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Finding the Limits of Open-Source Analysis to Uncover Clandestine Facilities

Abstract

Open-source investigations have demonstrated remarkable results by identifying and informing analysis of nuclear-related facilities. Satellite imagery, combined with other methods such as media monitoring and technical literature analysis, has demonstrated the ability to consistently provide new insights into known facilities. In some rare instances, these analyses have been able to uncover clandestine facilities. The limitations and expected sensitivity of these methods to identify clandestine facilities is not well understood. We provide an overview of integrated open-source analyses to analyse nuclear-related facilities and discuss tools and emerging techniques for identifying clandestine nuclear facilities. Moreover, we will evaluate the potential limits of these tools: i.e., with current and emerging capabilities which kinds of facility would we expect to be able to identify and with what confidence; particularly in the case of North Korea.

Keywords:

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1. Introduction

When it comes to North Korea, why can we find some facilities but not others? How many facilities are there in the world today related to fissile material production where we do not know their location, purpose, operational history and capacity? And, how many of these are in North Korea? Since 2000, clandestine nuclear facilities have been uncovered in Syria[2], North Korea and Iran and there are unconfirmed reports of undisclosed facilities in Saudi Arabia [1]. With available tools, including media monitoring, remote sensing and data analytics, NGOs have been able to identify and uncover some of these facilities using Open Source Intelligence (OSINT). But why can we find some facilities but not others, even if their existence is known or inferred?

In North Korea, the issue of clandestine facilities is especially pertinent. Experts that closely follow DPRK-US relations do not expect successful nuclear negotiations to take place without a change in position from at least one party [2]. Yet, if negotiations do take place. the facilities North Korea has not declared will be key to negotiations. In the 2017-2018 Leader Summits, the Trump administration reportedly rejected an offer to decommission the Yongbyon nuclear complex, containing all DPRK known plutonium production, uranium conversion and a gas centrifuge enrichment facility, as it would not constitute complete denuclearisation [3]. North Korea holding back, *inter alia*, a parallel clandestine HEU production pathway will remain a dealbreaker in any future negotiations.

The issue of unidentified facilities in North Korea goes beyond those inferred by intelligence community (IC) assessments. The Sunchon/Wolbisan mine was declared to the IAEA over 30

[2] The existence of the facility in Syria at Al Kibar was unknown until it was destroyed by an Israeli Air Strike.

years ago but its location is not confirmed.[3] From IC assessments it is thought that there is at least one more facility in the enrichment programme [3] and there may be other facilities from multiple components of the fuel cycle. In particular, for the enrichment programme to operate independently of Yongbyon a clandestine conversion facility would be required.

The use of remote sensing by NGOs for applications in arms control and nonproliferation has developed as commercial capabilities have improved in temporal, spatial and spectral resolution. Remote sensing of nuclear programmes can be divided into two primary applications: monitoring of known facilities and identification of previously unknown facilities. This paper is concerned with the second variety and the findings are based on a workshop with NGO experts in DPRK satellite imagery analysis held in Washington DC in May 2023.

There is a rich existing literature on methodologies to quantify the ability to identify clandestine facilities, led by acquisition pathway analysis designed for states where there is sufficient data but would be challenging to apply to North Korea [4]. There are also studies of how to uncover activity or increase the understanding of individual stages of the fuel cycle; including uranium sources and milling [5], reactors [6] and enrichment [7].

For all the challenges in finding clandestine facilities, there have been remarkable results from NGOs using OSINT, particularly with remote sensing, to uncover nuclear-related facilities. This paper explores the lessons learned from successful identifications of clandestine facilities; the limitations of current tools and methods and emerging tools and data analysis techniques.

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[3] Probable location 39°27'38.87"N, 126° 3'4.01"E

2. Lessons from identifications of clandestine facilities

What are the tools available for remote sensing?

Electro-Optical (EO) satellite imagery is the most widely available and most accessible tool for remote sensing analysis. In this context, Google Earth and other geo-mapping tools have revolutionised access to EO satellite imagery. Google Earth's time slider feature includes older imagery from 1m+ resolution down to 50cm and newer commercial imagery ranges from 31-50 cm[4]. In addition to purchasing available imagery and accessing free imagery, satellite companies allow customers to request imagery from specific locations. Temporal resolution, or the revisit rate, can now be up to multiple images per day, although acquisition of such a high revisit rate may be limited by budget and the increased cost of tasking.

Beyond EO imagery, commercial and archival remote sensing is available for infrared (IR)[5] and synthetic aperture radar (SAR).[6] Hyperspectral imagery, which uses a high number of bands has been available at low resolution from the Hyperspectral data, from the Hyperion sensor, aboard NASA's EO-1 satellite is available at 30m resolution [5].

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[4] Each pixel would be up to 30x30 cm. 30 cm resolution is sufficient to read tail numbers from aircraft or distinguish between types of vehicles, which may not be possible at lower resolutions.

[5] Landsat IR at 60m resolution is available from 1972 with the launch of Landsat-1 to Landsat-9 launched in 2021 which has 30m resolution.

[6] The European Space Agency's Sentinel, ERS-1, ERS-2 and Envisat data became available in 2014 and has 10-25m resolution (dependent on the mode and satellite).

How practicable is it to regularly scan an entire state for clandestine facilities?

NGOs do not have the capacity to regularly scan the globe or specific states of interest for nuclear related facilities. A search for a clandestine facility must be targeted. Successful searches require a 'signature' that is identifiable in available imagery that links a facility or specific building to the nuclear programme. This is relatively straightforward when identifying declared facilities with remote sensing, but is very challenging when a state is attempting to hide the existence of a facility.

Google Earth is a particularly user-friendly tool that enables rapid scans over a large area, and includes historical imagery. Yet, the temporal resolution of images is typically not sufficient, without a targeted image collection strategy, to see facilities of interest under construction. This can be one of the most valuable signatures.[7]

How are clandestine facilities uncovered?

Finding clandestine facilities does not come down to untargeted scans over a large area. In very few cases, such as the 2021 discoveries of the Chinese Missile Silos [8, 9] there is a clear overhead visual signature. Searches need a starting point, rely on interpretations of the analyst and require cross-checking and internal and external scrutiny. In many cases, a region or facility may be monitored over a long period of time before there is sufficient evidence to link it to a nuclear programme.[8]

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[7] This may not apply in North Korea if the facility is built after the construction of a roof, in a tunnel or is a re-purposed facility all of which prevents seeing what is under construction.

[8] Comments from a private workshop, held in May 2023.

Why begin a search for a clandestine facility?

Typically a search for a facility is prompted by another source of information, which could be a government source, privately or through the press [10], a VIP visit with ground imagery [11-13] or prompted from the results of another clandestine facility analysis [9].

How is the initial geographical region for the search chosen?

Searches can commence with a name associated with a geographic region[9] [14], from searches of similar or known facilities, [11] or by inferring that facilities may share common infrastructure so may be close by [9], or through other integrated OSINT analysis [13].

3. Limitations in searches for clandestine facilities

If a facility has no distinct signature – identifiable using overhead imagery – then any link between an observed facility and the nuclear programme will be low confidence. In the case of Suncheon-Wolbisan mine, it is highly likely the mine has been observed without linking it to the nuclear programme: there are large number of conventional mines in North Korea with clear signatures. Also, the ore for North Korean uranium at Pyongsan mine is thought to be either black shale [15] or anthracite coal [16]. As such there are no electro-optical signatures to distinguish a uranium mine from a conventional mine.

In North Korea, in particular, it is difficult for an analyst to identify the real purpose of facilities. First, the North Koreans are playing a game of remote sensing bluff with the US IC, not NGOs,

[9] In the case of Kangson, a clandestine facility related to the enrichment programme, the name of the facility was though a source chain altered to be 'Kangsong' associated with a different region.

and are quite adept at operating at night, putting sensitive facilities under a roof to make overhead monitoring more challenging. They also attempt to dictate when they want to disclose information, such revealing the uranium enrichment plant at Yongbyon to the Los Alamos delegation in 2010 [17]. Second, since before the Korean War of the 1950s, the country is rife with tunnels. Many tunnels predate satellite imagery so we cannot observe their construction or purpose without increased temporal resolution to observe what is entering and exiting. Moreover, tunnels are often difficult to observe – the North Koreans have placed many buildings adjacent to hills and mountains that may or may not be entrances to underground complexes. Third, North Korea frequently repurposes existing facilities without notable alterations to the exterior.

Within these limitations, NGOs may monitor a site of interest, that has been 'pinned' for months or years while evidence on the purpose of the facility can be gathered. Interior and exterior imagery of a facility can be key – an analyst may be able to link a facility with an indeterminate purpose with a military programme by linking features from images taken years apart at from different perspectives.

4. Emerging tools and techniques

Advances in analytical techniques are divided into two types: newly available remote sensing, either from newly available government data or new commercial satellites, and the use of AI and advanced data analytics for image processing and analysis.

Artificial intelligence, machine learning and advanced data analytics

The use of AI by arms control and nonproliferation NGOs in satellite imagery analysis is in an exploratory phase. One of the principal uses of AI is in change detection, which can be applied to monitoring known facilities, but also could be used to support an analyst for area scans. Object

detection – where AI searches for an object had been demonstrated in other use cases of overhead imagery analysis but is more challenging for nuclear-related facilities. This has been applied in the DPRK to track rail cars at nuclear sites [18].

The difficulty is that machine learning needs a large quantity of data for training, but most identified nuclear facilities have few common overhead imagery features. Uranium mills may have distinctive features such as mixer-settler tanks but these are also used in other mineral separation processes. Yet again what may apply elsewhere does not in North Korea: the pilot uranium mill at Pakchon and the multi-material mill at Pyongsan either use a process without these tanks or they are under a roof [19].

Other observable features in worldwide nuclear facilities are uranium hexafluoride storage tanks[10] [20], cooling infrastructure and signatures of nuclear facilities under construction. There are no public analyses of wide-area scans using object detection, although such classifiers have been developed in other fields [21].

Increasing spatial and temporal resolutions for EO and beyond

The deployment of previously of high spatial resolution non-EO commercial remote sensing tools may provide a significant boost to identifying clandestine facilities. Non-EO imagery is available in IR, SAR and hyperspectral bands. The deployment of high resolution EO-constellations is also increasing temporal resolution, with multiple revisits per day possible for

[10] Some enrichment plants store UF6 containers inside such as Almelo in the Netherlands (since 2013), but others such as Capenhurst in the UK, and Groneau in Germany store them outside.

sites of interest. Multiple images taken in a short duration is also possible, to create a short video that can show pattern of life and the side of interest from multiple angles.

New commercial satellite imagery is available in SAR from commercial providers such as Umbra and ICEYE and has been applied in nuclear nonproliferation and safeguards [22-25] and nuclear testing [25-27]. SAR is relevant for pattern of life activity but can also be used to observe through cloud cover and at night; potentially capturing previously unobserved activity at potentially nuclear-related facilities.

Hyperspectral data, from the Hyperion sensor, aboard NASA's EO-1 satellite, has been assessed for sensitivity ability to detect uranium [5, 28-30]. Hyperion collected data in 220 bands at 30m resolution and operated from 2000-2017. The resolution was found to be too low to detect uranium from large open pit uranium mines, such as Australia's Ranger mine, which would have one of the largest available signals. [5, 28-30]. The only detectable chemicals were magnesium chlorite and sulphur [30]. If high spatial-resolution hyperspectral data became commercially available, that was sufficient to detect nuclear-fuel cycle-related chemicals, then this should provide additional signatures for facilities at the front end of the fuel cycle.

Advances in the open-source toolkit

As assessment that a facility is potentially of relevance to the nuclear fuel cycle will use sources from ground-level imagery, social media, state media, technical literature, trade data and others. Although North Korea is a hard target for OSINT, with imagery from inside the country, besides the occasional Chinese tourist, comes from state media. As remote sensing and data analysis capabilities expand there are similarly advances in open source analysis capabilities: such as advances in speech to text, optical character recognition, translation, object tagging from

imagery, social media analysis tools and image forensics. Not every new technology provides an opportunity: the proliferation of synthetic media, including deepfakes, AI-text, AI-generated images and social media bots will also make determining the authenticity of sources more resource-intensive.

5. Conclusion

There is no silver bullet for identification of clandestine facilities related to the nuclear fuel cycle, in North Korea, or elsewhere with current tools and techniques. Identification is an artisanal, labour-intensive process that requires cross checking multiple sources, using experienced analysts and requires access to satellite imagery processing tools and databases. Breakthroughs in analysis may come from a new government-related source or the memory of an experienced analyst being able to associate two seemingly unrelated ground-level images.

Even the most well-resourced NGOs cannot cover all areas and follow all potential leads. Publishing complete and incomplete (or 'dead-end') analyses can act as a force multiplier for the community. In this way, organisations that do not have access to each other's internal assessments can focus resources in complementary areas. For validation and assessment of results, organisations may pool resources informally by privately sharing preliminary analyses, or formally by publishing supporting analyses that validate, or re-interpret, findings.

Remote sensing tools that increase temporal, spectral and spatial resolutions over currently available tools will not assuredly lead to new findings but open new avenues for analysis. If a facility is underground or has been repurposed, no new remote sensing tool can provide imagery from the past when a facility was under construction. SAR may show operations at night and

hyperspectral imagery may eventually reveal uranium sources, but the DPRK is playing a cat-and-mouse game with NTM, not commercial sensors.

Leveraging advances in machine learning and advanced data analytics may also provide new opportunities for analysis. This could be used to reduce analyst time spent on repetitive tasks. It could also be used to improve the understanding of interactions between facilities by permitting object identification over large areas, such as types of rail car. This could in turn lead to identifying new sites of interest, that if monitored over time may be revealed to be related to a nuclear programme.

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Bibliography

[1] IAN STEWART, et al. *The Status of the Front End of Saudi Arabia's Nuclear Fuel Cycle*. Available: https://nonproliferation.org/the-status-of-the-front-end-of-saudi-arabias-nuclear-fuel-cycle/. 2020.

[2] JENNY TOWN. *Challenges of Negotiating with North Korea* [Online]. Stimson Center. Available: https://www.stimson.org/2021/biden-review-challenges-of-negotiating-with-north-korea/. [Last Updated 2021].

[3] MARK E. MANYIN, EMMA CHANLETT-AVERY & MARY BETH D. NIKITIN. *Nuclear Negotiations with North Korea* [Online]. Congressional Research Service. Available: https://crsreports.congress.gov/product/pdf/R/R45033?source=GovD. [Last Updated 2021].

[4] MARGARET ARNO. Standardizing Acquisition Path Analysis: Quantifying a State's Ability to Establish and Clandestinely Operate a Nuclear Facility. Laurence Livermore National Laboratory. LLNL-TR-745003. Available: https://www.osti.gov/servlets/purl/1424622. 2021.

[5] GRACE LIU, et al. *Eyes on U: Opportunities, Challenges, and Limits of Remote Sensing for Monitoring Uranium Mining and Milling*. Available: https://nonproliferation.org/wp-content/uploads/2019/01/op44-eyes-on-u.pdf. 2019.

[6] S VACCARO. Methods for the detection of undeclared plutonium production facilities. *ESARDA Bulletin,* 37 (2007)

[7] JOHN E BISTLINE, et al. A Bayesian Model to Assess the Size of North Korea's Uranium Enrichment Program. *Science & Global Security,* 23 (2015) 71-100.

[8] JEFFREY LEWIS & DECKER EVELETH. *CHINESE ICBM SILOS* [Online]. Arms Control Wonk. Available: https://www.armscontrolwonk.com/archive/1212340/chinese-icbm-silos/. [Last Updated 2021].

[9] MATT KORDA & HANS KRISTENSEN. *China Is Building A Second Nuclear Missile Silo Field* [Online]. Federation of American Scientists. Available: https://fas.org/publication/china-is-building-a-second-nuclear-missile-silo-field/. [Last Updated 2021].

[10] WARREN P. STROBEL, MICHAEL R. GORDON & FELICIA SCHWARTZ. *Saudi Arabia, With China's Help, Expands Its Nuclear Program* [Online]. Wall Street Journal. Available: https://www.wsj.com/articles/saudi-arabia-with-chinas-help-expands-its-nuclear-program-11596575671. [Last Updated 2020].

[11] JEFFREY LEWIS & DAVE SCHMERLER. *THE CLOTHES GEOLOCATE THE MAN* [Online]. Arms Control Wonk. Available: https://www.armscontrolwonk.com/archive/1201459/a-tale-of-two-visits/. [Last Updated 2016].

[12] JEFFREY LEWIS. Recent Imagery Suggests Increased Uranium Production in North Korea, Probably for Expanding Nuclear Weapons Stockpile and Reactor Fuel [Online]. 38 North. Available: https://www.38north.org/2015/08/jlewis081215/. [Last Updated 2015].

[13] JEFFREY LEWIS, MELISSA HANHAM & AMBER LEE. *That Ain't My Truck: Where North Korea Assembled Its Chinese Transporter-Erector-Launchers* [Online]. 38 North. Available: https://www.38north.org/2014/02/jlewis020314/. [Last Updated 2014].

[14] ANKIT PANDA. *Exclusive: Revealing Kangson, North Korea's First Covert Uranium Enrichment Site* [Online]. The Diplomat. Available: https://thediplomat.com/2018/07/exclusive-revealing-kangson-north-koreas-first-covert-uranium-enrichment-site/. [Last Updated 2018].

[15] SULGIYE PARK, et al. Geologic Analysis of the Democratic People's Republic of Korea's Uranium Resources and Mines. *Science & Global Security,* 28 (2020) 80-109.

[16] IAEA. *IAEA footage of Director General Hans Blix Touring North Korean Nuclear Sites in 1992* [Online]. YouTube. Available: https://www.youtube.com/watch?v=qfr0PEf60xE. [Last Updated 1992].

[17] CHARLES DAY. *Visiting North Korea: Q&A with Siegfried Hecker* [Online]. Physics Today. Available: https://physicstoday.scitation.org/do/10.1063/pt.4.0324/full/. [Last Updated 2011].

[18] SULGIYE PARK, ALLISON PUCCIONI & RODNEY C. EWING. Machine learning improves satellite imagery analysis of North Korean nuclear activity. *Bulletin of the Atomic Scientists,* 78 (2022) 26-37.

[19] DAVID SCHMERLER. *A SATELLITE IMAGERY REVIEW OF THE PYONGSAN URANIUM MILL* [Online]. Armscontrolwonk.com. Available: https://www.armscontrolwonk.com/archive/1209625/pyongsan-uranium-mill/. [Last Updated 2020].

[20] S. B. FISHER & N. MCFERRAN. *Nuclear Safeguards: Feature Extraction for Machine Learning Enrichment Analysis of UF6 Cylinders*. Laurence Livermore National Laboratory. LLNL-TR-825524. Available: https://www.osti.gov/servlets/purl/1812580. 2021.

[21] OMDENA. *Developing an AI Model to Identify School Locations in Sudan from Satellite Imagery* [Online]. YouTube: Omdena. Available: https://www.youtube.com/watch?v=2rJl3qE9AjM. [Last Updated 2022].

[22] J. SHIN, M. FOWLER & P. PASQUALI. 2022. USAGE OF SYNTHETIC APERTURE RADAR DATA FOR NUCLEAR FUEL CYCLE MONITORING.

[23] MARC LAFITTE & JEAN-PHILIPPE ROBIN. Monitoring Nuclear Facilities Using Satellite Imagery and Associated Remote Sensing Techniques. *ESARDA Bulletin,* 52 (2015)

[24] MARIUS NECSOIU & GARY R. WALTER. Detection of uranium mill tailings settlement using satellite-based radar interferometry. *Engineering Geology,* 197 (2015) 267-277.

[25] N. FISCANTE, et al. Spaceborne SAR based assessment of nuclear test effects: the case of North Korea. 2021 Sensor Signal Processing for Defence Conference (SSPD), 14-15 Sept. 2021 2021. 1-5.

[26] SANDRA SLEAD & MENG WEI. Yield estimate for the January 2016 DPRK nuclear test based on InSAR and numerical modelling with mechanical heterogeneity. *Geophysical Journal International,* 231 (2022) 2048-2054.

[27] LISA GARNER. 2019. Conducting Complex Underground Chemical Explosion Experiments for Nuclear Explosion Monitoring.

[28] JIE-LIN ZHANG. THE UTILITY OF HYPERSPECTRAL DATA ON EXPLORATION OF SANDSTONE-HOSTED URANIUM DEPOSITS. ASPRS 2006, 2006 Reno, Nevada.

[29] Q.S. BOB TRUONG, et al. 2003. MULTISPECTRAL AND HYPERSPECTRAL IMAGERY FOR SAFEGUARDS AND VERIFICATION OF REMOTE URANIUM MINES

[30] CHRISTOPHER L. STORK, HEIDI A. SMARTT, DIANNA S. BLAIR & JODY L. SMITH. *Systematic Evaluation of Satellite Remote Sensing for Identifying Uranium Mines and Mills*. Sandia National Laboratory. SAND2005-7791. Available: https://www.osti.gov/servlets/purl/876527. 2006.