathways centre on UF_6 and uranium-bearing material. Yongbyon presents the broadest range of pathways because it combines reactors, spent-fuel management, reprocessing, enrichment and radioactive-waste storage.

Transboundary effects could arise through different pathways. Pyongsan presents the clearest potential waterborne route through the Ryesong system. A severe atmospheric release from Yongbyon could carry radioactive gases, aerosols or particles southwards. At Kangson, transboundary effects would require a major airborne release or uranium-bearing material to enter connected drainage, reach the Taedong River and subsequently undergo marine transport towards ROK waters. In each case, contaminants would need to remain at environmentally significant concentrations despite atmospheric dispersion, deposition, sedimentation or dilution. The available evidence suggests that any transboundary effects in the ROK would likely be limited. Even under the severe Yongbyon accident scenarios assessed, modelling indicates that radiological exposure in the ROK would remain low.

CHAPTER 9

Climate and External Stressors

Climate change is considered here as a cross-cutting risk amplifier rather than a separate source of nuclear risk.

Before an abnormal event, it may place additional pressure on water supplies, electricity, drainage and access. During an event, it may affect several systems simultaneously or impede intervention. After a release, it may influence contaminant transport and complicate monitoring, response and remediation.

Available climate projections indicate that the DPRK will become hotter and wetter overall, but with greater variability and more severe extremes.[157] More intense rainfall and flooding may occur alongside drought and low-flow conditions, while erosion and landslide pressure may also increase.

Three related safety issues are relevant. First, changing environmental conditions may make historical hazard assumptions less representative over a facility's lifetime.[158] Open sources do not establish how regularly DPRK institutions review these assumptions or whether evolving climate risks are systematically incorporated into safety assessments. Second, external hazards may disrupt supporting systems, including cooling, electricity, drainage, communications and emergency access, before affecting principal nuclear structures. Third, compound, common-cause or sequential hazards may place several systems and lines of defence under pressure simultaneously. The consequences will depend on the facility, its operating state and the systems or personnel required to maintain safe conditions.

157 Catherine Dill et al., Converging Crises in North Korea: Security, Stability & Climate Change, ed. Francesco Femia et al. (Woodwell Climate Research Center, 2021); DPR Korea's Second National Communication on Climate Change Submitted under the United Nations Framework Convention on Climate Change (National Coordinating Committee for Environment & United Nations Environment Programme, 2012), https://unfccc.int/sites/default/files/resource/prknc2.pdf.

158 IAEA, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18 (IAEA, 2011), https://nucleus-apps.iaea.org/nss-oui/Content/Index?CollectionId=m_c47c2f7b-fc7c-4b87-a589-8dc3aa147af2&type=PublishedCollection; Paolo Contri, 'Climate Change Impact on the Safety of Nuclear Installations', Presentation to the US Nuclear Regulatory Commission Regulatory Information Conference, IAEA External Event Safety Section, 10 March 2022, https://www.nrc.gov/docs/ML2208/ML22081A364.pdf?utm.

9.1. Implications Across the Nuclear Fuel Cycle

9.1.1. Yongbyon

Climate change is most directly relevant to Yongbyon through the complex's dependence on the Kuryong River and associated water-control and cooling infrastructure. Projected increases in extreme rainfall and flooding are relevant at one end of the hydrological range, while warming, drought and low-flow conditions are relevant at the other. The principal question is therefore whether the site can maintain sufficiently stable water conditions as both high- and low-flow extremes become more demanding.

The relevant infrastructure has already demonstrated exposure to hydrological extremes. In August 2020, high water in the Kuryong River reached the pump houses serving the 5 MWe reactor and ELWR and submerged their bases.[159] The overflow dam that maintains the reactor cooling-water reservoir was also submerged. The principal nuclear buildings were not reported to have been inundated, neither reactor appeared to be operating at the time of the flooding, and subsequent imagery did not identify significant damage to the pump houses.

The subsequent sequence is more significant. After the floodwaters receded, imagery showed a breach at the eastern end of the overflow dam, which substantially reduced the maintained reservoir level and exposed the reactor intake cisterns.[160] Analysts assessed that, had the reactors been operating, the resulting water level would have been insufficient to supply cooling water through the existing pump and cistern arrangement.[161] This remains a counterfactual assessment rather than evidence that cooling was actually lost, since the reactors were apparently not operating. It nevertheless shows a credible sequence in which excessive water damages infrastructure intended to stabilise water availability, producing a subsequent risk of insufficient water.

Later observations indicate that this was not an isolated exposure. High water again overflowed the reactor-area dam and filled the channels towards both pump houses in July 2022.[162] Further downstream, water-control infrastructure supporting the southeastern part of the complex was also affected by high water, while the principal buildings were assessed not to be at immediate risk of inundation. This provides additional evidence that supporting water infrastructure may be exposed before the main nuclear buildings. In early 2025, ice-related damage breached sections

159 Peter Makowsky, Frank Pabian, Jack Liu, Jenny Town, et al., 'North Korea's Yongbyon Nuclear Center: Significant Flooding of the Kuryong River', 38 North, 12 August 2020, https://www.38north.org/2020/08/yongbyon081220/.

160 Peter Makowsky, Frank Pabian, Jack Liu, Jenny Town, et al., 'North Korea's Yongbyon Nuclear Center: Drying Off', 38 North, 25 September 2020, https://www.38north.org/2020/09/yongbyon092520/.

161 Peter Makowsky, Frank Pabian, Jack Liu, and 38 North, 'North Korea's Yongbyon Nuclear Center: Flood Damage Repairs Underway', 38 North, 22 October 2020, https://www.38north.org/2020/10/yongbyon202210/.

162 Joseph S. Bermudez Jr. et al., 'Yongbyon Update: New Activity at Building 500 and Rising Waters', Beyond Parallel, 11 July 2022, https://beyondparallel.csis.org/yongbyon-update-new-activity-at-building-500-and-rising-waters/.

of the overflow dam and prompted construction of a temporary earthen barrier.[163] Heavy rainfall and flooding later that year breached the overflow dam again. The latter event was not assessed to have interrupted reactor operations, and construction of a more substantial replacement subsequently followed. These observations do not demonstrate inadequate maintenance or protection, but they show recurrent hydrological stress and repeated repair of infrastructure relevant to reactor cooling.

Low-flow conditions are also directly relevant to Yongbyon's cooling-water system. In 2018, satellite imagery showed refurbishment of the earthen dam forming the Kuryong River reservoir, which analysts assessed was most likely intended to provide a more consistent cooling-water supply during periods of low river levels and dry weather.[164] A subsequent assessment described the reservoir as maintaining sufficient water depth for the cooling systems of both reactors regardless of variations in river flow.[165] These observations indicate that maintaining adequate water levels during lower-flow conditions was already an operational consideration in the design and management of the cooling-water system. They do not, however, demonstrate that drought has previously caused a loss of cooling or other nuclear-safety failure.

The strongest documented shared dependency concerns the water-control infrastructure serving the two reactors. The overflow dam is intended to maintain the reservoir used by both the 5 MWe reactor and the ELWR, although each has its own pump-house arrangements. The available evidence therefore supports the possibility that damage to common reservoir infrastructure could affect both reactor cooling-water systems. It does not establish that all components of the two cooling systems are shared or that the loss of the dam would necessarily result in simultaneous loss of cooling at both reactors.

Potential future climate-related pressures at Yongbyon include increased flood frequency, with one screening-level assessment estimating that a flood classified as a 1-in-100-year event under the 1971–2000 baseline could occur approximately once every 68 years by 2050.[166] Although limitations in elevation data prevent assessment of impacts on individual facilities, more frequent or severe flooding could disrupt supporting infrastructure, including electricity, drainage, communications and access, even without directly affecting principal nuclear structures. Continued drought and low-flow risk could reduce the water available for reactor cooling, while higher air and water temperatures could further reduce cooling efficiency. The greatest concern may arise where hazards coincide; flooding could restrict access when pumps, dams or electrical equipment require repair, while low river flows could occur alongside high temperatures and increased cooling demands. Such compound conditions could also reduce the capacity to manage an unrelated equipment failure or abnormal event.

163 Peter Makowsky, Jack Liu, and Iliana Ragnone, 'Yongbyon Nuclear Scientific Research Center: Snowfall Shows Activity', 38 North, 7 March 2025, https://www.38north.org/2025/03/yongbyon-nuclear-scientific-research-center-snowfall-shows-activity/; Peter Makowsky, Jack Liu, and Iliana Ragnone, 'Yongbyon Nuclear Scientific Research Center: Modernization and Expansion in 2025', 38 North, 21 November 2025, https://www.38north.org/2025/11/yongbyon-nuclear-scientific-research-center-modernization-and-expansion-in-2025/.

164 38 North, 'North Korea's Yongbyon Nuclear Scientific Research Center: Work Continues on 5 MWe Reactor's Cooling System', 38 North, 9 August 2018, https://www.38north.org/2018/08/yongbyon080918/.

165 Frank Pabin et al., 'Update on Yongbyon: More Dredging Around the Reactor Cooling System; Flooding Tests the Reservoir Dam's Integrity', 38 North, 7 September 2018, https://www.38north.org/2018/09/yongbyon090718/.

166 Dill et al., Converging Crises in North Korea: Security, Stability & Climate Change.

9.1.2. Pyongsan

Climate change is relevant to Pyongsan principally through the complex's dependence on water and the location of its waste-management infrastructure around the Namchon River. The technical assessment in Chapter 5 identifies water management, drainage, erosion and waste transfer as relevant issues. Climate change does not introduce a new failure mechanism, but heavier rainfall could increase the demands placed on these systems.

The 2020 typhoon season provides more direct evidence of local exposure to severe hydrological conditions. Satellite imagery analysis found that the main processing facilities and tailings impoundment appeared to have been spared direct damage from the typhoons and rising waters.[167] However, flood damage was visible along the adjacent river, including the loss of part of a bridge approximately 500 metres upstream and damage to other crossings and water-control infrastructure in the surrounding area. The event therefore shows that climate-related impacts are already evident in the immediate vicinity of the complex, even though the principal processing and waste-management facilities have not yet been observed to be directly affected.

Closer to the plant, a small breach developed at the western end of the agricultural dam immediately east of the main complex between June and October 2020.[168] A footbridge across the Namchon connecting a nearby settlement with the western support area was also washed away during the 2020 typhoon season and had not been rebuilt by October 2021. Later imagery from October 2021 showed recent rainfall again causing water to overflow the agricultural dam, although no additional damage was evident and the nearby road bridge remained usable.[169] These observations reinforce the conclusion that local access and water-control infrastructure may be affected before the main facilities themselves sustain direct damage. Available evidence does not establish that either the agricultural dam or the footbridge performed a safety-critical function, or that their damage disrupted plant operations.

The tailings system itself has continued to operate through these events. Satellite imagery analysis in 2021 showed both pump houses operating and continued redistribution and accumulation of tailings within the impoundment, while imagery from 2022 and 2023 continued to indicate active processing and increasing tailings accumulation.[170] This demonstrates continued use of the system. Taken together, these observations suggest that the documented flood-related damage did not cause an observable sustained interruption to the system's main operations. They do not exclude, however, temporary disruption or damage that was not visible in satellite imagery.

Potential future climate-related pressures at Pyongsan are likely to arise primarily from more intense rainfall and flooding. No site-specific projection has been identified, although a

167 Peter Makowsky et al., 'Pyongsan Uranium Mines: Despite Typhoons, Mining and Processing Operations Continue', 38 North, 12 November 2020, https://www.38north.org/2020/11/pyongsan201112/.

168 Joseph S. Bermudez Jr. et al., 'Recent Activity at the Pyongsan Uranium Concentrate Plant (Nam-Chon Chemical Complex) and January Industrial Mine', Beyond Parallel, 26 March 2021, https://beyondparallel.csis.org/recent-activity-at-the-pyongsan-uranium-concentrate-plant-nam-chon-chemical-complex-and-january-industrial-mine/.

169 Joseph S. Bermudez Jr et al., 'Current Status of the Pyongsan Uranium Concentrate Plant (Nam-Chon Chemical Complex) and January Industrial Mine', Beyond Parallel, 8 November 2021, https://beyondparallel.csis.org/current-status-of-the-pyongsan-uranium-concentrate-plant-nam-chon-chemical-complex-and-january-industrial-mine/.

170 Peter Makowsky, 'Pyongsan Uranium Mines: Mining Continues as Older Mines Are Renewed', 38 North, 7 March 2023, https://www.38north.org/2023/03/pyongsan-uranium-mines-mining-continues-as-older-mines-are-renewed/; Makowsky et al., 'Pyongsan Uranium Mines'.

screening-level assessment for Sariwon, elsewhere in North Hwanghae Province, estimated that a flood with a historical 1-in-100-year return period could occur approximately once every 57 years by 2050.[171] This provides regional context but cannot determine future flood conditions at Pyongsan. Heavier rainfall and runoff could increase pressure on tailings storage, drainage, erosion control, embankments, waste-transfer systems and access routes, while high river levels could affect the river-crossing pipeline and waste-management area. Rainfall would not itself make pipeline failure more likely, but leakage during flooding could be more difficult to detect, contain and repair. Flooding could also affect pumps, wastewater treatment and electrical infrastructure simultaneously, potentially interrupting systems needed to manage rising water levels or waste transfers. However, drainage capacity, flood protection, backup electricity, system redundancy and temporary storage arrangements are not publicly documented, meaning the extent or probability of an accident is unknown. These interactions therefore represent potential climate-sensitive pressures rather than evidence that the tailings system will fail or that its existing safety margins will be exceeded.

9.1.3. Kangson

Kangson sits in proximity to the Taedong River, and the wider river system to which it belongs has reportedly experienced substantial high-water conditions. In August 2020, DPRK authorities issued flood alerts for the Taedong basin after forecasting 150–300 millimetres of rainfall and water levels above warning thresholds.[172] In August 2022, heavy rainfall again raised the Taedong sufficiently to inundate riverside pathways in Pyongyang, while authorities adjusted the West Sea Barrage to manage river levels.[173] These events demonstrate hydrological extremes within the wider river system, but cannot be used to infer flooding at Kangson.

Potential future climate-related pressures at Kangson include heavier rainfall, flooding and higher temperatures. Intense rainfall could increase local surface runoff and place greater demands on drainage even without flooding from the Taedong River, while high river levels could impede drainage if a hydraulic connection exists. However, no site-specific evidence establishes such connectivity or whether flooding would reach safety-relevant structures. Higher temperatures could increase demands on cooling, ventilation and other environmental-control equipment while also raising electrical loads. The greatest concern may arise from compound conditions: heavy rainfall or flooding could restrict drainage and access while severe weather may disrupt electricity or communications, or high temperatures could increase cooling demand during a loss or reduction of power. This could place simultaneous pressure on confinement, ventilation, monitoring and material-control functions, depending on the facility's operating state. As cooling margins, flood protection and electrical redundancy are not publicly documented, these interactions represent potential climate-sensitive pressures rather than demonstrated vulnerabilities or evidence that existing operating margins would be exceeded.

171 Dill et al., Converging Crises in North Korea: Security, Stability & Climate Change.

172 Oh Seok-min, 'Major River Passing through Pyongyang at Risk of Flooding', North Korea, Yonhap News Agency, 5 August 2020, https://en.yna.co.kr/view/AEN20200805001751325.

173 Chae Yun-hwan, 'N. Korea Issues Heavy Rain Alert for Southern Regions', North Korea, Yonhap News Agency, 9 August 2022, https://en.yna.co.kr/view/AEN20220809003800325.

9.2. Conclusion

Climate change is most likely to amplify existing dependencies across the DPRK nuclear programme rather than create a distinct accident scenario. The strongest evidence concerns Yongbyon, where flooding has repeatedly affected water-control infrastructure supporting reactor cooling and low-flow conditions are already an operational consideration. At Pyongsan, severe rainfall and flooding have damaged nearby infrastructure, while pipeline leakage could become more difficult to contain and repair during high water. Evidence of direct exposure at Kangson is limited, although its observable cooling capacity makes higher temperatures and reliable electricity relevant considerations.

Across the sites, climate pressures may stress cooling, electricity, drainage and access before an abnormal event; impair supporting systems or intervention during an event; and complicate contaminant monitoring and response after a release. The concern is greatest where flooding, drought or heat affect several functions simultaneously.

CHAPTER 10

Cross-Facility Synthesis of Nuclear Safety and Environmental Risks

The preceding chapters identify substantially different safety and environmental concerns across the DPRK nuclear fuel cycle.

Figure 13 brings these findings together, distinguishing concerns supported more directly by available evidence from higher-consequence scenarios that depend on additional conditions or remain poorly characterised.

FACILITY / NFC ACTIVITY	HAZARDOUS MATERIAL OR SOURCE OF HAZARD	PRINCIPAL SAFETY FUNCTIONS / BARRIERS	EVIDENCE-SUPPORTED CONCERNS	CONDITIONAL OR HIGHER-CONSEQUENCE SCENARIOS	RELEASE PATHWAYS, FIRST RECEPTORS AND LIKELY SCALE	KEY UNCERTAINTIES AND EXTERNAL DEPENDENCIES
PYONGSAN URANIUM MINING AND MILLING COMPLEX	Uranium-bearing ore and dust; radon; ore slurry; tailings and process water containing residual radionuclides, metals and processing chemicals; leaching reagents	Mine ventilation and occupational controls; integrity of ore- and tailings-transfer pipelines; tailings confinement and stability; water and drainage management	Continuous generation of large volumes of tailings and wastewater. Recurring spillage or leakage has been reported around the cross-river tailings-transfer system, together with wastewater drainage from the site. Radon, ore dust and processing chemicals create occupational hazards. Seepage from the impoundment is plausible but has not been established.	Major tailings-impoundment failure; large pipeline rupture; serious chemical spill or process accident. No full breach of the tailings impoundment could be identified.	Workers are the nearest receptors. Soil, drainage channels and sediment around the process and waste infrastructure are the most immediate environmental receptors. Surface-water transport through the Namchon/Yesong system is the clearest off-site pathway; groundwater transport remains poorly characterised. The evidence principally supports occupational, near-site and local river-corridor concern. ROK monitoring in 2026 found no abnormal uranium concentrations at the sampled downstream and coastal locations, which does not resolve conditions closer to Pyongsan or contaminants that were not measured.	Release composition and concentration; discharge rates; tailings-liner or subsurface condition; groundwater direction; mine ventilation and worker monitoring; local water and land use. Heavy rainfall and high water could increase runoff and erosion and make an existing leak harder to detect or repair; nearby infrastructure has been damaged during severe flooding, although the principal tailings system continued to operate.
YONGBYON URANIUM FUEL FABRICATION PLANT AND ENRICHMENT FACILITIES, INCLUDING POSSIBLE BUILDING-J	UF_6 and its reaction products; enriched and depleted uranium; uranium-bearing residues; conversion chemicals where present	Process and cylinder confinement; ventilation; cylinder and piping integrity; cooling and electrical supply; criticality controls; drainage and waste management	The site combines active conversion and enrichment with refurbished legacy conversion infrastructure and newer enrichment construction. The condition of UF_6 cylinders, process piping and confinement systems cannot be observed externally. Repeated small leaks, degraded cylinders or equipment, contaminated ventilation/drainage systems and depleted tails are credible longer-term concerns.	Substantial UF_6 or other hazardous-chemical release following loss of confinement, cylinder damage, process failure or fire. Criticality is a potentially severe worker/facility hazard but is less directly connected to routine environmental transport in the evidence reviewed.	A substantial UF_6 release would create an immediate near-field HF and uranium-compound inhalation hazard, followed by deposition of uranium-bearing material on surfaces and soil. Workers and the immediate site would be affected first. Deposited material could later enter drainage; a direct connection from these facilities to the Kuryong has not been established.	UF_6 inventory and cylinder condition; process configuration; ventilation and filtration; confinement boundaries; criticality controls; maintenance; drainage; emergency arrangements. Power loss, flooding and heat could challenge ventilation, monitoring, cooling and drainage, although the current resilience of these systems is unknown.
KANGSON SUSPECTED URANIUM-ENRICHMENT FACILITY	UF_6; enriched uranium product; depleted tails and other uranium-bearing material	Confinement; cylinder/material handling; ventilation; cooling and electrical supply; criticality controls; drainage	Available evidence supports enrichment activity, but no on-site conversion line has been established. The principal concerns therefore relate to UF_6 handling and storage, depleted tails, process confinement and supporting systems. Conversion-specific chemical hazards should not be assumed.	A substantial UF_6 loss of confinement could produce an acute HF/uranium-compound exposure hazard. Criticality is technically relevant to enrichment but cannot be characterised from the available site information.	Workers and the immediate facility surroundings are the most plausible first receptors. Uranium-bearing material could deposit on soil or enter drainage. Transport to the nearby Taedong would require a connected surface-water or groundwater pathway that has not been established. The available evidence therefore supports principally site-local and near-site concern.	Material inventories; enrichment configuration; cylinder and piping condition; ventilation; depleted-tails form and storage; drainage and hydrogeology; cooling margins; backup power and flood protection. Evidence of direct climate exposure at the site remains limited.
YONGBYON 5 MWE REACTOR	Irradiated reactor fuel and associated fission-product inventory; graphite-moderated reactor systems	Reactivity control; heat removal; confinement of radioactive material; reliable instrumentation and electrical support	The reactor has operated since the 1980s. Historical reporting identifies ageing components and dependence on operator intervention in some systems. The most clearly documented current external dependency is the Kuryong cooling-water system: the reservoir and overflow dam have experienced repeated flooding, ice damage and repair. These events did not establish an actual loss of reactor cooling.	Loss of adequate heat removal or another severe reactor accident could damage fuel and create an atmospheric release.	Workers and the reactor site would be affected first. A severe atmospheric release could produce deposition farther downwind; contaminated water could enter the Kuryong only if radioactive material reached connected cooling or drainage systems. No single impact radius can be assigned from current evidence.	Condition and redundancy of cooling systems; reactor-control and protection systems; electrical supply and backup power; instrumentation; confinement; emergency cooling and response. Flooding, low river flow, heat and ice are relevant because of the demonstrated dependence on shared water-control infrastructure.

Figure 13: Facility Overview and Nuclear Safety Risks

FACILITY / NFC ACTIVITY	HAZARDOUS MATERIAL OR SOURCE OF HAZARD	PRINCIPAL SAFETY FUNCTIONS / BARRIERS	EVIDENCE-SUPPORTED CONCERNS	CONDITIONAL OR HIGHER-CONSEQUENCE SCENARIOS	RELEASE PATHWAYS, FIRST RECEPTORS AND LIKELY SCALE	KEY UNCERTAINTIES AND EXTERNAL DEPENDENCIES
YONGBYON EXPERIMENTAL LIGHT WATER REACTOR (ELWR)	Irradiated fuel and fission-product inventory associated with reactor operation; detailed inventory not publicly known	Reactivity control; heat removal; confinement; instrumentation and electrical support	Indications of commissioning and operation have been observed since 2023. Detailed design and safety arrangements remain unavailable publicly. The ELWR has its own pump-house arrangement but shares the reservoir and overflow-dam system with the 5 MWe reactor, creating a documented hydrological dependency.	Severe loss of cooling or another reactor accident could lead to fuel damage and release. The present evidence is insufficient to identify a credible ELWR-specific source term, containment performance or accident frequency.	A severe release could create atmospheric deposition and, if contaminated water entered connected systems, a waterborne pathway.	Reactor and containment design; core and fuel characteristics; safety-system redundancy and independence; emergency cooling; electrical supply; instrumentation and operating history.
YONGBYON SPENT-FUEL POND AND TRANSFER OPERATIONS	Metallic uranium Magnox fuel; fission and corrosion products; contaminated pond water; radioactive sludge	Confinement; subcriticality; heat removal; radiation shielding; maintenance of water inventory and chemistry; safe retrieval and transfer	Magnox cladding is susceptible to corrosion during prolonged wet storage. The strongest concerns are possibly continued fuel degradation, contaminated pond water, sludge accumulation and possible low-rate leakage. Historical evidence shows that water treatment and sludge removal were practised, but the present capability is unknown.	Sustained loss of water coverage could expose degraded fuel. Drying or poorly controlled handling of heavily corroded fuel could create an ignition hazard where uranium hydride has formed. Fuel transfer creates an additional period of vulnerability.	Workers and the pond building are the nearest receptors. Loss of pond integrity could release contaminated water into structures, soil or groundwater. A handling fire could create a local airborne pathway. The evidence more strongly supports local degradation and contamination than a large atmospheric release.	Current fuel inventory and cladding condition; pond integrity; water chemistry and treatment capacity; sludge inventory; pumps and make-up water; instrumentation; electrical supply; current handling procedures and emergency arrangements.
YONGBYON RADIOCHEMICAL LABORATORY — REPROCESSING OPERATIONS	Irradiated fuel; plutonium, uranium and fission-product-bearing process streams; radioactive off-gases; acids, solvents and other process chemicals	Prevention of criticality; process confinement; radiation shielding/ protection; ventilation and filtration; controlled chemical processing and transfer	Reprocessing activity generates highly radioactive and chemically hazardous streams. Recent steam-plant operation and chemical deliveries have been assessed as consistent with a further reprocessing campaign. Direct information on current internal equipment condition and operating controls is unavailable.	Criticality accident; fire involving contaminated process material, solvents or resins; abnormal ventilation/off-gas release; process-chemical accident. A criticality event would primarily be an acute worker hazard unless radioactive material were also dispersed.	Workers and internal facility areas are the first receptors. Process liquids could produce local contamination following loss of confinement; volatile or particulate material could enter the atmosphere through an abnormal release. The extent cannot be estimated without source-term and filtration information.	Fissile-material and process inventories; process chemistry; criticality controls; cell and piping condition; ventilation/filtration; instrumentation; fire protection; current radiation-protection practice.
YONGBYON WASTE STORAGE ASSOCIATED WITH THE RADIOCHEMICAL LABORATORY	Liquid high-/higher-activity and intermediate-level radioactive waste; uranium-bearing solutions; potentially plutonium-bearing sludge; exact present inventories unknown	Tank and transfer-line confinement; secondary containment; monitoring; cooling, ventilation or pumping where required by waste characteristics; criticality control during storage and retrieval	Historical evidence establishes liquid-waste storage and highly contaminated areas. The best-supported concern is gradual loss of containment from ageing tanks, seals or transfer lines. Poorly characterised sludge creates additional problems during maintenance or retrieval. Current tank contents and condition are unknown.	Major tank failure or substantial liquid release; gas or pressure build-up; fire or explosion where the necessary waste chemistry and loss-of-cooling conditions exist. These scenarios have potentially greater consequences but are much less constrained by DPRK-specific information.	A chronic leak would most likely affect the building, nearby soil or groundwater first. An energetic event could create an atmospheric pathway. Direct hydrological connectivity between the storage facilities and Kuryong River has not been established.	Number and contents of tanks; waste chemistry and heat load; tank and line condition; secondary containment; sludge composition and fissile content; cooling and power requirements; leak detection; local hydrogeology.
YONGBYON BUILDING 500	Conditioned radioactive and chemically hazardous waste; historically highly contaminated internal areas; waste drums stored in pits	Waste-package integrity; pit/building containment; shielding; safe access and retrieval	Historical accounts describe conditioned waste stored in two large pits and highly contaminated internal areas. The partly buried structure and present package condition are concerns. Excavation or material movement has been observed nearby, but its purpose is unknown.	Damage to packages or contaminated structures during excavation, retrieval or transfer could produce a local release. The present evidence does not support a distinct large off-site accident scenario for this facility.	Primarily building- and site-local contamination: soil, dust, runoff or groundwater if containment is lost. Workers undertaking access or retrieval would be the nearest receptors.	Waste inventory and classification; package condition; condition of pits and building; purpose of recent activity; contamination extent; retrieval arrangements and local groundwater.

FACILITY / NFC ACTIVITY	HAZARDOUS MATERIAL OR SOURCE OF HAZARD	PRINCIPAL SAFETY FUNCTIONS / BARRIERS	EVIDENCE-SUPPORTED CONCERNS	CONDITIONAL OR HIGHER-CONSEQUENCE SCENARIOS	RELEASE PATHWAYS, FIRST RECEPTORS AND LIKELY SCALE	KEY UNCERTAINTIES AND EXTERNAL DEPENDENCIES
YONGBYON OLD WASTE SITE	Legacy liquid-waste tanks and solid-waste compartments; new semi-buried structure of uncertain inventory	Integrity of tanks, compartments and cover; confinement; controlled retrieval/repackaging	A previously covered waste area was re-exposed in 2023, revealing tanks and compartments; a new semi-buried structure was installed in 2025. The contents and condition of older storage units remain unknown. Historical comparison suggests an IRT-associated waste-storage design whose suitability for long-term high-level waste storage was questioned by a former inspector.	Leakage from an old tank or compartment; release during exposure, retrieval, repackaging or renewed use.	Expected effects are principally site-local unless mobile material enters groundwater, drainage or becomes airborne during disturbance.	Current inventory and activity; tank and compartment integrity; function of the new structure; groundwater conditions; contamination beneath the site; purpose and controls associated with renewed activity.
YONGBYON DECLARED WASTE SITE	Mixed legacy dry waste from several Yongbyon facilities, including spent-fuel canning sludge, filters and debris; historical temporary liquid-waste storage/transfer	Integrity of pits and containers; cover and isolation; recordkeeping; controlled retrieval and transfer	The site is comparatively well documented historically and is currently covered. No recent externally visible activity has been identified. The principal concern is the unknown long-term condition of packages and the mixed legacy inventory rather than evidence of an active release.	Package failure or disturbance during future retrieval/transfer could create local contamination.	Mainly local soil, subsurface and occupational pathways unless material is mobilised during retrieval or water intrusion.	Package/container condition; exact inventories and records; subsurface water ingress; contamination beneath the pits; future retrieval or transfer arrangements.

CHAPTER 11

Policy-Relevant Implications

The findings point to two kinds of action. Some work can begin without access to DPRK facilities: archival recovery, imagery analysis, external monitoring, preparedness and public communication.

Other measures, such as more direct sampling, facility assessment, operator training and waste stabilisation, require cooperation or an emergency request. Preparations for the second group should, however, begin before an opening occurs.

Preserve knowledge from earlier periods of access

Much of the best information on DPRK facilities and safety practices still resides with former IAEA inspectors, KEDO personnel, US technical teams and other specialists who had direct access to Yongbyon. Much of this experience is already decades old. A structured knowledge-preservation programme should be established while these sources remain available, alongside recovery of relevant IAEA, KEDO, ROK and US archival material.

Maintain remote monitoring capabilities

Satellite imagery remains the most consistent source of current information and should be continuously leveraged to track changes in infrastructure and operational patterns relevant to safety; in particular: the cooling-water system and waste facilities at Yongbyon, the tailings impoundment and transfer system at Pyongsan, and external cooling and support infrastructure at Kangson. Environmental monitoring is most useful when it is sustained over time and accompanied by clear reporting of methods and detection limits. ROK water-quality and radiological monitoring should be maintained as a continuous effort. Authorities should consider publishing sampling locations, dates, analytes, detection limits, methods and the interpretation placed on the results. If direct environmental access becomes possible, the first priority should be the areas where the report identifies plausible release routes, particularly Yongbyon's spent-fuel and waste-management areas and the Pyongsan tailings and drainage system.

Prepare technical capacity before it is needed

A future opportunity for cooperation may arise through diplomacy or in response to a safety incident. Technical preparation should not wait for that moment. Relevant organisations should retain expertise on issues such as Magnox fuel, radioactive-waste management, uranium processing, environmental sampling and emergency assessment, together with deployable procedures and equipment. This is particularly important for Magnox fuel, where first-hand operational expertise is becoming increasingly scarce as experienced practitioners retire. ROK authorities and relevant international organisations should develop scenario-specific assessment protocols covering both chemical and radiological hazards. A UF_6 release, for example, requires different protective and sampling decisions from a reactor release, contaminated river discharge or loss of liquid high-level waste. Further, any future arrangement involving facility shutdown or dismantlement should include waste characterisation and stabilisation from the outset; these activities require specialised analytical capability, equipment and storage arrangements that cannot be improvised once access begins.

Consider nuclear safety as an area for future engagement

Nuclear safety will not be an easy or apolitical subject of discussion. It is inseparable from facilities that support the DPRK's weapons programme, and technical engagement should not be presented as a substitute for engagement on safeguards, arms control or denuclearisation. It may nevertheless provide a practical area in which all parties have an interest in preventing accidental harm. Early engagement need not begin with access to sensitive production areas. Possible first steps include: establishing emergency contact points; exchanging non-sensitive information on external hazards; discussing flood, cooling-water and power resilience; reviewing general notification and assistance procedures; and conducting tabletop exercises based on hypothetical events. Worker protection, environmental sampling methods and the management of ageing or legacy waste may offer further areas for discussion.

A staged approach would allow cooperation to expand as confidence and access permit. Information exchange could be followed by joint workshops, training, observation of exercises, environmental baseline work and eventually facility-specific assessment. The IAEA, the ROK and other technically capable states and organisations should establish, in advance, what expertise and equipment they could offer, through which channel, and under what legal and political conditions if the DPRK requested help.

Ensure technically grounded public information

Discussion of DPRK nuclear safety can intensify when there are reports of a possible release or fears of contamination reaching the ROK. Public authorities should communicate monitoring results in terms that distinguish detection from exposure and explain what a negative result can actually exclude. The same standard should apply to independent analysis. Sustained support for technically competent research, imagery analysis and environmental assessment would help reduce the space for both exaggerated claims and unsupported reassurance. The consequences of a release within the DPRK also deserve attention even where no measurable cross-border effect occurs.

CHAPTER 12

Conclusion

This report finds that the most credible nuclear-safety and environmental risks in the DPRK are likely to develop gradually and remain concentrated close to the facilities where they originate.

At Pyongsan, the clearest concerns arise from the routine production and management of tailings and process water. At Yongbyon, spent fuel, radioactive liquid waste and older waste-storage areas present longer-term management problems whose present condition cannot be independently assessed. Conversion and enrichment add a separate set of chemical hazards associated with uranium hexafluoride and uranium-bearing residues. More severe accidents are technically possible, but the available evidence provides much less basis for judging their likelihood.

The historical record also complicates any simple assumption that these risks stem from a lack of technical expertise. DPRK personnel have demonstrated competent operating practice in a number of documented cases and have worked effectively with international specialists. The greater uncertainty lies in the institutions and systems around them. External observers cannot establish whether equipment deterioration is consistently detected, whether corrective action is timely, or whether regulatory oversight and emergency arrangements remain effective across the programme. Much of the direct evidence on these questions dates from periods of access that ended many years ago.

The potential geographic extent depends on the release mechanism, material form, quantity and environmental conditions. Most scenarios examined would affect workers, nearby land, local groundwater or adjacent river systems first. Dissolved contaminants could move downstream, while particle-associated material could accumulate in sediment and later be remobilised. Airborne material would disperse with distance, although deposition could be uneven. Available evidence and modelling do not support an expectation that the chronic and localised releases identified in this report would produce significant environmental or health effects in the ROK. A major atmospheric release or other high-consequence accident could produce a different pattern, but the report does not find evidence that such an event should be treated as the most likely outcome.

Climate and severe weather add further pressure to this picture. Repeated damage to water-control infrastructure at Yongbyon shows that supporting systems can be exposed even when the principal nuclear buildings remain intact. Similar events around Pyongsan could make an existing release harder to detect or contain. These pressures reinforce the value of continued monitoring and preparedness without providing evidence that a nuclear accident is imminent.

Many of the largest uncertainties cannot be resolved without renewed access to the DPRK. Others can be reduced now. Former inspectors and participants in earlier periods of cooperation still hold facility-specific knowledge that will become harder to recover with time. Historical records can be preserved and compared against longer satellite-imagery and environmental-monitoring baselines. Maintaining that body of knowledge, together with the technical expertise needed to interpret new evidence, would leave governments and international organisations better prepared for a future diplomatic opening or a request for assistance after an incident. Much of that knowledge is still recoverable. It will not remain so indefinitely.

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