SATELLITE IMAGERY ANALYSIS OF NUCLEAR FACILITIES USING AI AND THERMAL DATA: A CASE STUDY OF THE YONGBYON NUCLEAR CENTRE IN THE DPRK

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Abstract

Taking the Yongbyon Nuclear Research Centre in the Democratic People's Republic of Korea as a case study, the paper examines two complementary approaches that can enhance safeguards-relevant analysis. First, it demonstrates the use of artificial intelligence and machine-learning methods for image enhancement, feature extraction, and the assisted identification of objects and changes over time. Second, the paper assesses the added value of repeated thermal infrared data for identifying facility-scale heat-related behaviour. Thermal data can provide additional evidence of operational status when compared against historical baselines and other safeguard-relevant information. Together, these approaches can strengthen safeguards-relevant monitoring by improving analytical capacity and efficiency, expanding the range of observable indicators, and supporting the review of growing multi-sensor imagery datasets.

1. INTRODUCTION

Satellite imagery is an established source of safeguards-relevant information for the International Atomic Energy Agency (IAEA) [1-4]. Growing imagery volumes require efficient review without reducing expert oversight, while optical imagery alone provides a limited range of indicators of facility activity. AI-assisted analysis can support the first, while thermal infrared (TIR) imagery can expand the range of observable indicators.

The paper elaborates on earlier methodological work introduced by Open Nuclear Network (ONN) [5]. It focuses on the Yongbyon Nuclear Research Centre in the Democratic People's Republic of Korea (DPRK). Artificial intelligence (AI) was applied to electro-optical imagery for super-resolution, change detection (CD) and object detection (OD), with analyst validation of the outputs. Separately, repeated high-resolution TIR observations were manually analysed for facility-scale thermal behaviour. The paper evaluates these workflows for monitoring, structured analysis, historical baselining and analyst prioritisation.

2. DATA AND ANALYTICAL APPROACH

The optical dataset consisted of 59 high-resolution images from Airbus Pléiades Neo (0.3 m native ground sample distance (GSD)) and Planet SkySat imagery (~0.5 m native GSD) acquired between 3 January 2024 and 16 December 2025. Imagery was acquired using continuous tasking orders throughout the study period. Cloud-free acquisition opportunities were tasked and scheduled where available, although the resulting coverage varied because of weather and seasonal conditions. The imagery therefore provides repeated observations over time, but not at regular intervals. The TIR component consisted of 22 Constellr collections from 7 September 2025 to 25 January 2026. The same general approach was used, with possible cloud-free acquisition opportunities scheduled where possible. As with the optical imagery, the timing of successful collections varied because of weather and seasonal conditions. AI performance depends on imagery quality, training data and site characteristics, and super-resolution may introduce artefacts. TIR interpretation is affected by atmosphere, emissivity, viewing geometry and mixed pixels; sharpening does not remove the native thermal-resolution limit.

ONN partner SI Analytics (SIA) applied its proprietary SuperX model to the optical imagery, producing enhanced outputs at GSD equivalents of 0.15 m for Pléiades Neo and 0.25 m for SkySat [5]. The same workflow was used for both sensors. Enhanced outputs were treated as analytical aids and checked against original imagery to manage possible artefacts.

SIA's proprietary CD and OD models, developed, trained and fine-tuned for DPRK monitoring, were then applied to selected areas of interest. CD compared co-registered images from different dates to identify candidate infrastructure and land-use changes, while OD identified selected objects, primarily vehicles. Analysts manually reviewed candidate outputs against original imagery for false positives, missed detections and misclassifications;

no automated output was treated as validated before review. Validated CD and OD outputs were exported as polygons, tables and GeoJSON layers for analysis in a geographic information system.

The TIR imagery was analysed manually to assess repeated facility-scale thermal behaviour as an additional indicator of operational status when interpreted against surrounding areas, optical imagery and site history [5].

3. AI-ASSISTED IMAGERY ANALYSIS

3.1. Super-resolution

SuperX-enhanced imagery supported direct analyst review by making small objects and subtle site features easier to distinguish and was also used as input to downstream AI-assisted analysis. Fig. 1 compares native Planet SkySat imagery of the 5 MWe reactor with the corresponding enhanced output. Because enhanced imagery may contain reconstruction artefacts, automated findings were checked against the original imagery. This study did not separately compare CD or OD performance using native versus SuperX-enhanced inputs.

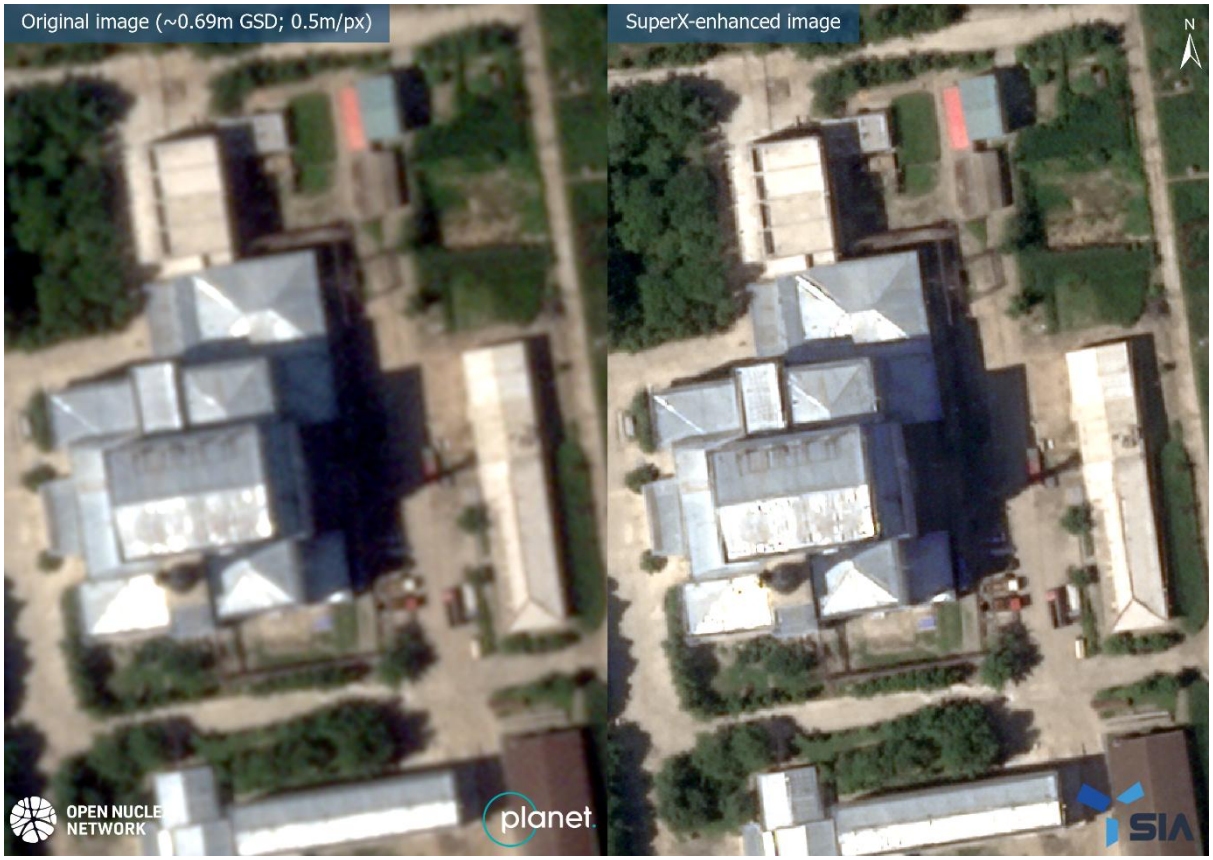


FIG. 1. The 5 MWe reactor at the Yongbyon Nuclear Research Centre in native Planet SkySat imagery (left) and the corresponding SuperX-enhanced output (right), 27 July 2025 (39.797 N, 125.755 E). Imagery © 2026 Planet; SuperX processing © SI Analytics.

3.2. Change detection

CD helped identify candidate changes for further analyst review. Infrastructure change included construction and demolition, excavation and backfilling, damage to or loss of infrastructure such as bridges or dams, and the appearance or disappearance of site features or objects relative to earlier imagery.

3.3. Object detection

OD was used primarily to identify road vehicles, railcars, and vessels.

Vehicle detection was applied to imagery from both 2024 and 2025. For this study, the 2025 results were selected as an initial demonstration. Analyst-validated vehicle detections from 33 high-resolution Planet and Airbus images acquired in 2025 were combined into map layers and heatmaps [10]. Fig. 2 shows vehicle activity near the Radiochemical Laboratory.



FIG. 2. Analyst-validated vehicle detections near the Radiochemical Laboratory. 16 Dec 2025. 39.768 N, 125.753 E. Image: © Airbus DS (2026). More at the ONN's interactive map, Detected Vehicle Activity at Yongbyon Nuclear Center (2025) [10].

The resulting vehicle detections support comparison across different Yongbyon areas and dates and contribute to historical activity baselines.

The broader AI-assisted analysis also identified smoke and cooling-water discharge. Cooling-water discharge provided a more facility-specific indicator of activity. Analyst-validated observations at the 5 MWe reactor and Experimental Light Water Reactor (ELWR) were converted into a chronological table. Repeated observations can support assessments of reactor operational status when compared with visible steam, facility history and other safeguards-relevant information (Table 1).

TABLE 1. AI-ASSISTED COOLING-WATER DISCHARGE OBSERVATIONS AT THE 5 MWe REACTOR AND ELWR

Date	**20 Jan**	**30 Jan**	**14 Feb**	**10 Apr**	**21 Apr**	**23 Apr**	**23 Apr**	**24 May**	**26 May**
5 MWe	O	O	O	O	Cloud	Cloud	O	Cloud	O
ELWR	O	O	O	NO	NO	Cloud	NO	Cloud	O
Date	**28 May**	**4 Jun**	**5 Jun**	**9 Jun**	**10 Jun**	**12 Jun**	**16 Jun**	**23 Jun**	**11 Jul**
5 MWe	O	O	O	O	O	O	O	O	O
ELWR	O	NO	NO	O	NO	O	O	O	O
Date	**27 Jul**	**2 Aug**	**11 Aug**	**14 Aug**	**5 Sep**	**13 Sep**	**21 Sep**	**14 Oct**	**22 Oct**
5 MWe	O	O	O	O	O	O	O	O	O
ELWR	O	O	NO	NO	NO	NO	NO	O	NO
Date	**1 Nov**	**10 Nov**	**11 Nov**	**21 Nov**	**2 Dec**	**16 Dec**			
5 MWe	O	O	O	O	O	O			
ELWR	NO	NO	NO	NO	O	O			

Table 1. "O" (Observed) means that discharge was identified and confirmed by analyst review. "NO" (Not observed) means that no signature was identified in the available image; it does not establish absence. Source: adapted from SIA nK Insight report of 31 December 2025 [11].

4. THERMAL DATA AS AN INDICATOR OF FACILITY ACTIVITY

TIR imagery adds a complementary analytical layer by measuring emitted radiance rather than reflected light. Constellr observations assessed relative facility-scale heat behaviour over time and were interpreted against surrounding areas, optical imagery and historical site knowledge [5]. Fig. 3 shows selected, cloud-free observations.

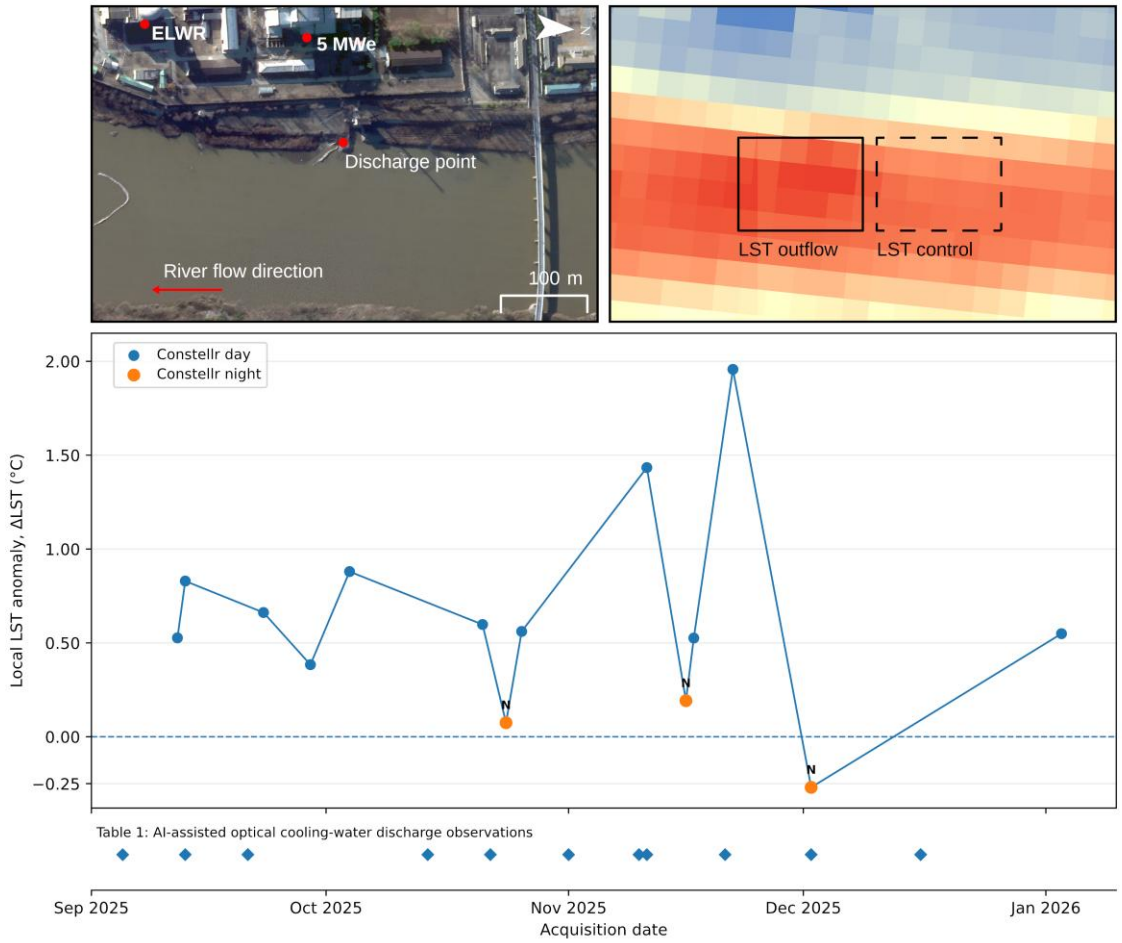


FIG. 3. Multi-sensor observations of cooling-water-related thermal behaviour at the 5 MWe reactor. (Top left) Optical reference imagery acquired on 21 November 2025 showing the 5 MWe reactor cooling-water discharge point and river-flow direction. (Top right) Nighttime Constellr LST observation acquired on 16 November 2025, displayed using a locally stretched blue–red scale; boxes indicate the outflow and control areas used for the quantitative comparison. (Bottom) The control area was selected in the same river reach, upstream of the cooling-water discharge point and outside the expected thermal influence of the outflow. Its proximity to the outflow area was intended to provide a local background reference under broadly comparable environmental and observational conditions. Local thermal anomaly at the cooling-water outflow, calculated as the difference between the outflow and nearby control area ($\Delta LST = LST_{outflow} - LST_{control}$. Daytime and nighttime Constellr acquisitions are distinguished by marker type, and diamonds indicate dates of AI-assisted, analyst-validated optical observations of cooling-water discharge reported in Table 1. The weaker nighttime contrasts illustrate acquisition-dependent variability in the TIR signal and should not be interpreted independently as evidence of inactivity; optical and thermal observations provide complementary indicators. Optical Image © 2025 Planet Labs All Rights Reserved. Reprinted by permission; TIR data © Constellr.

Persistent relative warmth at a facility, changes in river temperature or heat associated with electrical infrastructure may be consistent with facility use and support assessment of operational status. Conversely, a sustained absence of an expected thermal signature may support, but cannot independently confirm, inactivity.

For safeguards, TIR observations could be used to compare the thermal behaviour of a specific facility with its declared operational status, helping to assess it against State-declared information, inspector observations and other sources. On the other hand, an unexpected thermal signature could identify a location for follow-up analysis or consideration in planning of inspection.

5. OUTLOOK FOR SAFEGUARDS-RELEVANT ANALYSIS

Together, super-resolution, CD, OD and TIR observations address two IAEA safeguards needs: managing expanding imagery volumes and broadening observable indicators [6]. In this study, SuperX-enhanced imagery was also used as input to downstream CD and OD models. While this can support analysis of small features, artefacts introduced during super-resolution could spread into subsequent automated detections. Outputs, therefore, require validation against the original imagery. Validated AI-assisted outputs could contribute to foundation geospatial datasets and Structured Observation Management, support historical site baselines and comparison across imagery dates, and prioritise further review [6–9]. Although demonstrated only at Yongbyon, the workflow is transferable to other nuclear sites and could assist preliminary analysis, comparison with State-declared information and other safeguards-relevant sources, and preparation for on-site inspection activities.

Future AI/ML work should prioritise cross-sensor and cross-site validation. Operational integration requires standardised data and metadata, quality assurance, secure access and traceability to the original imagery. Key risks include acquisition gaps, limited transparency of proprietary algorithms, processing constraints and information-security requirements.

For TIR analysis, further work should evaluate emerging commercial sensors against safeguards-specific requirements, including spatial resolution, revisit frequency, acquisition timing and the ability to distinguish facility-scale thermal behaviour from seasonal variability. Higher-resolution and more frequent observations in the future would improve its utility, development of historical thermal baselines and comparison with optical indicators, but repeated observations and corroboration will remain necessary.

A further priority is the integration of these approaches. AI/ML could help identify locations or periods requiring closer review, while TIR could provide an independent indicator of facility behaviour. Future development should further focus on integrated multi-sensor, time-series workflows in which automated outputs remain traceable to the original data and are assessed by analysts alongside other safeguards-relevant information.

6. CONCLUSION

The Yongbyon case illustrates how AI/ML can be combined with repeated TIR observations: AI supports imagery screening, task prioritisation and structured geospatial records, while TIR data adds a distinct indicator of heat-related behaviour. Together, these approaches could strengthen historical baselines, consistency analysis

and the identification of developments requiring further review. However, their contribution remains analyst-centred; analytical process traceability, validation, corroboration and qualified interpretation are essential.

ACKNOWLEDGEMENTS

This paper drew on a larger project in which the Verification Research, Training and Information Centre and ONN assessed the DPRK's nuclear capabilities. The project was undertaken with the James Martin Center for Nonproliferation Studies and the Royal United Services Institute, with funding from Global Affairs Canada.

The authors acknowledge the use of GPT-5.6 Sol (accessed August 2026), to support preparation of the manuscript through copy-editing and formatting. All AI-generated suggestions were reviewed, revised, and approved by the authors, who take full responsibility for the accuracy and integrity of the work.

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