Dual Use in the DPRK: Uranium Extraction from Phosphate Fertilizer Factories

CNS
OCCASIONAL PAPER
#47 · APRIL 2020

Margaret Croy

Middlebury Institute *of* International Studies at Monterey
James Martin Center for Nonproliferation Studies

James Martin Center for Nonproliferation Studies
Middlebury Institute for International Studies at Monterey

460 Pierce Street, Monterey, CA 93940, USA
Phone: +1 (831) 647-4154
Fax: +1 (831) 647-3519

www.nonproliferation.org **www.middlebury.edu/institute**

The author would like to extend a special thanks to Catherine Dill, Jill Luster, Dave Schmerler, and Jeffrey Lewis, without whom this research would not have been possible. This work is part of an ongoing joint project between the Verification Research, Training and Information Centre (VERTIC), the James Martin Center for Nonproliferation Studies (CNS) at the Middlebury Institute of International Affairs (MIIS), and the Royal United Services Institute (RUSI). The project seeks to update and systematize analysis of North Korea's nuclear complex, using remote sensing data and industry-standard nuclear fuel cycle modelling to generate independent models of plausible scenarios for that complex, in the past, present and future, and to use those results to assess priorities for control and verification. The project is generously funded by Global Affairs Canada.

Cover image: Phosphate mine processing mill, by Chatrawee Wiratgasem, c/o Shutterstock. Royalty-free stock photo ID: 1280800591.

Dual Use in the DPRK: Uranium Extraction from Phosphate Fertilizer Factories

MARGARET CROY

Contents

Introduction

In May 2017, Robert Kelley and Vitaly Fedchenko published Non-Proliferation Paper No. 59 with the EU Non-Proliferation Consortium, entitled “Phosphate Fertilizers As A Proliferation-Relevant Source of Uranium.” In it, Kelley and Fedchenko detail a number of case studies wherein uranium extraction from phosphoric acid as part of the phosphate fertilizer production process was a significant source of U_3O_8, or yellowcake uranium.[1] The cases in their paper demonstrate that both declared and undeclared nuclear-weapon programs have had success in obtaining uranium by extracting it from phosphoric acid, an intermediate product in the process of phosphate fertilizer production. This Occasional Paper considers the possibility that the Democratic People’s Republic of Korea (DPRK) could undertake the same work, and as such, this paper is an open-source analysis of the applicability of this unconventional method of uranium acquisition to the DPRK. The DPRK has both the means and the motivation to undertake such work, and neither appears likely to diminish in the near future. An analysis of open-source information and remote-sensing data reveals evidence that the DPRK has already conducted such activities, and is likely to continue to do so, particularly as international pressure to take concrete steps toward denuclearization mounts. *The implication of such work being conducted in the DPRK is clear: it has the potential to considerably alter open-source estimates of how much yellowcake uranium the DPRK is able to produce annually, which in turn affects estimates of how many nuclear warheads the DPRK can make.*

This paper proceeds in four sections. The first section explains the science behind uranium extraction from phosphoric acid produced as an intermediary in the production of phosphate fertilizer from phosphate rock. The second section highlights some of the historical cases of states using this method to obtain uranium.[2] The third section elucidates the reasoning and rationale for using this method in the DPRK, and the fourth section examines the open-source evidence available indicating that this uncommon method of obtaining uranium is in use in the DPRK today, and is likely to continue and expand in scale.

---

[1] “Yellowcake” uranium contains on average 70–90 percent U_3O_8.

[2] The section on historical case studies will specifically reference and build on previous work in Robert Kelley and Vitaly Fedchenko, “Phosphate Fertilizers as a Proliferation-Relevant Source of Uranium,” EUNPC Paper No. 59, May 2017, https://www.sipri.org/sites/default/files/2019-11/eunpc_no_59.pdf. The author is indebted to them for their extraordinary research.

Uranium Extraction from Phosphoric Acid

There are numerous resources available on the scientific processes underlying the extraction and recovery of uranium from phosphoric acid, but two of the most thorough are: "The Recovery of Uranium from Phosphoric Acid," a technical document produced by the International Atomic Energy Agency (IAEA) in 1989, and "Potential Uranium Supply from Phosphoric Acid: A U.S. Analysis Comparing Solvent Extraction and Ion Exchange Recovery," a document prepared by the US Department of Energy's Idaho National Laboratory (INL) in 2016.

The IAEA technical document is the report of an advisory group meeting organized by the IAEA and held in Vienna, Austria, March 16–19, 1987, though the report was published in 1989. The meeting had the main objective of "reviewing the current status of the technology and to suggest guidelines for the application of existing processes in developing countries,"[3] and the resulting document includes a summary and recommendations, as well as two review papers on discussing the technology and current industrial practices of recovering uranium recover from phosphoric acid. The report also includes summaries of two panel discussions, "one on capital and operating costs and the other on guidelines for the preparation of feasibility studies."[4]

The INL paper addresses both the technical and financial details of the two primary processes for uranium extraction from phosphoric acid worldwide: solvent extraction and ion-exchange recovery. The INL study "estimates how much uranium might be recoverable from current phosphoric acid production in the United States and what the associated costs might be considering two different recovery processes: solvent extraction and ion exchange."[5]

To better understand the feasibility of uranium extraction from phosphoric acid in fertilizer factories in the DPRK, the INL publication offers two diagrams (Figures 1 and 2) depicting these two extraction processes.[6]

[3] IAEA, "Foreword," in "The Recovery of Uranium from Phosphoric Acid," IAEA-TECDOC-533, November 1989.
[4] Ibid.
[5] Haeyon Kim, Roderick G. Eggert, Brett W. Carlsen, and Brent W. Dixon, "Potential Uranium Supply from Phosphoric Acid: A U.S. Analysis Comparing Solvent Extraction and Ion Exchange Recovery," Idaho National Laboratory, Publication INL/JOU-15-37419, September 2016, p. 1.
[6] Ibid., pp. 19, 22.

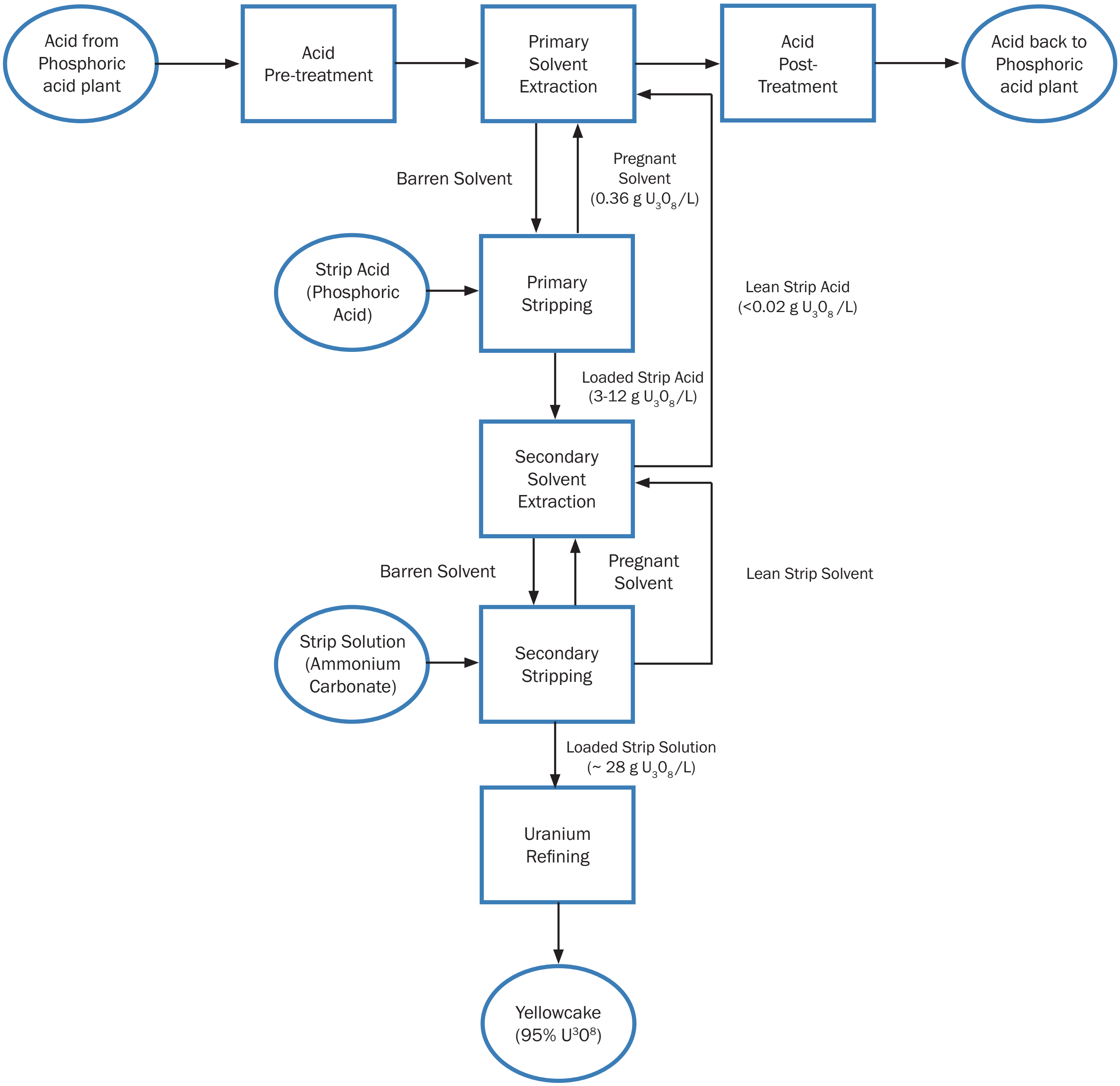


Figure 1. Solvent extraction flow chart

Kim, Eggert, Carlsen, and Dixon, “Potential Uranium Supply from Phosphoric Acid,” p. 19.

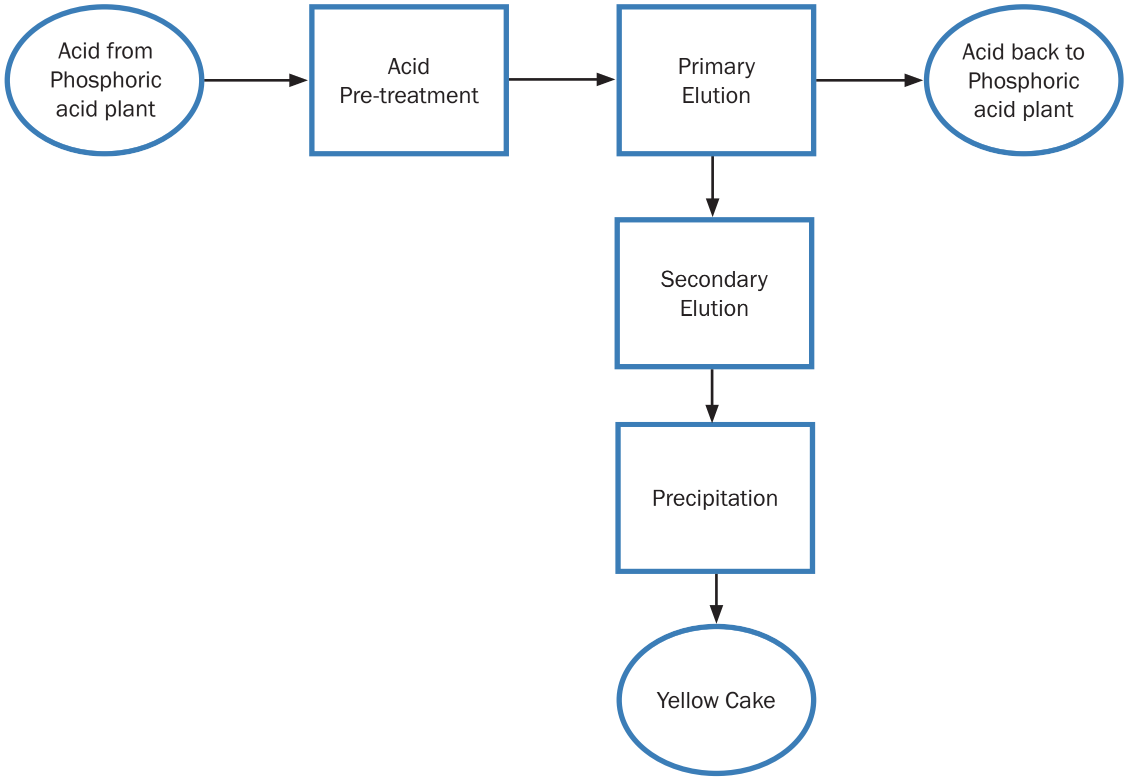


Figure 2: Ion-exchange flow chart

Kim, Eggert, Carlsen, and Dixon, “Potential Uranium Supply from Phosphoric Acid,” p. 22.

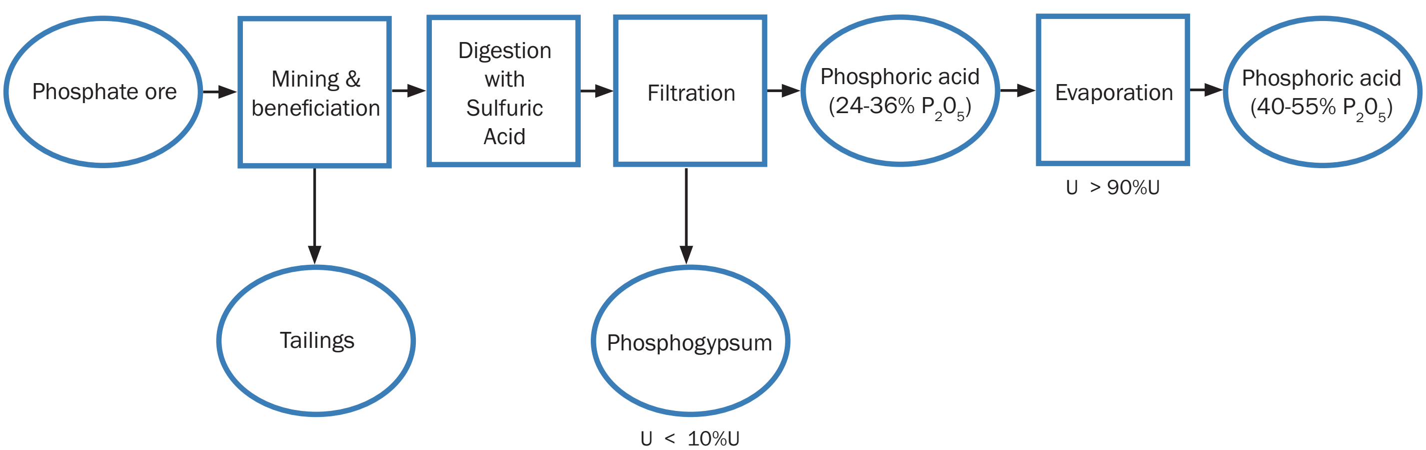


Figure 3: Wet process phosphoric acid flow chart

The percentages in the figure refer to the disposition of the uranium contained in the phosphate ore. Kim, Eggert, Carlsen, and Dixon, “Potential Uranium Supply from Phosphoric Acid,” p. 5.

An additional diagram, Figure 3, shows the production of phosphoric acid from phosphate rock, to help demonstrate the complete process.[7]

Although these diagrams are not comprehensive, they indicate process and material flows, and the appendices of the INL report explicitly detail the steps necessary for uranium extraction using both processes. The authors are clear that the United States primarily used the solvent-extraction method in the past, that its efficacy is "historically proven" (albeit with high operating costs), and that "among the 11 previous operations in the U.S., 10 plants were based on solvent extraction."[8]

The IAEA report shows that, in 1987, the ion-exchange recovery method was still in the research and development phase.[9] The solvent-extraction method had been commercialized by 1987 (the INL paper authors note that the United States began this process on a commercial scale in the 1950s)[10] and the IAEA technical document states that the use of three different extractants had been commercialized in three different processes.

Those processes are:

- The DEPA/TOPO[11] process, developed at the Oak Ridge National Laboratories, using di(2-ethylhexyl) phosphoric acid and trioctyl phosphine oxide as extractants,
- The OPAP process, also developed at Oak Ridge but using octyl phenyl acid phosphate as extractant, and
- The OPPA process, developed by Dow Chemical and using octyl pyro phosphoric acid as extractant.[12]

Additional tables in the INL report demonstrate that, from the 1950s to the 1990s, the DEHPA/TOPO process was the most common method of solvent extraction for the recovery of uranium from phosphoric acid in the United States. It therefore seems most likely that, from a technical standpoint, the DPRK would use the method with both the most historical proof of efficacy and the most available information.

---

[7] Ibid., p. 5.
[8] Ibid., p. 6.
[9] IAEA, "The Recovery of Uranium from Phosphoric Acid," IAEA-TECDOC-533, November 1989, p. 8.
[10] Kim, Eggert, Carlsen, and Dixon, "Potential Uranium Supply from Phosphoric Acid," p. 2.
[11] This material is also referred to as DEHPA/TOPO and D2EHPA/TOPO. This paper will use DEHPA/TOPO as the standard.
[12] IAEA, "The Recovery of Uranium from Phosphoric Acid," p. 7.

Historical Case Studies

There are numerous historical case studies demonstrating that countries around the world have effectively extracted uranium from phosphoric acid, often in the context of phosphate fertilizer factories. In their May 2017 paper, Kelley and Fedchenko walk through several country case studies—the United States and Iraq particularly notable among them—wherein uranium extraction from phosphoric acid as part of the phosphate fertilizer production process was a significant source of U_3O_8. The authors state that "between 1954 and 1962 US companies recovered about 17,150 [metric tonnes] which was mainly used for military purposes, from phosphate rocks in Florida,"[13] and that, in the mid-1990s in the United States, "about 20 per cent of US uranium production was from phosphate fertilizer byproducts."[14] While the United States is a declared nuclear-weapon state under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), not all countries who have engaged in such uranium extraction, either for military purposes or alternate goals, have the same overt declaration of such activities. Either way, the method has been demonstrated to produce sizeable quantities of uranium.

In Iraq, the al-Qaim Phosphate Fertilizer Plant contained a production unit designed to "use the Prayon process to extract uranium from phosphoric acid," making al-Qaim Iraq's "main source of UOC until it was destroyed in 1991. During its six years of operation (from 1985-1991), it produced 109 tonnes of uranium in 168 tonnes of yellowcake."[15] Since the failure to detect Iraq's covert nuclear-weapon program was one of the main drivers behind the creation of the IAEA Model Additional Protocol, it is particularly noteworthy that the primary source of the uranium for the weapons program was a known phosphate fertilizer plant.

The Republic of Korea (South Korea) has a more recent case of uranium extraction, and one that, consistent with their Additional Protocol, placed them in violation of their IAEA safeguards obligations. According to a November 2004 IAEA Board of Governors report, the South Korean government had informed the IAEA on August 23,

---

[13] Organization for Economic Cooperation and Development, Nuclear Energy Agency and International Atomic Energy Agency, "Uranium 2011: Resources, Production and Demand," Paris, 2011, p. 32, as cited in Kelley and Fedchenko, p. 5.

[14] Kelley and Fedchenko, "Phosphate Fertilizers as a Proliferation-Relevant Source of Uranium," p. 5.

[15] United Nations Security Council, "Fourth consolidated report of the Director General of the International Atomic Energy Agency under para. 16 of Security Council resolution 1051 (1996)," S/1997/779, October 6, 1997, p. 27.

2004, that scientists at the Korea Atomic Energy Research Institute in Daejeon had carried out “laboratory scale experiments involving the enrichment of uranium using the atomic vapour laser isotope separation (AVLIS) method” in June of that year. According to the IAEA, “the approximately 2500 [kilograms] kg of ammonium uranyl tricarbonate and the approximately 100 kg of U308 recovered from uranium bearing phosphate ore, as declared by the ROK, were consistent with the records provided to the Agency.”[16] The ROK case is particularly interesting because the uranium extraction was conducted on ore purchased from abroad, which raises questions about the proliferation implications of the import or export of phosphate-bearing rock.

In Israel, uranium extraction from phosphates has been of critical importance. Kelley and Fedchenko state that “[a] geological survey conducted in 1949–51 demonstrated that the only domestic source of uranium in Israel is low-level phosphate ore from the Negev desert.”[17] If the geological survey is correct, it means that all domestically produced uranium for Israel’s nuclear-weapon program is derived from phosphate extraction, thus further demonstrating the efficacy and feasibility—past and present—of the pathway. This evidence tracks with the claim that “Israel has been making serious efforts to mine and extract significant amounts of uranium from indigenous phosphates at least since the 1960s,”[18] leading to estimates of 18 tonnes of [extracted] uranium per year.[19] Though any information relevant to Israel’s nuclear industry is tightly controlled, the Nuclear Threat Initiative identifies three locations in the Negev where phosphate rock is reportedly mined—Arad, Zin, and Oron—by a fertilizer company called Rotem Amfert Negev Ltd.[20]

The Syrian Arab Republic also has a history of extracting yellowcake. In 1986, Syria asked the IAEA for assistance “obtaining a micro-pilot plant for UOC recovery from phosphoric acid [...] known as IAEA TC Project SYR/3/003,”[21] and asked the United Nations Development Programme (UNDP) for assistance in constructing a full-scale uranium

---

[16] IAEA, “Implementation of the NPT Safeguards Agreement in the Republic of Korea, Report by the Director General,” GOV/2004/84, November 11, 2004, pp. 1, 4.
[17] Avner Cohen, *Israel and the Bomb* (Columbia University Press: New York, 1998), p. 26.
[18] Z. Ketzinel, Y. Volkman, and D. Yakir, “Recovery of Uranium from the IMI Phosphoric Acid Process,” Israel Atomic Energy Commission, Report IA1268, 1972.
[19] Kelley and Fedchenko, “Phosphate Fertilizers as a Proliferation-Relevant Source ofsranium,” p 5.
[20] Nuclear Threat Initiative, “Rotem Amfert Negev Ltd,” January 1, 2011, http://www.nti.org/learn/facilities/336/.
[21] IAEA, “Technical Cooperation Project SYR/3/003: Uranium Recovery from Phosphoric Acid,” IAEA-TC Projects by Country: Syria, https://fas.org/nuke/guide/syria/iaea-syria.pdf.

recovery plant.[22] Ultimately, in 1996, "the IAEA (Project SYR/3/005) and the UNDP (Project SYR/95/002) initiated a programme to build a small pilot-scale uranium extraction facility at the Homs Fertilizer Plant. The goal was to extract uranium from the phosphoric acid produced there. This project was successful and small-scale UOC production began in 1999."[23] Years later, traces of the uranium produced at the fertilizer plant would be found in the Chinese-supplied miniature neutron source reactor near Damascus, during the IAEA inspections in June 2008 that followed the Israeli bombing of the alleged al-Kibar reactor the previous fall.

Several other countries have also experimented with extracting uranium from phosphoric acid, though the details of these activities are less widely known. In Egypt, the Egyptian Nuclear Materials Authority established a semi-pilot plant for extraction in 1996.[24] According to a presentation given at an IAEA regional training course in 2015, the plant is still operational, allowing Egypt to "further develop its uranium extraction capabilities with technical assistance from the IAEA as part of its general policy to develop its nuclear energy infrastructure."[25] Morocco, which holds 75 percent of the world's reserves of phosphates, signed an agreement in 2007 with the French company Areva "concerning the extraction of uranium from phosphoric acid produced from Moroccan phosphate ore," for French use.[26] In 2015, Morocco and France agreed to a second, separate arrangement wherein France would provide the technical assistance Morocco needed to conduct its own extraction of uranium from its domestic phosphates. India, too, announced plans to construct two uranium and rare-earth-metal-extraction plants in Paradeep at two different fertilizer factories: Paradeep Phosphates Limited and Indian Farmers Fertiliser Co. Ltd. Both will extract these products from wet phosphoric acid already being produced at both locations.[27]

Clearly, uranium extraction from phosphoric acid at fertilizer factories is neither particularly uncommon nor do states necessarily try to conceal the activity. Information on the process is also widely available and is certainly accessible by the relevant parties in the DPRK.

---

[22] Kelley and Fedchenko, "Phosphate Fertilizers as a Proliferation-Relevant Source of Uranium," p. 7.
[23] Ibid.
[24] Ibid., p. 5.
[25] M.H. Taha, "Uranium from phosphates: Current status of Egyptian UxP project," Presentation at the IAEA Regional Training Course, Luxor, October 18–22, 2015, https://www.unece.org/fileadmin/DAM/energy/se/pp/unfc/unfc_ws_U.Th_Luxor.Oct.2015/9_Helmy-Luxor.pdf.
[26] Kelley and Fedchenko, "Phosphate Fertilizers as a Proliferation-Relevant Source of Uranium," p 9.
[27] Ibid., p. 11.

Concealment is more likely in the DPRK, given the clear proliferation relevancy of such extraction. Nothing in the case studies or the technical discussion indicates that the DPRK is incapable of carrying out this process. The task, then, is to determine the DPRK's rationale for pursuing this method of U_3O_8 acquisition, and, more challengingly, whether or not it has done so. The remainder of this report seeks to answer those questions.

Reasoning and Rationale for the DPRK

In addition to the history of success (both overt and covert) with this process, an additional appeal for the DPRK is that it makes use of existing, dual-use infrastructure in the country. This provides two major advantages: it is cost effective and more concealable. As scrutiny and international pressure mounts on the DPRK to take some type of concrete step toward denuclearization, a path to yellowcake that is concealable within existing infrastructure would seem ever more appealing.

Cost Effectiveness

The INL paper details the cost effectiveness considerations for both the solvent-extraction and ion-exchange methods of uranium extraction from phosphoric acid. The authors are careful to note their methodology[28] in estimating production cost, and are only considering the cost it takes to recover the uranium from the phosphoric acid, not the total cost for the production of the phosphate fertilizer, including the extraction of uranium.[29] This process is technically simple in the scheme of fertilizer production, and thus not a significant expense in terms of expertise. However, despite the simplicity of the method, the authors are careful to note that neither solvent extraction nor ion exchange are cost-effective methods of yellowcake acquisition unless the price of uranium rises, or the cost of recovery/extraction falls.[30] The authors state that "consistent uranium prices in excess of US$44 to US$61 [per pound of U_3O_8], depending on the interest rate and plant life, are needed to justify investment in new plants."[31] Given the spot price of $24.10 for U_3O_8,[32] it is clear that, per the INL methodology, uranium extraction from phosphate fertilizer plants is far from cost effective in the US context.

[28] "Recovering uranium from phosphoric acid is an example of by-product production. As long as the phosphoric acid production is commercially viable on its own, only the additional costs of recovering the uranium by-product should be attributed to uranium. In other words, the costs of mining and transporting the phosphate rock, producing phosphoric acid, and other processes prior to recovering the uranium as a by-product are not relevant for considering the commercial viability of recovering by-product uranium." Kim, Eggert, Carlsen, and Dixon, "Potential Uranium Supply from Phosphoric Acid," pp. 7–8.

[29] The total process cost of both the fertilizer production and the uranium extraction would only be considered if an entity wishing to extract uranium from phosphoric acid built a new facility for this express purpose, and treated the uranium as the primary product, with the fertilizer as a secondary product.

[30] Kim, Eggert, Carlsen, and Dixon, "Potential Uranium Supply from Phosphoric Acid," p. 2.

[31] Ibid., p. 14.

[32] Week average spot price as of March 16, 2020.

While this manner of considering cost effectiveness may be logical in the United States, the costs associated with this process must be considered differently in the DPRK. There are three main differences of cost in the DPRK: first, most factory infrastructure, including fertilizer factories, is state-owned; second, the slump in agricultural production evinces a national need for phosphate-based fertilizer; and third, nuclear-weapon infrastructure is a national priority.

A privately owned factory in the United States would likely be concerned with profit margin on the sale of U_3O_8, but the DPRK's state ownership of both fertilizer factories and the facilities associated with the nuclear fuel cycle mitigates much of that concern. These factories and facilities do not have to turn a profit, so long as they can continue to operate. When combined with the significantly cheaper cost of labor in North Korea, the need for "consistent uranium prices in excess of US$44 to US$61 [per pound of U_3O_8] ... to justify investment in new plants"[33] is likely less stringent in North Korea, given the lower prioritization of profit, the lower cost of labor, and the higher demand for fertilizer.

North Korea is in desperate need of fertilizer to boost its agricultural production, and thus, the construction of fertilizer-production factories is an economic necessity, aside from any additional merit derived from uranium extraction. North Korean state media sources frequently cite the need to increase fertilizer production to support the domestic agriculture. In his 2019 New Year's Day speech, Kim Jong Un referenced not only the construction of a specific "phosphatic fertilizer factory," but also called for a "nationwide effort" to "run the chemical fertilizer factories at full capacity."[34] He used similar language in the 2018[35] and 2017[36] New Year's Day speeches, but this is the

[33] Kim, Eggert, Carlsen, and Dixon, "Potential Uranium Supply from Phosphoric Acid," p. 14.
[34] From the 2019 New Year Address: "The chemical industry should step up the building of the phosphatic fertilizer factory and the establishment of the C1 chemical industry, develop the glauberite and synthetic fibre industries and convert the existing equipment and technical processes into energy-saving and labour-saving ones. This year a nationwide effort should be made to run the chemical fertilizer factories at full capacity and boost production at the February 8 Vinalon Complex." Kim Jong Un, "2019 New Year Address," Pyongyang, North Korea, https://www.ncnk.org/resources/publications/kimjongun_2019_newyearaddress.pdf/file_view.
[35] From the 2018 New Year Address: "The chemical industry should step up the establishment of the C1 chemical industry, push the projects for catalyst production base and phosphatic fertilizer factory as scheduled, and renovate and perfect the sodium carbonate production line whose starting material is glauberite." Kim Jong Un, "2018 New Year Address," Pyongyang, North Korea, https://www.ncnk.org/node/1427.
[36] From the 2017 New Year Address: "The chemical industry is a basis for all other industries and plays an important role in consolidating the independence of the economy and improving the people's living standards. This sector should revitalize production at the February 8 Vinalon Complex, expand the capacity of other major chemical factories and transform their technical processes in our own way, thus increasing the output of various chemical goods." Kim Jong Un, "2017 New Year Address," Pyongyang, North Korea, https://www.ncnk.org/

strongest language to date. A paper from the Korea Rural Economic Institute speaks more directly to the lack of fertilizer and the resulting hardship for the North Korean agricultural sector: "As economic difficulties resulted in a shortage of energy, and of raw materials such as fertilizer and agricultural chemicals, agricultural productivity decreased."[37] Furthermore, phosphate-based fertilizers are the most effective type of fertilizers for crop growth. The decision to renovate existing phosphate-based fertilizer factories or build new ones, then, could be entirely and legitimately dual-use; phosphate fertilizer is an absolute necessity from an economic and agricultural standpoint, but the extraction of additional U_3O_8 is equally necessary from a nuclear-weapons stockpile/production perspective.

From his policy of *byungjin,*[38] his New Year's speeches, numerous missile tests, and the six underground nuclear tests, Kim Jong Un has made it clear that the development of a credible nuclear deterrent is a national priority for North Korea. As such, and given North Korea's extensive efforts to acquire and produce the materials needed for a nuclear weapon, the extraction—however minimal—of uranium from a phosphate fertilizer factory is a perfectly logical piece of the puzzle. That the process is likely cost effective, concealable, and dual-use in nature is evidence of feasibility and rationale, but that the process supports the national priority of building a credible nuclear deterrent indicates that, if it can be done, it probably is.

Concealability

Uranium extraction from phosphoric acid has historically taken place in fertilizer factories. As such, these factories become dual-use, making the verification of activities significantly more difficult. There are several challenges in identifying a facility as dual-use through remote-sensing work, ground-imagery research, and (hypothetical) on-site inspections. Two questions must be answered about each facility: is the facility capable of producing the substance in question and is this substance

---

sites/default/files/KJU_2017_New_Years_Address.pdf.

[37] Woon-Keun Kim, "The Agricultural Situation of North Korea," Korea Rural Economic Institute, Seoul: September 1999, http://www.fftc.agnet.org/htmlarea_file/library/20110726131553/eb475.pdf.

[38] Beyond cost effectiveness and concealability, deriving uranium from phosphoric acid through a phosphate fertilizer production factory is an embodiment of the policy of *byungjin,* or parallel nuclear-weapon development and economic expansion. *Byungjin* is a uniquely North Korean concept, announced by Kim Jong Un at a March 2013 Korean Workers' Party Meeting. In his 2018 New Year's Day speech, Kim declared that the "historic cause of perfecting the national nuclear forces" had been achieved in the last year, and that North Korea had "attained our general orientation and strategic goal with success." While some have interpreted these comments as the end of the *byungjin* strategy, Kim's statement is more likely to indicate that his initial requirement for effective deterrence —the ability to deter US aggression with the possession of nuclear-capable intercontinental ballistic missiles (ICBM) and nuclear warheads—has been met (consider the successful November 2017 launch of the Hwasong-15, North Korea's first ICBM test).

being produced? These are not the same questions, and it is usually easier to answer the latter with circumstantial evidence, as opposed to "hard proof."

The case studies[39] in this paper demonstrate that the process of uranium extraction from phosphoric acid is relatively simple to carry out in a small section of a site otherwise dedicated to producing phosphate fertilizer. All of the uranium extraction facilities referenced are small offshoots of larger fertilizer factories, and thus the various case studies indicate that a fertilizer factory does not need to be significantly larger than normal to include a site for uranium extraction. This makes it more difficult to positively identify a uranium extraction facility at a phosphate fertilizer plant. In addition, the process by which uranium is extracted from phosphoric acid in the making of phosphate fertilizers does not have distinctive visual signatures, making it even more difficult to conclusively identify uranium extraction taking place.

Additional Advantages: Information/Knowledge Availability

Information on how to do this extraction process is readily available; both INL and the IAEA have published detailed documents.[40] The process of uranium extraction also has a long history of success, as noted by the aforementioned case studies. Furthermore, there is a wealth of scientific papers and industry brochures on how to conduct uranium extraction from phosphoric acid, which detail the type of equipment needed, the various processes for this work, and their respective benefits and drawbacks. If the technical expertise of carrying out the process is not too challenging for the DPRK industrial enterprise and its scientists—and there is no reason to believe that it would be—there is no shortage of information on how to do it.

[39] The al-Qaim phosphate fertilizer plant in Iraq contained Unit-340, the site section responsible for extracting 168 tonnes of yellowcake from 1985 to 1991. The Homs Fertilizer Plant in Syria has a "small pilot scale uranium extraction facility" built through a program run jointly by the IAEA and the UNDP. The semi-pilot plant established in Egypt for "experimental uranium extraction from phosphoric acid" is "about 1 kilometer away from the Abu Zaabal Fertilizer Company." Kelley and Fedchenko, "Phosphate Fertilizers as a Proliferation-Relevant Source of Uranium," pp. 6–7.

[40] Kim, Eggert, Carlsen, and Dixon, "Potential Uranium Supply from Phosphoric Acid"; and IAEA-TECDOC-533.

Conclusions: Reasoning and Rationale

There is ample rationale for the DPRK to extract uranium from phosphates. While analysts have often considered the matter of cost effectiveness through a distinctly Western lens, the real cost of this process in North Korea is likely much lower. Additionally, the DPRK has made it clear that their national priority is the production of a credible nuclear deterrent, and thus, financial cost may not be the best judge of feasibility. This prioritization of nuclear-weapon development is another reason why this method of uranium extraction would be appealing to the DPRK; the dual usage of existing infrastructure would both conceal the activity and make it more difficult for international audiences to positively identify and condemn. The DPRK does need fertilizer, and the information on how to extract uranium in the midst of that process is readily available. Lastly, this method of yellowcake production embodies the policy of *byungjin*, a hallmark of Kim Jong Un's strategy. Given all of these factors, the rationale for the pursuit of this method is clear. The evidence is even more so.

Evidence: Uranium Extraction in the DPRK

There is much evidence to suggest that the DPRK is capable of extracting uranium at fertilizer factories, at least on a pilot scale. When assessing the evidence and considering the likelihood of the DPRK's engagement in this method of uranium extraction, it is critical to consider whether the evidence points to capability or to ongoing activity. There is a substantial amount of both types of evidence.

Rise of the Chemical Fertilizer Industry

The rise in profile of North Korean phosphate fertilizer factories and the chemical fertilizer industry as a whole signals the increasing importance of this industry to the Kim regime. This increase in importance is probably due to several factors, including the decline in agricultural production and the possibility of extracting uranium as part of the phosphate fertilizer production process.

The chemical fertilizer industry has also benefitted from an increase in resources—labor, fiscal, and mechanical—dedicated to improving the C1 chemical industry.[41] Improvement in this sector is an economic necessity given the agricultural crisis, but the steady and significant rise in the industry's profile suggests that it may have greater strategic significance for the DPRK than the singular purpose of solving a massive crop shortage.

Additionally, Kim Jong Un himself has frequently emphasized the importance of developing the chemical fertilizer industry, particularly in his 2017, 2018, and 2019 New Year's Day speeches. Analysts of North Korea and its leadership widely agree that the annual New Year's Day speeches, while certainly performative for domestic and international audience alike, are the clearest indication of the Kim regime's priorities available. Speeches prior to and during 2016

[41] During the last three years, there has been a spike in mentions of the chemical fertilizer industry in DPRK media sources, and particular emphasis has been on the augmentation of the chemical fertilizer industry and associated infrastructure. The C1 chemical industry refers to the conversion of simple carbon compounds (compounds created with single carbon molecule substances) into more complex products used across a variety of industries. For more information on the C1 chemical industry in North Korea, see Hamish Macdonald, "Could N. Korea's C1 Chemistry industry enhance its self-sufficiency?" *NK News,* June 14, 2017, https://www.nknews.org/2017/06/could-n-koreas-c1-chemistry-industry-enhance-its-self-sufficiency/.

reference the importance of modernizing agricultural practices among several other parts of the economy, but the first mention of the chemical industry was in 2017.[42] The 2018 speech further stressed the importance of the chemical industry in addition to referencing the chemical fertilizer industry and, even more specifically, a phosphatic fertilizer factory.[43] Kim mentions this factory again in his 2019 speech, indicating its continued importance to the Kim regime:

> The chemical industry should step up the building of the phosphatic fertilizer factory and the establishment of the C1 chemical industry, develop the glauberite and synthetic fibre industries and convert the existing equipment and technical processes into energy-saving and labour-saving ones. This year a nationwide effort should be made to run the chemical fertilizer factories at full capacity and boost production at the February 8 Vinalon Complex.[44]

Further research into this "phosphatic fertilizer factory" shows a wealth of DPRK state media coverage of its construction in Sunch'on, a city and industrial hub in South Pyongan province.

Sunch'on

The second piece of evidence for this activity in the DPRK is the new construction of a phosphate-based fertilizer factory in Sunch'on. DPRK state media sources announced the groundbreaking of the Sunch'on Phosphatic Fertilizer Factory on June 16, 2017. Ground imagery confirms that there was a ceremony for this groundbreaking, and when compared to satellite imagery, one can determine precisely where the ceremony took place.

[42] See footnotes 34–36.
[43] Ibid.
[44] Kim, "2019 New Year Address."

Site of the groundbreaking ceremony at the Sunch'on Phosphatic Fertilizer Factory
(Source: Maxar Technologies via Google Earth, August 31, 2018).

Groundbreaking ceremony held at the Sunch'on Phosphatic Fertilizer Factory on June 16, 2017
(Source: Korean Central News Agency).

Since the groundbreaking, the site has been under active construction. From June 2017 to August 2018, most of the work on the site has been deconstructing and removing the old buildings that previously occupied the area.

Images from Maxar via Google Earth from April 22, 2017 (left) and August 31, 2018 (right) showing the deconstruction of the old structures at the site of the new Sunch'on Phosphatic Fertilizer Factory.

Between August 2018 and November 2019, satellite images and ground images reveal extensive construction work, including the framing and roofing of numerous buildings.

From left to right: Images of Sunch'on Phosphatic Fertilizer Factory from 9 July 2019 (Planet 3 band PlanetScope Scene); 16 September 2019 (Digital Globe via TerraServer); and 28 November 2019 (Source: CNES/Airbus via Google Earth).

The new construction of the phosphate fertilizer factory in Sunch'on is not the only such factory to have been built there. According to a declassified document from April 1962 on the North Korean chemical industry, "The main producer of phosphorus fertilizer in NK was the Sunch'on Chemical Factory, whose 1960 production goal was 300,000 tons. Though it was unknown what expansion program this factory had, the NK government appeared to be making efforts to raise the production amount of phosphate as much as nitrate fertilizers."[45] According to *NK News,* the site was most recently the location of the old Sunch'on Nitro-Lime Fertilizer Factory.[46]

Geology

The geological location of Sunch'on is also conducive to both phosphate-based fertilizer production and uranium extraction from said phosphate fertilizer. Sunch'on has long been suspected as the site of a uranium-producing mine for the DPRK, though it is unclear where exactly the mine is located in Sunch'on[47] and whether the mine is depleted or still yielding uranium. As noted North Korea analyst Jeffrey Lewis writes, "According to Kim Tae Ho, a defector who worked at both uranium mills and left North Korea in May 1994, North Korea had only two sources of uranium ore, consistent with the report of the Hungarian ambassador, [one of which being] a mine in the Sunch'on region, [which] was limestone and was exhausted [of uranium] by 1987."[48]

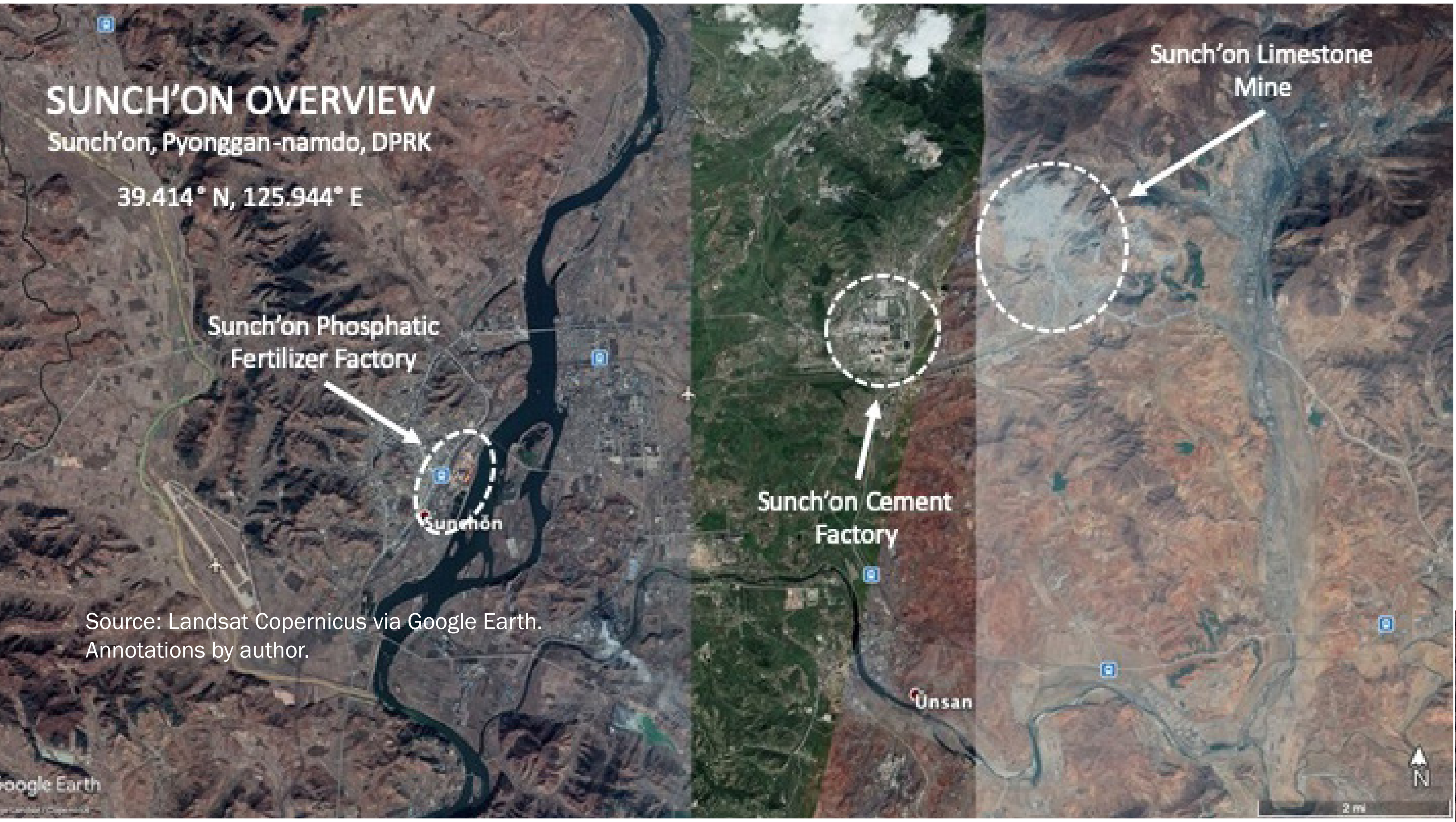
While the existence of uranium in the Sunch'on mine is still debated, the existence of a large limestone mine in Sunch'on is not. The DPRK's own state media apparatus has referred to it on several occasions given the importance of limestone to several industrial processes, especially the making of cement. The Sunch'on Cement Factory is just down the hill from the limestone mine and one of the largest in the DPRK, and a September 2019 state news report noted that:

> According to Ri Myong Il, department director of the Ministry of Construction and Building-materials Industry, the country abounds in resources of raw materials and fuel for the development of the

---

[45] "The North Korean Chemical Industry," Central Intelligence Agency, April 1962, https://www.cia.gov/library/readingroom/docs/CIA-RDP80T00246A062800230001-9.pdf.
[46] Colin Zwirko, "North Korean top-priority fertilizer plant appears to be nearing completion," *NK News,* December 13 2019, https://www.nknews.org/pro/north-korean-top-priority-fertilizer-plant-appears-to-be-nearing-completion/.
[47] There are several mines visible in satellite imagery of Sunch'on, but uranium-producing mines do not have distinctive visual signatures.
[48] Jeffrey Lewis, "Conversion Note," email correspondence with author, October 2019.

> cement industry. For example, limestone, one of the main raw materials for cement production, is deposited in all parts of the country, especially North Hwanghae, South Phyongan, Kangwon and North Hamgyong provinces, together with anthracite. In the places with rich deposits of raw materials, there are large-scale cement production bases, whose annual capacity is more than millions of tons, including Sangwon and Sunch'on cement complexes as well as medium and small-sized cement factories.[49]

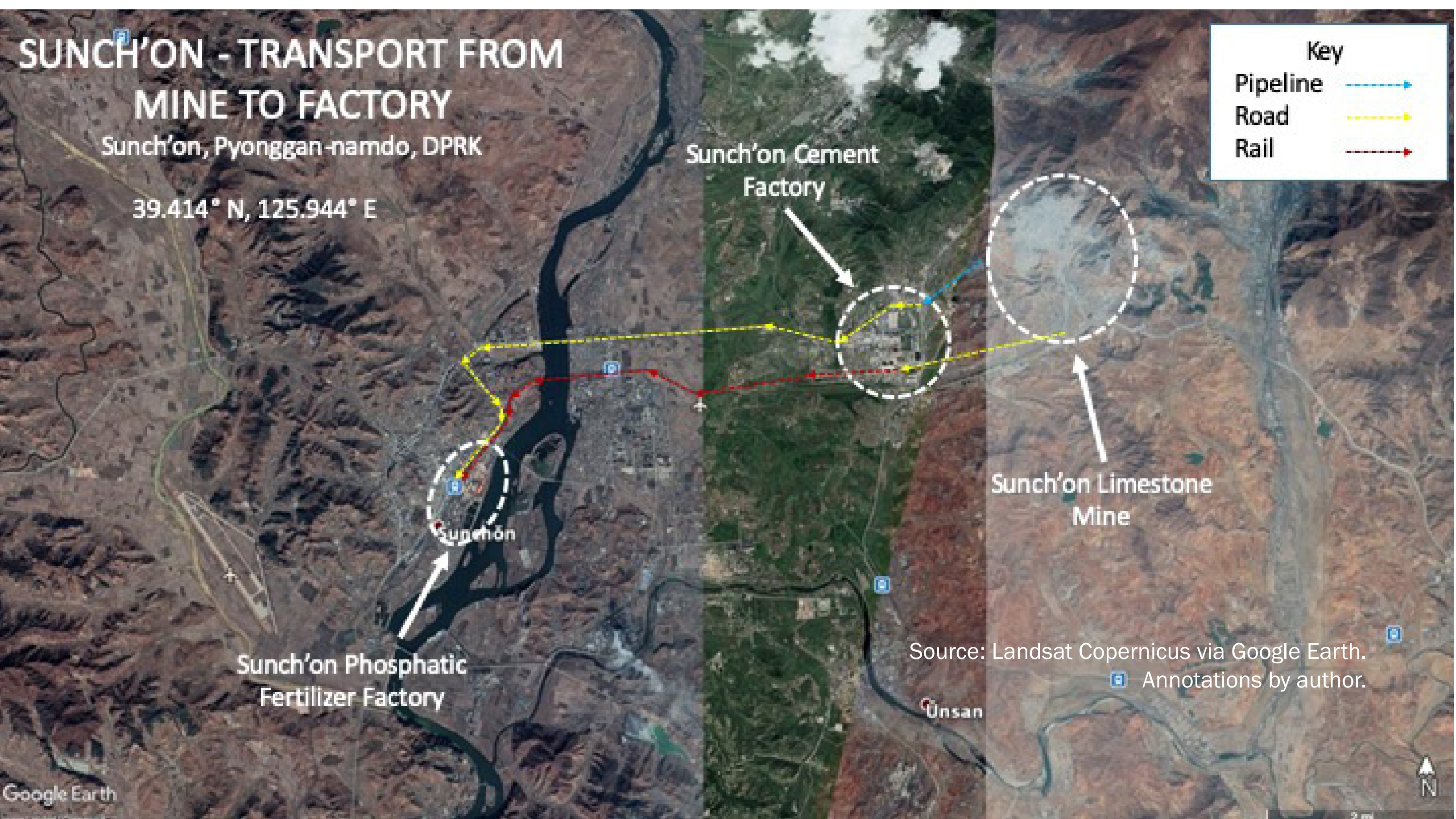


Source: Landsat Copernicus via Google Earth. Annotations by author.

This statement also references the co-location of limestone with anthracite in various parts of the country. When North Korea declared its nuclear activities to the IAEA in 1992 and 1994, they characterized the mine at Pyongsan—largely thought to be their main source of uranium—as an anthracite mine producing uranium, vanadium, and nickel. That Sunch'on has a limestone mine, and that it is characterized as being "together with anthracite," only bolsters the geological case that the mine produced uranium at one point and potentially still could.

[49] "Cement producers go full steam ahead in keeping with construction boom," *Pyongyang Times,* September 19, 2019, https://kcnawatch.org/newstream/1568880027-552304612/cement-producers-go-full-steam-ahead-in-keeping-with-construction-boom/.

Regardless of direct uranium production, however, limestone is one of the materials in which phosphate rock is found, and thus is one of the materials mined for the making of phosphate-based fertilizers, the process of which allows for the extraction of trace amounts of uranium. Satellite imagery shows train tracks connect the limestone mine in Sunch'on to both the cement factory and the new phosphate fertilizer plant under construction. This makes it plausible that material from the limestone mine could be processed at the fertilizer plant.



Additionally, DPRK state media has explicitly linked apatite mining with the production of phosphate fertilizer and has reported that Sunch'on has considerable reserves of apatite, a phosphate mineral comprised most commonly of calcium phosphate attached to either a chlorine, fluorine, or hydroxide ion. The main use of mined apatite throughout the world is in the production of phosphate fertilizers. However, sedimentary apatite also contains significant levels of cadmium, uranium, thorium, and radon; levels of uranium range from 800 to 5,200 Becquerels per kg, or 64.8 to 421.2 parts per million, a relatively considerable source of trace quantities of uranium.[50] The DPRK's sizable apatite resources, much of which are located in Sunch'on, further indicate the feasibility of extracting uranium from the new Sunch'on Phosphatic Fertilizer Factory.

A May 9, 2019, article from the *Pyongyang Times* details the "big efforts now being directed to strengthening the base for phosphate fertilizer production, along with the construction of the Sunch'on Phosphate Fertilizer Factory going in real earnest."[51] It notes that, "The electric power industrial sector has supplied electricity without letup to various mines in charge of the production of apatite concentrate. Meanwhile, the Anju Pump Factory and the Jonchon Rock-drill Factory and other mining machine factories have produced highly efficient pumps, rock-drills, pneumatic motors and air power loaders and tens of kinds of accessories needed for producing apatite concentrate."[52] This article clearly links the production of phosphate fertilizer to the necessity for "apatite concentrate," confirming that apatite is a key requirement for phosphate fertilizer production in North Korea.

High-Profile, High-Level Visits

The other related and notable factor about the construction at Sunch'on is its high profile, both in state media and in terms of high-level visits. Articles about the Sunch'on site have appeared in DPRK state media on average once per month since mid-2018, a notable volume. Sometimes those articles reference specific progress that has been made at the site, sometimes they reference auxiliary factories, mines, or industries linked to the site, and sometimes they simply highlight a visit made by a high-level official to the site.

[50] Christophe Poinsoot and Horst Geckeis, eds., *Radionuclide behaviour in the natural environment: science, implications and lessons for the nuclear industry* (Oxford; Philadelphia: Woodhead Pub Ltd, 2012); http://radiopurity.in2p3.fr/conversion.html.
[51] "Nation concentrates on strengthening phosphate fertilizer production basis," *Pyongyang Times,* May 5, 2019, https://kcnawatch.org/newstream/1557388838-82201530/nation-concentrates-on-strengthening-phosphate-fertilizer-production-basis/.
[52] Ibid.

Until Kim Jong Un's visit in January 2020, the DPRK premier was the highest-level representative from the North Korean government to have visited the site. Between Premier Kim Jae Ryong and his predecessor, Pak Pong Ju, the DPRK premier visited the site nine times from November 2017 to September 2019, five of which occurring in 2019 alone (see Table 1).

Most of the state media articles associated with the North Korean premier's visits included ground photos of various parts of the site, detailed updates on the progress of site construction, and the guidance given by the premier to the workers.

On January 6, 2020, DPRK state media sources reported that Kim Jong Un had visited the phosphate fertilizer construction site in Sunch'on. Though an exact date for the visit was not provided, state media characterized the visit as the "first onsite inspection of 2020."[53] The reports included twelve photographs of the site, including three aerial views that were critical to analyzing the pace of construction.

[53] Colin Zwirko, "Kim Jong Un touts chemical industry in first economic site visit of 2020," *NK News,* January 6, 2020, https://www.nknews.org/2020/01/kim-jong-un-touts-chemical-industry-in-first-economic-site-visit-of-2020/.

Date Visiting	Individuals	KCNA Article Title
11/12/2017	Premier Pak Pong Ju	Pak Pong Ju Inspects Construction Project for Building C1 Chemical Industry
5/16/2018	Premier Pak Pong Ju	Premier Inspects Various Units in Sunch'on
11/10/2018	Premier Pak Pong Ju	Pak Pong Ju Inspects Various Units
12/19/2018	Premier Pak Pong Ju	Pak Pong Ju Inspects Various Units
1/15/2019	Premier Pak Pong Ju	Premier Inspects Various Units in Sunch'on Area
4/29/2019	Premier Kim Jae Ryong	DPRK Premier Inspects Different Units
7/29/2019	Former Premier Pak Pong Ju	Pak Pong Ju Inspects Units in Sunch'on City
8/1/2019	Premier Kim Jae Ryong	Kim Jae Ryong Inspects Several Units
9/28/2019	Former Premier Pak Pong Ju	Pak Pong Ju Inspects Units in South Phyongan Province
01/06/2020	Kim Jong Un, Premier Kim Jae Ryong, Minister of Chemical Industry Jang Kil Ryong, Top Party Central Committee Officials: Jo Yong Won, Ma Won Chun, & Ri Jong Nam	Kim Jong Un Touts Chemical Industry in First Economic Site Visit of 2002

Table 1 based on data from Korean Central News Agency (KCNA); Updated January 10, 2020.

Image from Korean Central Television Network (KCTV).
Note the obelisk in the lower left of the photo (described in more detail below).

The photos also revealed an obelisk-shaped monument, constructed near the site of the groundbreaking ceremony held in 2017. Such obelisks are often associated with commemorating visits by the Kim family. A review of satellite imagery from September 2019 shows the same monument on the site, but the monument is not evident in imagery from January 2019, and additional imagery within that date range of a high-enough resolution to see the monument is unavailable. What is clear is that the visit by Kim Jong Un represents the continued and mounting importance of the Sunch'on Phosphatic Fertilizer Factory under construction.

Additional aerial images of the Sunch'on Phosphatic Fertilizer Factory. The precise date of the images is unknown, but they were likely taken in late December 2019 or at the same time as Kim Jong Un's visit in January 2020.

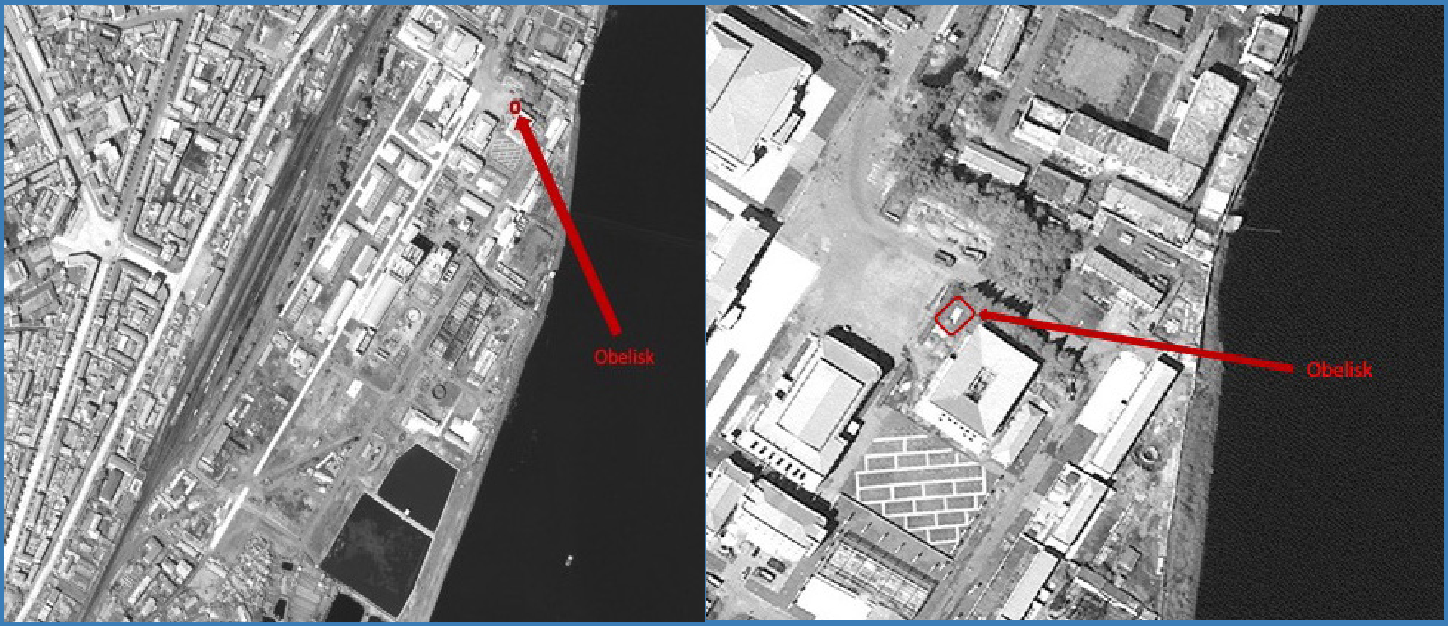


Image over Sunch'on fertilizer factory site on September 16, 2019, Source: DigitalGlobe via TerraServer.

Although the evidence for Sunch'on's involvement in uranium extraction from a phosphate fertilizer plant is quite strong, Sunch'on is not the first phosphate-based fertilizer factory in the DPRK. This suggests the possibility that a pilot program for uranium extraction, or indeed a larger-scale operation, could have taken place elsewhere in the DPRK. If one assumes Sunch'on's future involvement in uranium extraction for all of the aforementioned reasons, it could be viewed through one of three lenses: as an additional pilot site for testing this process, as an additional site for conducting this process at a full scale, or as the first phosphate fertilizer plant that will conduct uranium extraction activities at full scale, after having been tested at other plants on a pilot scale. This last option is the most probable, given that the construction timeline for the plant matches the timeline for several key factors, including: the increased mention of the need to produce phosphate-based fertilizers in the DPRK, rising international pressure on the DPRK to denuclearize (uranium extraction from phosphates being a covert method of obtaining an intermediary material for nuclear weapons with an excellent track record of success), and the increase in DPRK scientific publications and patents related to phosphate fertilizer production processes. The numerous high-level visits to Sunch'on taking place every few months, often at the level of the DPRK premier, further confirms the importance of the site to the executive.

Other Fertilizer Factories

It is important to note that Sunch'on is far from the only site mentioned by DPRK state media or declassified US documents in relation to the chemical fertilizer industry. The author identified several chemical fertilizer plants across North Korea using a variety of sources and open-source verification techniques. The primary research challenge was not identifying chemical fertilizer plants, but rather which chemical fertilizer plants are phosphate-based; i.e. used phosphate ore or phosphate-containing rock. There are multiple nitrogen-based chemical fertilizer plants in North Korea in addition to those phosphate-based plants, but rarely do media reports specify which is which.

The author identified eight other sites in the DPRK associated with the production of phosphate-based fertilizer, and thus conceivably associated with uranium extraction activities. While the list is not exhaustive, research demonstrates that the sites are all producing some quantity of phosphate-based fertilizer for the DPRK. The names and a thorough description of each are located in Annex I, while Annex II details the mines associated with producing the raw materials needed by these factories.

Production Estimates

While many of these sites have no production estimates associated with them, a few output numbers have appeared in various sources over the years. Using these numbers, and the formula associated with U_3O_8 yield from phosphate fertilizer production processes published by INL, one can calculate the potential U_3O_8 yield from these factories at different percentages of pro cess effectiveness. The numbers are not small. Below is an example of such a calculation for two factories producing phosphate fertilizer in the DPRK. The yields of U_3O_8 in kilograms are given in the last two columns (based on two slightly different calculation methods provided by INL), and are provided for U_3O_8 recovery percentages of 25%, 50%, 75%, and 100% at both Nampo and Moon-Pyong. The figures used for the "amount of material" column are sourced from the aforereferenced Nautilus Institute publication from 2011.

LOCATION	PHOSPHATE MATERIAL	P2O5 PERCENTAGE	AMOUNT OF MATERIAL (METRIC TONS)	PERCENT RECOVERY OF U3O8	U3O8 (KG) AT X% RECOVERY (BASED ON L)	U3O8 (KG) AT X% RECOVERY BASED ON KG
Nampo Phosphate Fertilizer Plant (annual production)	Superphosphate of lime	20.00%	200,000	25.00%	3,888.89	3,890.00
Moon-Pyong Smelting Factory (annual production)	Superphosphate of lime	20.00%	200,000	25.00%	3,888.89	3,890.00
Nampo Phosphate Fertilizer Plant (annual production)	Superphosphate of lime	20.00%	200,000	50.00%	7,777.78	7,780.00
Moon-Pyong Smelting Factory (annual production)	Superphosphate of lime	20.00%	200,000	50.00%	7,777.78	7,780.00
Nampo Phosphate Fertilizer Plant (annual production)	Superphosphate of lime	20.00%	200,000	75.00%	11,666.67	11,670.00
Moon-Pyong Smelting Factory (annual production)	Superphosphate of lime	20.00%	200,000	75.00%	11,666.67	11,670.00
Nampo Phosphate Fertilizer Plant (annual production)	Superphosphate of lime	20.00%	200,000	100.00%	15,555.56	15,560.00
Moon-Pyong Smelting Factory (annual production)	Superphosphate of lime	20.00%	200,000	100.00%	15,555.56	15,560.00

Table 2. Calculating hypothetical U_3O_8 output at two North Korean facilities.

Conclusion

The proliferation crisis on the Korean Peninsula is one of the foremost challenges facing both the region and the existing global nonproliferation and arms-control regime in the world today. With international pressure mounting on the DPRK to roll back its nuclear program and engage in comprehensive, verifiable, and irreversible disarmament, it is critical to consider alternative paths of uranium acquisition that may be hidden more easily from the international community. This method of uranium acquisition has been successfully hidden from the international community in the past, makes use of existing agricultural infrastructure, and has the potential to produce a sizeable amount of U_3O_8 annually. As such, it cannot be ignored and must be further considered as a possible yellowcake acquisition pathway for the DPRK, one which could considerably alter open-source estimates of nuclear materials produced annually in the country.

Much of the evidence for this case is circumstantial; without on-the-ground environmental sampling or inspections, it is very difficult to tell whether the DPRK has turned the possibility of uranium extraction from phosphate fertilizers into a reality. This paper demonstrates that the DPRK has both the means and motivation to take this course of action. It may already be doing so, or may be planning to begin such activity in the near future. As such, estimates of North Korean nuclear-material stockpiles based solely on traditional methods of yellowcake acquisition must be reconsidered.

Annex 1: DPRK Phosphate Fertilizer Facilities

Nampo Phosphate Fertilizer Plant

As its title suggests, Nampo Phosphate Fertilizer Plant is one of the clearest cases of a plant that produces phosphate-based fertilizers. This is based on a wealth of sources from past and present. Nampo is known for producing superphosphate, which comes in two varieties—Single Superphosphate (SSP), which is about 16–20 percent Phosphorus pentoxide (P_2O_5), and Triple Superphosphate (TSP), which is about 45 percent P_2O^5.[54] SSP is created by combining phosphate rock with sulfuric acid, while TSP is created by combining phosphate rock with phosphoric acid.[55]

Nampo's fertilizer plant has long been associated with phosphate-based fertilizer production. A March 1971 declassified document entitled "Basic Imagery Interpretation Report: Nampo Phosphate Fertilizer Plant" states:

> The Nampo Phosphate Fertilizer Plant is collocated with the Nampo Copper and Zinc Plant [redacted] in the eastern suburbs of Nampo, Pyonggan-namdo Province. It is one of two phosphate fertilizer plants in North Korea. The other is located within the Hungnam Nitrogen Fertilizer Plant [redacted]...
>
> Analysis of the Nampo Phosphate Fertilizer Plant on high-resolution photography shows that superphosphate fertilizer is the primary product of the plant and sulfuric acid is a secondary product. It is one of two phosphate fertilizer plants in North Korea...
>
> The major facilities of the superphosphate fertilizer and sulfuric acid production areas of the Nampo plant were complete when they were first observed in December 1962. Since that time, facilities have been constructed in an unidentified processing area and the sulfuric acid plant has been expanded. The plant was seen in operation from December 1962 through February 1964. The superphosphate fertilizer area has been inactive when observed

[54] "Triple Superphosphate," The Mosaic Company, 2020, https://www.cropnutrition.com/triple-superphosphate; "Single Superphosphate," The Mosaic Company, 2020, https://www.cropnutrition.com/single-superphosphate.
[55] Ibid.

> since June 1964...The cut-off date for information is March 1970...[56]

An additional declassified document from April 1962 also links Nampo to the production of phosphate fertilizer, saying:

> The main producer of phosphorus fertilizer in NK was the Sunch'on Chemical Factory, whose 1960 production goal was 300,000 tons. Though it was unknown what expansion program this factory had, the NK government appeared to be making efforts to raise the production amount of phosphate as much as nitrate fertilizers. For instance, it was under consideration to set up a factory for production of phosphate of lime from apatite which was abundant in the Sukch'on area of P'yongan-namdo. The probable site for this factory was Namp'o in P'yongan-namdo. This factory was said to be additionally installed with a system for compounding various fertilizers. In the production of chemical fertilizers, NK had no particular bottlenecks, except that the existing production facilities were incapable of handling the entire NK produce of lime stones and apatites. Therefore, what was needed for greater production of chemical fertilizers was the expansion of production facilities rather than the improvement of techniques.[57] (emphasis added)

This means that, as early as 1962, but certainly by 1970, the Nampo fertilizer factory was involved in the production of phosphate fertilizers.

The linkage between Nampo and phosphate fertilizer continues through the present, with numerous sources confirming that the plant is either wholly or largely dedicated to its production, which in turn supports the possibility that some uranium extraction is taking place onsite. A Nautilus Institute report from 2011 entitled "Status and Future of the North Korean Minerals Sector," by Edward Yoon notes that the annual production capacity of the Nampo Metals/Minerals Refinery (understood to be co-located with the fertilizer factory) is 200,000 tons of superphosphate of lime, among other products.[58]

---

[56] "Basic Imagery Interpretation Report: Nampo Phosphate Fertilizer Plant," Central Intelligence Agency, Directorate of Intelligence, March 1971, https://www.cia.gov/library/readingroom/docs/CIA-RDP79T00909A001000010017-7.pdf.

[57] "The North Korean Chemical Industry."

[58] Edward Yoon, "Status and Future of the North Korean Minerals Sector," Nautilus Institute for Security and Sustainability at the University of San Francisco Center for the Pacific Rim, January 6, 2011, http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf.

Hungnam Fertilizer Factory

Hungnam Fertilizer Factory has existed since at least October 1963.[59] A review of the declassified literature provides a sizeable insight into the historical activities of the plant, and conclusively links it with the production of phosphate fertilizers. A declassified document entitled "Basic Imagery Interpretation Report: Hungnam Nitrogen Fertilizer Plant" from June 1969 indicated that "the primary products of the plant are superphosphate and ammonia- based fertilizers including urea, ammonium nitrate, and ammonium sulfate."[60] This is not immediately apparent from the fertilizer plant's name, but a second declassified document from March 1971 corroborates Hungnam's production of superphosphate: "The Nampo Phosphate Fertilizer Plant is collocated with the Nampo Copper and Zinc Plant [redacted] in the eastern suburbs of Nampo, Pyonggan-namdo Province. It is one of two phosphate fertilizer plants in North Korea. The other is located within the Hungnam Nitrogen Fertilizer Plant [redacted]."[61] Additionally, the document from June 1969 provides some insight into how the North Koreans produced superphosphate at Hungnam at the time, saying, "Superphosphate is produced in Area A by reacting sulfuric acid with phosphate ore."[62] Furthermore, the document confirms activity at the plant, noting that, "On October 1963 photography ... an ore stockpile at the superphosphate plant indicated that [this area] was in operation as well."[63]

An analysis of recent satellite imagery and DPRK state media indicates that the plant is still active and producing fertilizer. An October 5, 2019, article in the *Pyongyang Times* states that "the Hungnam Fertilizer Complex changed the AC contactor into relay self-powered AC contactor, thus making it possible to save thousands [of kilowatts per hour, kWh] of electricity per month."[64] The implication of saving "thousands [of] kWh of electricity per month" is that there is high electricity usage at the plant, which is consistent with a plant in operation.

---

[59] "Basic Imagery Interpretation Report: Hungnam Nitrogen Fertilizer Plant," Central Intelligence Agency, Directorate of Intelligence, June 1969, https://www.cia.gov/library/readingroom/docs/CIA-RDP79T00909A000500010020-9.pdf.
[60] Ibid.
[61] "Basic Imagery Interpretation Report: Nampo Phosphate Fertilizer Plant."
[62] "Basic Imagery Interpretation Report: Hungnam Nitrogen Fertilizer Plant."
[63] Ibid.
[64] "Chemical industrial establishments try to save power," *Pyongyang Times,* October 10 2019, https://kcnawatch.org/newstream/1570269622-637150198/chemical-industrial-establishments-try-to-save-power/.

Moon-Pyong Smelting Factory

According to the same aforementioned Nautilus 2011 report, the Moon-Pyong Metals/Minerals Refinery, also known as the Moon-Pyong Smelting Factory, has a production capacity of 200,000 tons of superphosphate of lime.[65] Little other information on this site seems to be available.

Jongju Microelement Perphosphoric Acid Lime Fertilizer Factory

There is less information on Jongju Microelement Perphosphoric Acid Lime Fertilizer Factory than some of the aforementioned sites, but the author still assesses that this site is likely involved in the production of phosphate fertilizer. The chapter on Jongju in Rainer Dormels's book, *North Korean Cities,* mentions the linkage between this site and phosphate fertilizer, saying, "in the Jongju Microelement Perphosphoric Acid Lime Fertilizer Factory mainly phosphate fertilizer is produced."[66] In addition to this reference, a March 26, 2019, article from the Korean Central News Agency stated:

> Big efforts are directed to the production of phosphate fertilizer in the DPRK, true to the intention of the Workers' Party of Korea on channeling all efforts into the agricultural front, the major point of attack in socialist economic construction. The Ministry of Mining Industry has taken steps to settle the knotty problems in the phosphate fertilizer production after grasping the actual conditions of relevant mines and enterprises...a fertilizer factory in Jongju has made innovation in fertilizer production by introducing rational production methods suited to the actual condition.[67]

Phyongbuk Smeltery

Similar to the Jongju Microelement Perphosphoric Acid Lime Fertilizer Factory, there is less information available on the Phyongbuk Smeltery, also located in Jongju. According to Dormels, "Jongju has fewer companies than it could have been expected in regards to its

---

[65] Yoon, "Status and Future of the North Korean Minerals Sector."
[66] Rainer Dormels, *North Korea's Cities: Industrial facilities, internal structures and typification* (Seoul, Republic of Korea: Jimoondang Publishing Company, 2014), p. 147.
[67] "Efforts Concentrated on Phosphate Fertilizer Production in DPRK," KCNA, March 26, 2019, https://kcnawatch.org/newstream/1553592135-970654403/efforts-concentrated-on-phosphate-fertilizer-production-in-dprk/.

population. However, this is not surprising due to the agricultural orientation of the city. Comparatively high, though, is the number of important companies. Almost every source implies for this city a distinct specialization towards heavy industry."[68]

Furthermore, it is interesting to note that two sites potentially involved in the production of phosphate-based fertilizers are located in the same city. Dormels addresses both of them in his book, but Phyongbuk Smeltery gets a much longer treatment than does the Jongju Fertilizer Factory. Dormels states:

> The Phyongbuk Smeltery is of great importance for the foreign exchange revenue of North Korea. Mainly gold, silver, and copper are smelted but also phosphate fertilizer etc. is produced here. The smeltery is located 800 m southeast of the train station in Wolyang-ri at the riverside of Talchon-gang. In total 2,300 people are employed there. The total area size is about 264,000 sq meters or 388,400 sq meters. The construction work started in August 1979. In 1983 the first stage was completed and so it went into operation, in 1991 another part of the smeltery was finished. In 2009 in some parts of the building restoration and renovation work was carried out. The smeltery benefits from the favorable transport and geographical position of Jongju, since the railway line from Pyongyang to Sinuiju and the Phyongbuk-line as well as the road from Kaesong to Sinuiju pass through the city. The smeltery is connected to the rail network with a branch terminal line. The smeltery obtains electrical energy out of the Chongchongang Thermal Power Plant (Pakchon-kun). The raw materials that are to be processed are most commonly brought from nearby.[69]

Tanch'on Smeltery/Magnesia Factory

According to Dormels: "The Tongam Mine is by far the largest apatite mine in the DPR Korea. In 1980, they began with their development. The mine supplies the Hungnam Fertilizer Factory and the Tanchon Phosphatic Fertilizer Factory. By train to Tanchon Fertilizer Factory it is about 40km and to Kimchaek port 70km. The Tongam station can be reached by truck or by cableway."[70]

[68] Dormels, *North Korea's Cities,* p. 146.
[69] Ibid., p. 147.
[70] Ibid., p.355.

Chongsu Chemical Plant

The 1980 *Minerals Yearbook* produced by the United States Geological Survey (USGS) lists the Chongsu Chemical Plant as producing phosphate fertilizer, deliquescent phosphate fertilizer, and other fertilizer-related products.[71]

Haeju Smeltery

An article in the *Pyongyang Times* from December 1, 2019, confirms the linkage of this site to the production of phosphate fertilizers, reporting:

> The Haeju Smeltery has newly established the production process of nutritive phosphatic compound fertilizer. The process makes it possible to more than double the productivity while saving much more labour and electricity than before. The fertilizer contains sufficient nutrients that are suitable for the growth of crops. The smeltery is now overfulfilling its daily production plan by 20 percent in order to fully satisfy the demands for grain production.[72]

Though the smeltery may have established a new production process, it seems as if its production of phosphate fertilizers is longstanding; the 1980 Minerals Yearbook produced by the USGS lists the Haeju Smelter as producing phosphate fertilizer, and lists an additional facility as the Haeju Phosphate Fertilizer Plant, which is said to produce deliquescent phosphate fertilizer.[73] As of this writing, it is not clear if both referenced facilities are in fact separate sites, separate facilities at the same site, or two different names for the same site and facility.

---

[71] Edmond Chin, "The Mineral Industry of North Korea," in US Geological Survey, *Minerals Yearbook Area Reports: International 1980,* Volume 3, (Washington, DC: US Government Publishing Office, 1980), p. 595.
[72] "Weekly Roundup," *Pyongyang Times,* December 1, 2019, https://kcnawatch.org/newstream/1575248473-731135436/weekly-roundup/.
[73] Chin, "The Mineral Industry of North Korea," p. 595.

Annex 2: DPRK Mines Providing Raw Material

There is little information both available and reliable on the mines in the DPRK that provide raw material to the various fertilizer factories. Below is a summation of that which is available, in addition to the information provided on Sunch'on in the body of this report. The list below is not meant to be comprehensive; references to new mining sites continually appear throughout DPRK state media, in obscure blogs from around the world written by authors of varying qualifications, and in publications by subject matter experts interested in DPRK mining activity. Rather, this list is meant to be a summation of what this author has been able to reliably dredge up (pardon the pun) about mines linked to phosphate fertilizer production at the time of publication. This author has no doubt that more mines eventually will need to be added to this list.

Tongam (Dongam) Mine

According to Dormels, "the Tongam Mine is by far the largest apatite mine in the DPR Korea. In 1980, they began with their development. The mine supplies the Hungnam Fertilizer Factory and the Tanchon Phosphatic Fertilizer Factory. By train to Tanchon Fertilizer Factory it is about 40km and to Kimchaek port 70km. The Tongam station can be reached by truck or by cableway."[74] As aforementioned, apatite is one of the primary minerals in which phosphate is found, and thus is frequently mined around the world for the production of phosphate-based fertilizer. DPRK state media has also linked the Tongam mine directly to fertilizer production; according to an article published on KCNA on March 26, 2019:

> The Ministry of Mining Industry has taken steps to settle the knotty problems in the phosphate fertilizer production after grasping the actual conditions of relevant mines and enterprises. In particular, it gives priority to the transportation of concentrate and raw and other materials in contact with related units like the Ministry of Railways...The Tongam Mine, too, is turning out a great deal of fertilizer by raising the operation rate of floatation machine and electric motors.[75]

[74] Dormels, *North Korea's Cities,* p. 355.
[75] "Efforts Concentrated on Phosphate Fertilizer Production in DPRK," KCNA, March 26, 2019, https://kcnawatch.org/newstream/1553592135-970654403/efforts-concentrated-on-

Ssangryong Mine

When it comes to apatite production in the DPRK, Ssangryong is one of the most often referenced mines. One of its earliest mentions is in a March 23, 2016, KCNA article, which names four mines in connection with the production of phosphate fertilizer, including Ssangryong.[76] According to a January 26, 2018, KCNA article, "the Ssangryong Mine is putting spurs to earth-scrapping at an open-cast cutting site to produce phosphate fertilizer and pushing ahead with the work for reconstructing the hauling track and extending new electric-car lines."[77] KCNA reported on March 26, 2019, that "the Ssangryong Mine has markedly boosted the production of apatite concentrate by ensuring the normal operation of equipment, while a fertilizer factory in Jongju has made innovation in fertilizer production by introducing rational production methods suited to the actual condition."[78] Additionally, the DPRK sought foreign investment in this mining project; on February 8, 2019, *NK News* reported that:

> Another bid listed on the trade [Ministry of External Economic Relations-run Korea Foreign Investment and Economic Cooperation Committee] website this week hopes to bring in €12 million (USD$13.6 million) in investments to modernize the Ssangryong Mine in Kimchaek City, North Hamgyong Province. A Korean-language bid says the purpose of the investment is to produce apatite concentrate, required to manufacture phosphate fertilizer. The production of magnetic iron concentrate is another goal of the project, with funds set to pay for a "complete set of mining and concentrating facilities including excavator, automobile, bulldozer, and winch." Like the previous proposal, the North says investment can take the form of either an equity or contractual joint venture, currently prohibited under UN Security Council Resolution 2375 adopted in September 2017.[79]

At the time of writing. it is unclear whether the project has been funded.

---

phosphate-fertilizer-production-in-dprk/.

[76] "Production of Phosphate Fertilizer on Increase," KCNA, March 23, 2016, https://kcnawatch.org/newstream/1546389691-439630997/production-of-phosphate-fertilizer-on-increase/.

[77] "Mineral Production Increases in DPRK," *Korean Central News Agency* (KCNA), January 26, 2018, https://kcnawatch.org/newstream/1546363340-49159037/mineral-production-increases-in-dprk/.

[78] Dagyum, Ji. "North Korea seeking foreign direct investment in mining, energy sector: website," *NK News*, February 8, 2019, https://www.nknews.org/2019/02/north-korea-seeking-foreign-direct-investment-in-mining-energy-sector-website/.

[79] "Production of Phosphate Fertilizer on Increase," KCNA, March 23, 2016, https://kcnawatch.org/newstream/1546389691-439630997/production-of-phosphate-fertilizer-on-increase/.

Taedaeri and Phungnyon

A March 23, 2016, article by KCNA mentions several mines related to the phosphate industry, including Taedaeri and Phyngnyon, as well as the aforementioned Ssangryong and Tongam/Dongam mines:

> Production of phosphate fertilizer is on the increase in the DPRK with the 70-day campaign as a momentum. According to data available at the Phosphate Fertilizer Industry Management Bureau, the monthly plan was carried out at 105 percent as of March 21, four times higher as compared with the same period last year. The Ssangryong, Tongam, Taedaeri, Phungnyon and other mines under the Ministry have operated vehicles and mining facilities at full capacity, over-fulfilling their daily quotas over 160 percent. The increased production of phosphate fertilizer is encouraging agricultural workers to round off farming preparations.[80]

[80] "Production of Phosphate Fertilizer on Increase," KCNA, March 23, 2016, https://kcnawatch.org/newstream/1546389691-439630997/production-of-phosphate-fertilizer-on-increase/.

About the Author

Margaret (Maggie) Croy conducts research for the East Asia Nonproliferation Program (EANP) at the James Martin Center for Nonproliferation Studies (CNS) at the Middlebury Institute of International Studies at Monterey (MIIS). Croy uses remote sensing technologies, data analytics tools, and traditional research methods to study a variety of topics, including North Korean WMD proliferation, military facilities across the Middle East, the nuclear fuel cycle, and compliance with multilateral nonproliferation and arms-control treaties.

Previously, Margaret worked as a graduate research assistant at CNS, a political affairs intern at the United Nations Office for Disarmament Affairs, an international nuclear safeguards policy intern at Lawrence Livermore National Laboratory, and as an analyst at the Center for Homeland Defense and Security at the Naval Postgraduate School.

Margaret graduated from MIIS in 2018 with an MA in Nonproliferation and Terrorism Studies. Previously, she earned her AB in Anthropology from Dartmouth College in 2014. Margaret has also taken part in several specialized training courses, including the International Nuclear Safeguards Policy and Information Analysis course hosted by CNS in conjunction with LLNL, the Nuclear Research Reactor Practicum course at the Czech Technical University Department of Nuclear Reactors, and the Middlebury Summer Intensive Language Program in Arabic.

Occasional Papers from CNS

#46 • Options for a Verifiable Freeze on North Korea's Missile Programs

#45 • The Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States

#44 • Eyes on U: Opportunities, Challenges, and Limits of Remote Sensing for Monitoring Uranium Mining and Milling

#43 • North Korea's International Scientific Collaborations: Their Scope, Scale, and Potential Dual-Use and Military Significance

#42 • The Other Fissile Material: Strengthening National and International Plutonium Management Approaches

#41 • Monitoring Uranium Mining and Milling in India and Pakistan through Remote Sensing Imagery

#40 • Monitoring Uranium Mining and Milling in China and North Korea through Remote Sensing Imagery

#39 • Safeguards and Verification in Inaccessible Territories

#38 • Geo4Nonpro 2.0

#37 • All the World Is Staged: An Analysis of Social Media Influence Operations against US Counterproliferation Efforts in Syria

#36 • North Korea's Information Technology Networks

#35 • Countering North Korean Procurement Networks Through Financial Measures: The Role of Southeast Asia

#34 • Open-Source Monitoring of Uranium Mining and Milling for Nuclear Nonproliferation Applications

#33 • WMD Proliferation Risks at the Nexus of 3D Printing and DIY Communities

#32 • Taiwan's Export Control System: Overview and Recommendations

#31 • Revisiting Compliance in the Biological Weapons Convention

#30 • Crowdsourcing Systems and Potential Applications in Nonproliferation

#29 • The Verification Clearinghouse: Debunking Websites and the Potential for Public Nonproliferation Monitoring

#28 • Geo4nonpro.org: A Geospatial Crowdsourcing Platform for WMD Verification

#27 • Searching for Illicit Dual Use Items in Online Marketplaces: A Semi-Automated Approach

#26 • 2016 Symposium Findings on Export Control of Emerging Biotechnologies

#25 • Outlawing State-Sponsored Nuclear Procurement Programs and Recovery of Misappropriated Nuclear Goods

#24 • Strengthening the ROK-US Nuclear Partnership

#23 • Replacing High-Risk Radiological Materials

#22 • A Blueprint to a Middle East WMD-Free Zone

#21 • Biotechnology E-commerce: A Disruptive Challenge to Biological Arms Control

#20 • Countering Nuclear Commodity Smuggling: A System of Systems

#19 • Alternatives to High-Risk Radiological Sources

#18 • Stories of the Soviet Anti-Plague System

#17 • Ugly Truths: Saddam Hussein and Other Insiders on Iraq's Covert Bioweapons

#16 • Rethinking Spent Fuel Management in South Korea

#15 • Engaging China and Russia on Nuclear Disarmament

#14 • Nuclear Challenges and Policy Options for the Next US Administration

#13 • Trafficking Networks for Chemical Weapons Precursors: Lessons from the 1980s Iran-Iraq War

#12 • New Challenges in Missile Proliferation, Missile Defense, and Space Security

#11 • Commercial Radioactive Sources: Surveying the Security Risks

#10 • Future Security in Space: Commercial, Military, and Arms Control Trade-Offs

#09 • The 1971 Smallpox Epidemic in Aralsk, Kazakhstan, and the Soviet Biological Warfare Program

#08 • After 9/11: Preventing Mass Destruction Terrorism and Weapons Proliferation

#07 • Missile Proliferation and Defences: Problems and Prospects

#06 • WMD Threats 2001: Critical Choices for the Bush Administration

#05 • International Perspectives on Ballistic Missile Proliferation and Defenses

#04 • Proliferation Challenges and Nonproliferation Opportunities for New Administrations

#03 • Nonproliferation Regimes at Risk

#02 • A History of Ballistic Missile Development in the DPRK

#01 • Former Soviet Biological Weapons Facilities in Kazakhstan: Past, Present, and Future

Occasional Papers from CNS

#46 • Options for a Verifiable Freeze on North Korea's Missile Programs

#45 • The Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States

#44 • Eyes on U: Opportunities, Challenges, and Limits of Remote Sensing for Monitoring Uranium Mining and Milling

#43 • North Korea's International Scientific Collaborations: Their Scope, Scale, and Potential Dual-Use and Military Significance

#42 • The Other Fissile Material: Strengthening National and International Plutonium Management Approaches

#41 • Monitoring Uranium Mining and Milling in India and Pakistan through Remote Sensing Imagery

#40 • Monitoring Uranium Mining and Milling in China and North Korea through Remote Sensing Imagery

#39 • Safeguards and Verification in Inaccessible Territories

#38 • Geo4Nonpro 2.0

#37 • All the World Is Staged: An Analysis of Social Media Influence Operations against US Counterproliferation Efforts in Syria

#36 • North Korea's Information Technology Networks

#35 • Countering North Korean Procurement Networks Through Financial Measures: The Role of Southeast Asia

#34 • Open-Source Monitoring of Uranium Mining and Milling for Nuclear Nonproliferation Applications

#33 • WMD Proliferation Risks at the Nexus of 3D Printing and DIY Communities

#32 • Taiwan's Export Control System: Overview and Recommendations

#31 • Revisiting Compliance in the Biological Weapons Convention

#30 • Crowdsourcing Systems and Potential Applications in Nonproliferation

#29 • The Verification Clearinghouse: Debunking Websites and the Potential for Public Nonproliferation Monitoring

#28 • Geo4nonpro.org: A Geospatial Crowdsourcing Platform for WMD Verification

#27 • Searching for Illicit Dual Use Items in Online Marketplaces: A Semi-Automated Approach

#26 • 2016 Symposium Findings on Export Control of Emerging Biotechnologies

#25 • Outlawing State-Sponsored Nuclear Procurement Programs and Recovery of Misappropriated Nuclear Goods

#24 • Strengthening the ROK-US Nuclear Partnership

#23 • Replacing High-Risk Radiological Materials

#22 • A Blueprint to a Middle East WMD-Free Zone

#21 • Biotechnology E-commerce: A Disruptive Challenge to Biological Arms Control

#20 • Countering Nuclear Commodity Smuggling: A System of Systems

#19 • Alternatives to High-Risk Radiological Sources

#18 • Stories of the Soviet Anti-Plague System

#17 • Ugly Truths: Saddam Hussein and Other Insiders on Iraq's Covert Bioweapons

#16 • Rethinking Spent Fuel Management in South Korea

#15 • Engaging China and Russia on Nuclear Disarmament

#14 • Nuclear Challenges and Policy Options for the Next US Administration

#13 • Trafficking Networks for Chemical Weapons Precursors: Lessons from the 1980s Iran-Iraq War

#12 • New Challenges in Missile Proliferation, Missile Defense, and Space Security

#11 • Commercial Radioactive Sources: Surveying the Security Risks

#10 • Future Security in Space: Commercial, Military, and Arms Control Trade-Offs

#09 • The 1971 Smallpox Epidemic in Aralsk, Kazakhstan, and the Soviet Biological Warfare Program

#08 • After 9/11: Preventing Mass Destruction Terrorism and Weapons Proliferation

#07 • Missile Proliferation and Defences: Problems and Prospects

#06 • WMD Threats 2001: Critical Choices for the Bush Administration

#05 • International Perspectives on Ballistic Missile Proliferation and Defenses

#04 • Proliferation Challenges and Nonproliferation Opportunities for New Administrations

#03 • Nonproliferation Regimes at Risk

#02 • A History of Ballistic Missile Development in the DPRK

#01 • Former Soviet Biological Weapons Facilities in Kazakhstan: Past, Present, and Future

nonproliferation.org

Middlebury Institute *of*
International Studies at Monterey
James Martin Center for Nonproliferation Studies