North Korea's Uranium Enrichment Facilities: What We Learned from KCNA's Images

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For the first time ever, North Korea has released images of the inside of two of its gas centrifuge uranium enrichment plants. The first set of images was released on September 13, 2024, by the Korea Central News Agency (KCNA), including five images of the North Korean leader Kim Jong Un touring gas centrifuge cascade halls.[1] On January 29, 2025, *Pyongyang Times* released nine KCNA images of Kim touring another gas centrifuge plant.[2]

The September images appear to show a major portion of the inside of the undeclared Kangsong, aka Kangson, enrichment plant, which the Institute first revealed publicly in May 2018, and which has since been expanded in size.[3] The second imagery set from January appears to show major portions of the Yongbyon enrichment plant, which North Korea admitted to having in 2010. It should be noted that while the images and official assessments are consistent with Kangsong being an enrichment plant, this conclusion remains unverified and there is no definitive proof that the images were taken at Kangsong, or Yongbyon, for that matter. Figures 1 and 2 show recent commercial satellite images of these two facilities.

Previously, North Korea has only allowed a brief view of an enrichment hall at Yongbyon to one select group of non-governmental U.S. experts in 2010.[4] None of the experts was a centrifuge expert, and their North Korean hosts rushed the group through the plant and were hesitant to answer questions. Further, the enrichment plant at Yongbyon has undergone notable changes

[1] "Respected Comrade Kim Jong Un Inspects Nuclear Weapons Institute and Production Base of Weapons-Grade Nuclear Materials," KCNA, September 13, 2024, http://www.kcna.kp/en/article/q/69c852101729d6055a771219d3f0a8fd.kcmsf.
[2] "Respected Comrade Kim Jong Un inspects nuclear-material production base and Nuclear Weapons Institute," *Pyongyang Times,* January 29, 2025, http://www.pyongyangtimes.com.kp/blog?page=revolutionary&blogid=6799924ec3387205a7e1437a.
[3] David Albright, with assistance from Sarah Burkhard, "Revisiting Kangsong: A Suspect Uranium Enrichment Plant," *Institute for Science and International Security,* October 2, 2018, https://isis-online.org/isis-reports/detail/revisiting-kangsong-a-suspect-uranium-enrichment-plant/10.
[4] Siegfried Hecker, "A Return Trip to North Korea's Yongbyon Nuclear Complex," Center for International Security and Cooperation, November 20, 2010. Siegfried S. Hecker, "A Return Trip to North Korea's Yongbyon Nuclear Complex", NAPSNet Special Reports, November 22, 2010, https://nautilus.org/napsnet/napsnet-special-reports/a-return-trip-to-north-koreas-yongbyon-nuclear-complex/. This study was also published by the Center for International Security and Cooperation on November 20, 2010.

and expansions since that visit in 2010. Thus, these images offer a unique opportunity to study North Korea's enrichment facilities and centrifuges and estimate their current capabilities.

Based on the images and two accompanying official statements, North Korea appears to be expanding its uranium enrichment capabilities. It also claims that it is deploying or will deploy more advanced centrifuges, although this assertion cannot be ascertained in any quantitative manner from the images.

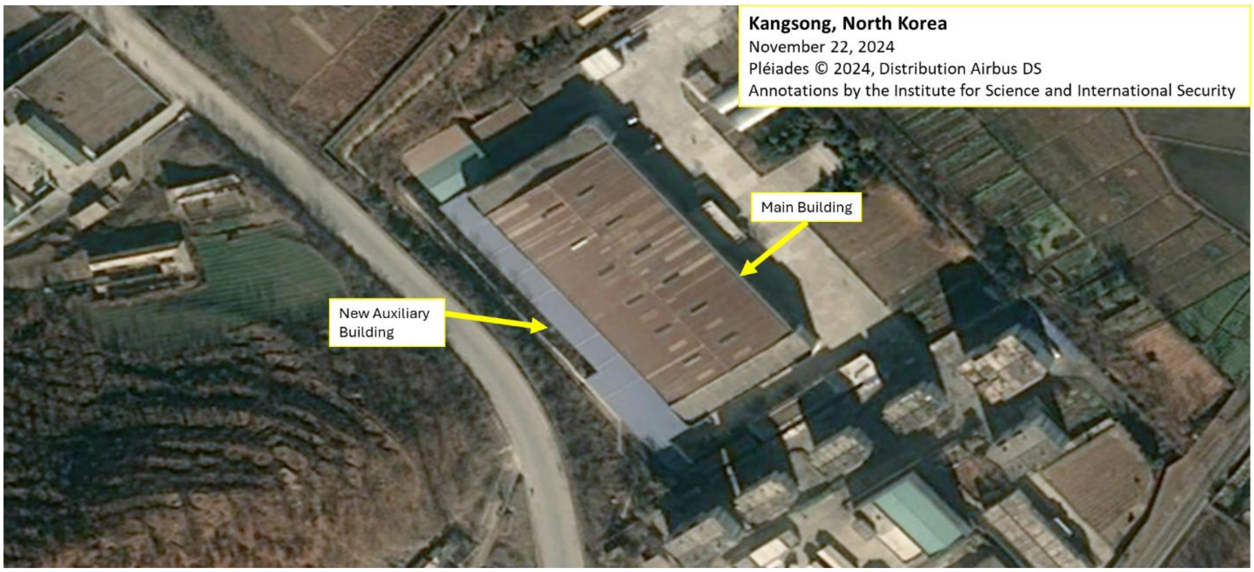

Figure 1. A recent commercial satellite image of the Kangsong plant, alleged to be a gas centrifuge enrichment plant.

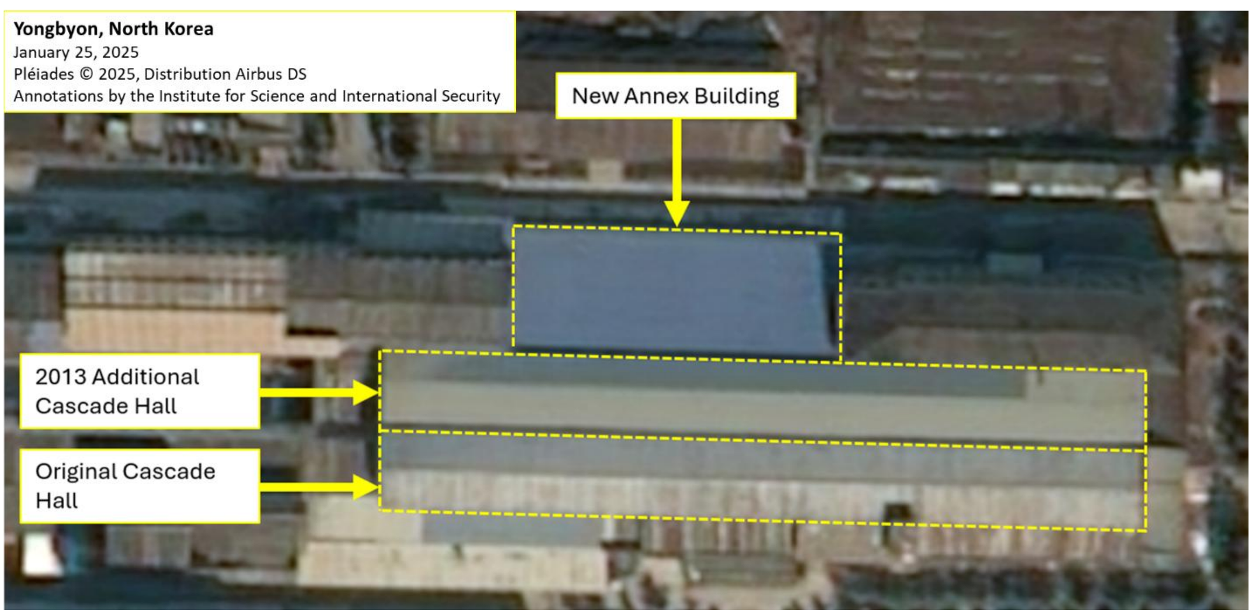

Figure 2. A recent commercial satellite image of the Yongbyon centrifuge plant, located at the Yongbyon Nuclear Complex.

The North Korean statements accompanying the pictures make clear that the major purpose of these facilities is to make weapon-grade uranium (WGU). For example, accompanying the January 2025 images, the *Pyongyang Times* reported that Kim Jong Un viewed the "core processes for producing weapons-grade nuclear materials" and "learned in detail about the present production of nuclear materials" and future production plans. He "underlined the need to further raise the present surging spirit and thus to achieve epochal successes in overfulfilling the plan for producing weapons-grade nuclear materials and in strengthening the nuclear shield of the country."

While not stated by KCNA, another important purpose of the enrichment plants, particularly Yongbyon, is to produce low enriched uranium (LEU) for the 100 megawatt-thermal (MWth) light water reactor (LWR), which has already started operation. In addition, North Korea has previously stated that it is building a nuclear reactor for use in a submarine that is under construction. If so, the 100 MWth LWR is likely the model for this naval reactor and would also require a steady supply of enriched uranium.

As well as can be ascertained, the images do not show any cascades dedicated to making highly enriched uranium (HEU, uranium enriched above 20 percent) or weapon-grade uranium (HEU enriched to 90 percent or more). However, for Kim Jong Un's statement to be true, those cascades would be expected in these buildings or elsewhere, or the low enriched uranium (LEU) cascades would be used in a batch recycling mode to make WGU. However, the latter is highly inefficient and thus unlikely, particularly when a country has had decades to build a more efficient arrangement.

As will be shown, Kangsong is large enough to hold both the cascade halls shown in the September images and another hall(s), not shown, that can enrich LEU up to weapon-grade. The case of Yongbyon is more difficult to assess as to weapon-grade uranium production, but the facility is also large enough to make WGU in areas not shown, or it could ship the LEU to Kangsong. Alternatively, LEU from either plant could be shipped to another unknown facility for dedicated enrichment up to weapon-grade. In this report, however, each plant in the images is assumed to make WGU. Other options will be considered in a separate report focused on North Korea's cumulative WGU inventory. Here the intention is to perform a limited set of scoping calculations based on the images to better understand the potential of North Korea to produce weapon-grade uranium in the two shown facilities, assessed to be two separate facilities, and consistent with being Yongbyon and Kangsong.

The images show cascades of centrifuges that are consistent with the centrifuge and cascade design supplied by Pakistan's A.Q. Khan network to North Korea. Specifically, the cascades shown appear consistent with the 344-centrifuge LEU cascade design which Pakistan used to make low enriched uranium, while the centrifuge height and diameter, as far as they can be discerned from the outer casings shown, are consistent with a centrifuge type called P2, which is modeled on a German centrifuge design called G2 that was stolen by A.Q. Khan in the 1970s. Khan and his associates deployed it in large numbers in the 1980s at the A.Q. Khan Research Laboratories (KRL) to make weapon-grade uranium for Pakistan's nuclear weapons program.

Khan decided to proliferate Pakistan's centrifuge capabilities in the 1980s, and North Korea is known to have received significant help to build P2 centrifuges from KRL in the late 1990s.[5]

An analysis of the images, combined with information about KRL's assistance to North Korea and its centrifuges, allows for an estimate of the number of cascades and thus of the number of centrifuges at each site and their potential WGU output. Kangsong is estimated to hold 5630 P2-type centrifuges in two main areas in the original building and another at least 1912 additional P2-type centrifuges in a recently constructed auxiliary building. Yongbyon is estimated to hold 4550 P2-type centrifuges in the two primary halls and another 2064 in an annex completed in about 2023. In total, Kangsong is estimated to contain nominally 7542 centrifuges, and Yongbyon contains nominally 6614 centrifuges, for a grand total of 14,156 centrifuges, rounded to 14,000. It should be noted that these numbers are not as precise as they appear. Overly precise numbers are used here to facilitate calculations, but the estimates of these numbers contain several assumptions that generate significant uncertainties. These uncertainties and a more accurate development of ranges in the numbers of the centrifuges are better calculated in a historical reconstruction, which will be done in a separate publication.

In terms of current WGU production potential, assuming the centrifuges are P2-types with typical enrichment outputs and inefficiencies, starting with natural uranium, Kangsong could make nominally about 100 kilograms WGU per year in the main building and another 35 to 50 kilograms in the annex, when the latter is finished. Also starting with natural uranium, Yongbyon could nominally make about 80 kilograms of WGU in its two main halls. Combined, Kangsong and Yongbyon are estimated to nominally be able to make 180 kilograms of WGU per year, increasing to 215 to 230 kilograms of WGU per year when the annex is operational. The enrichment capacity of the Yongbyon annex is not included in the WGU estimate as it is assumed to be dedicated to producing LEU and is capable of producing enough for the 100 MWth LWR.

This estimate of the WGU production of the main halls of two enrichment plants is only somewhat higher than an earlier Institute estimate. In 2023 and 2024, prior to the publication of the images, the Institute calculated North Korea's WGU stocks, assuming the existence of two enrichment plants. The calculations result in a range of values, with a median of 150 kilograms of WGU per year.

The estimate derived from the images is a higher end scoping calculation of North Korea's annual current WGU production. A lower end estimate would assume that only Kangsong makes WGU, at a rate of about 100 kilograms per year, or 135 to 150 kilograms per year when the annex is finished.[6] Yongbyon would be dedicated to two purposes, both utilizing LEU,

[5] David Albright, *Peddling Peril* (New York: Free Press, 2010); and "Statement by Dr A.Q. Khan March 2004," which is a written confession that Khan provided to the Pakistani government in 2004 after he was detained. Here it is referred to as the "2004 Statement."

[6] These scoping calculations are not suitable for historical WGU production estimates without more consideration of historical changes in the plants and their centrifuges.

implying that the plant would contain only LEU cascades, for a total of 6880 P2-type centrifuges. They would be used for:

- The production of LEU for the 100 MWth reactor, where the reactor would produce weapon-grade plutonium in the enriched uranium fuel. This scenario would involve a considerable amount of LEU fuel since the fuel would be discharged after only about six months in the reactor, thus, this mode would require two full cores per year. The annual requirement of enriched uranium would require a large fraction of Yongbyon's cascades, but the result would be the production of about 20 kilograms of weapon-grade plutonium per year.[7]

- The production of LEU for a naval LWR, possibly deployed in the next few years, at least from a North Korean planning point of view.

It is unlikely that North Korea showed images of a yet to be discovered enrichment plant. While this statement cannot be proven, it would be surprising if North Korea were to provide any window into such a secret site that could potentially reveal its location to its adversaries' intelligence services.

However, the fact that North Korea released photos from what look like two distinct, widely known sites raises questions on whether there is another unknown site. After all, when North Korea revealed the Yongbyon site, it insisted until recently that there was no other centrifuge enrichment site. Now, it appears to be obliquely indicating that Kangsong is an enrichment site. Maybe it is revealing Kangsong and more about Yongbyon in order to better shield a third site.

Whatever the reality of a third enrichment plant, North Korea is releasing these images to assert that it has a significant capability to make WGU and also additional enriched uranium for the LWR and a nuclear-powered submarine. However, the operational performance of the centrifuges is not discussed in either statement. The cascades look to be older, less reliable Pakistani models and may suffer large centrifuge breakage rates. That does not mean that the above WGU production rates cannot be achieved, but it does mean that such rates may not be uniform over time, and historical reconstructions of WGU stocks need to account for that consideration. It may also mean that North Korea will not be able to build as many nuclear weapons as it wants its enemies to believe.

[7] A more efficient way to produce weapon-grade plutonium in this LWR is to use a driver/target system, described in other Institute reports. This system will reduce the amount of enriched uranium (and separative work) required but result in about 20 kg of weapon-grade plutonium per year, like the use of LEU fuel only. The targets would be easier to process in the Radiochemical Laboratory, and the driver fuel would be stored after irradiation. See for example Institute publication, "North Korea's ELWR: Finally Operational After a Long Delay," by David Albright, Sarah Burkhard, Victoria Cheng, and Spencer Faragasso, January 23, 2024, https://isis-online.org/isis-reports/detail/north-koreas-elwr-finally-operational-after-a-long-delay/10.

Photo Sets

The five KCNA images from September 2024 all show Kim Jong Un touring centrifuge halls containing centrifuge cascades. The photos were most likely taken on the same day given that the same entourage is present, and clothes worn by Kim Jong Un and those around him are the same in all images. As will be shown, the September set of images is consistent with being taken inside the Kangsong enrichment plant, a view also expressed by the IAEA. However, requests sent to the North Korean mission in New York to confirm this view went unanswered.

The nine images released in January 2025 show cascade halls likely from another facility, which is likely the Yongbyon enrichment facility, a view shared by the IAEA. These images also look like they were all taken on the same day.

One possibility is that the photos were taken at the same site on different days and of different sections of the plant. Although this possibility cannot and should not be excluded without confirmation from North Korea or robust intelligence information, comparisons of the sets of images show sufficient differences, and no concrete overlap that would confirm it was one and the same facility.

The images contain objects expected in an enrichment plant and in particular follow at least some of the patterns identified in the 2010 visit. The centrifuges are consistent with those reportedly seen in 2010, although the cascade arrangement is not. In 2010, the U.S. group reported cascades with two rows of centrifuges at Yongbyon; the images show cascades with four rows of centrifuges. The U.S. group reported a bridge over the cascade hall; both sets of images show bridges over the cascade halls. The bridges hold typical cascade equipment, such as piping, electro-pneumatic valves (with a compressed air line), other types of valves, control panels, and pressure measuring equipment. There are also observation windows in the two facilities.

The images also show differences between the two sites, which are discussed next.   Overall, the images show that the facility shown in the September image appears to be different than the one visible in the January images.

Comparison of High-Bay Hall Images

Both sets of images show high-bay halls holding centrifuge cascades. While the centrifuge cascades present in Figure 3 have nearly identical design, that being four rows of centrifuges per cascade, the high-bay halls have different design details. A key difference in the halls is their width and the number of cascades present. One January 2025 image shows only three cascades in a narrow hall; another January image of a different high-bay hall shows a narrow hall with four cascades. This is in comparison to the September 2024 images, which indicate a wider high-bay hall, with at least six cascades shown in the images, namely three cascades on each side of a set of pillars supporting the ceiling.

Other design details include that the floor is tiled in the September high-bay hall images and is not tiled in either of the January images. Overall, the comparison indicates that the location of the September high-bay hall is different from the high-bay halls shown in the January images.

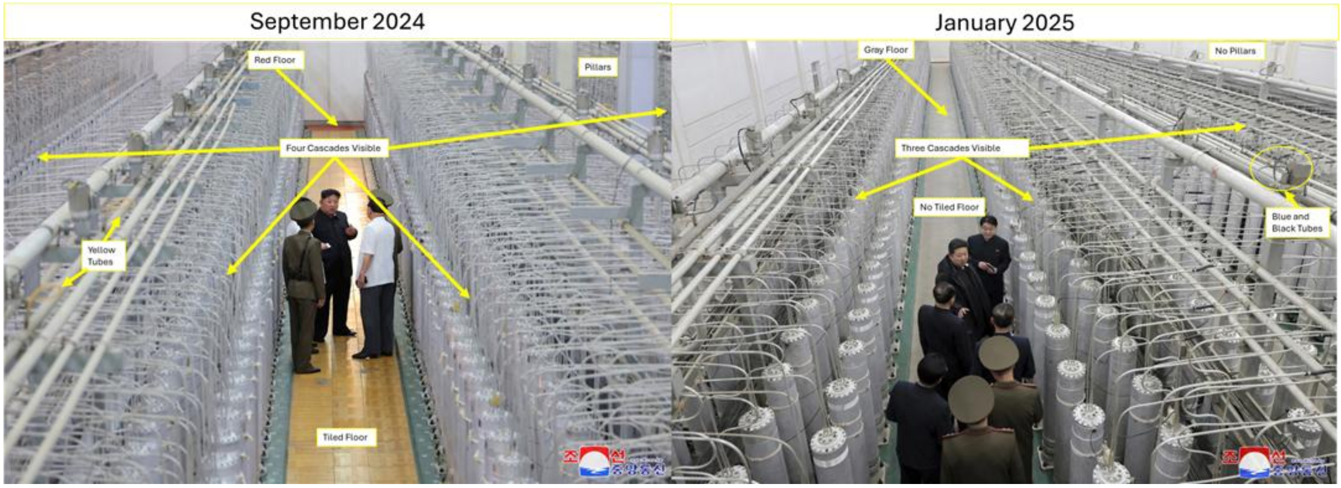

Figure 3. A comparison and contrast of two of the high-bay hall images released by KCNA; a wide hall with support beams in September 2024, and a narrower hall in January 2025.

Bridge Images

The images of the bridges containing piping, valves, measuring equipment, among other items, offer additional details that point toward separate locations (see Figure 4). Both bridges are likely positioned in the middle of the high-bay halls, with centrifuge cascades on either side; however, the placement of the overhead pipes visible in the two sets of images differ. Other minor differences also exist, like the placement of lightbulbs and the numbering of the equipment pipes (likely lines of centrifuges or cascades).

Siegfried Hecker, one of the experts who visited the Yongbyon enrichment plant in 2010, recollected that the bridge he saw had observational windows on either side of it. Unfortunately, the released images appear to only show one end of the bridge respectively for January and September and neither shows the type of window reported. The September images show a series of continuous observational windows overlooking both the bridge and a cascade hall. The January images on the other hand appear to show a continuous bridge running between two high-bay halls toward a window looking outward, not inward. That window is overlooking an annex building which was built in recent years and is discussed later. In this case, the side of the bridge not shown in the images may well have observational windows as described by Hecker, where the observational windows on the other side of the bridge were replaced with a connection to 2013 addition.

Figure 4. Comparison of the bridges in the image sets. On the left image, there is no partition wall visible as is the case on the right image.

Low Roofed, Long Hall Images

Both sets of images released by KCNA show Kim Jong Un also touring cascade configurations in long halls with low-slanted roofs. Based on details in the images, these cascades are most likely in different locations, and the images are not of the same facility (see Figure 5). Several details stand out. The September 2024 image shows a long hall with at least one cascade fully installed and a second cascade in the process of being installed. The room's floor is green and the padding on which the centrifuges are installed is yellow. The January images instead show a room with a gray floor and green padding for the centrifuges, with shown cascades apparently fully installed.

Other details exist in the construction and design of the rooms that point toward different locations. The room shown in the September image has only one row of roof support pillars, while the January image shows two rows of roof support pillars. The September image shows a roof truss installed on the ceiling, while the January image has no roof truss installed. The support beams holding up the piping are also different. The September image has larger upside-down "L"-shaped columns holding the piping over one cascade, while the January image has "T"-shaped support beams holding the piping. Another notable detail is that in one of the January images, a higher-bay hall can be seen far in the background where the slanted roof ends, showing that the room is connected to another.

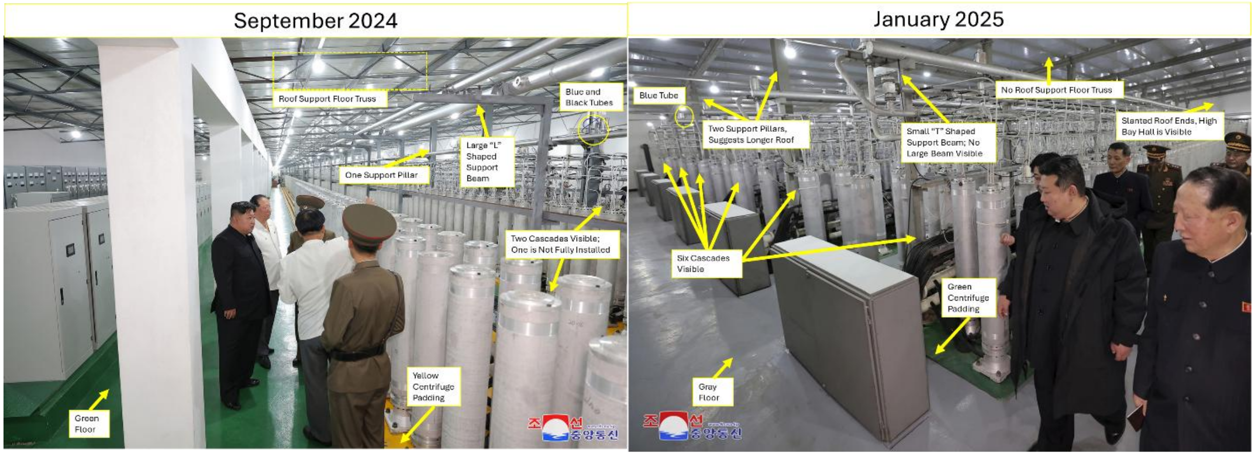

Figure 5. A comparison of the September 2024 and January 2025 images of Kim Jong Un touring the low-roofed long hall centrifuge cascade hall. Many details differ between the images.

P2 Centrifuge

The centrifuges in the images look like P2-type centrifuges, based on the diameter and height of their outer casing. This is consistent with Hecker's reporting about his 2010 visit.

P2 is a nomenclature for the Pakistani version of a highly successful German centrifuge called the G2.[8] North Korea started installing P2 centrifuges in large numbers in the 2000s. However, it is unclear whether the centrifuges in the images are older or newer versions.

The P2 centrifuge design uses a maraging steel rotor(s) with a single bellows. It was stolen by A.Q. Khan from the European enrichment consortium Urenco in the mid-1970s. In the late 1990s, Khan and his colleagues provided the North Koreans with centrifuge technology, a number of P2 centrifuges, and centrifuge equipment. They also provided on-site training in making P2 centrifuges, especially the difficult-to-make rotor tubes and bellows, in KRL's centrifuge workshops that at the time were making P2 centrifuges for Khan's own program to make WGU.

The P2 centrifuge enrichment output depends on the length and speed of the rotor assembly, where the speed depends on the properties of the rotor material. With grade 350 maraging steel, the enrichment output of a single G2 was about five separative work units (swu) per year. However, the images do not indicate the rotor material, and North Korea may have used the equivalent of grade 300 maraging steel instead (the G2 centrifuge did so originally), resulting in an enrichment output about 20 percent less, or four swu per year.

The outer casings may exhibit some differences near their tops between the various centrifuge halls, and some casings may be slightly wider (although this could be just a distortion in the

[8] Note: the G2 centrifuge has no cooling coils wrapped around its outer casing, consistent with the images.

image), but all outer casings look to be of a similar height. The differences do not suggest a significant change in enrichment output.

The age of the visible centrifuges is not evident. Many outer casings are visible, and these are known to be made out of a relatively soft aluminum.[9] Based on procurement information, North Korea acquired internationally thousands of 6000-series aluminum tubes with the correct dimensions of a P2 outer casing. It may manufacture them domestically today. With age, this type of aluminum will oxidize, starting with a shiny surface and ending with one that has a powdery white or dull gray coating, the latter consistent with the surfaces in the pictures and the former consistent with Hecker's description of the centrifuges in 2010. However, aging can happen relatively quickly, making age determination difficult.

Hecker stated that the lengths of the centrifuges he saw in 2010 were about six feet (183 centimeters), about 20 centimeters (nine inches) taller than a P2 centrifuge on a stand. However, he may have overestimated the centrifuge's height as he gazed down on them without the reference point of a human or other known object near the centrifuges.[10]

LEU Centrifuge Cascade

There are many cascades in the images, each with four rows of centrifuges, organized with a pair on each side of a set of pipes running along the cascade. In all images, the cascades are too long to provide a definite count of centrifuges, as the centrifuges in the back blur together. However, rough counts are possible, and their lengths appear consistent with the cascade design used at KRL to make low enriched uranium (see also below).

This conclusion is based on several pieces of information. Based on the investigation of the Khan network by Swiss authorities and the International Atomic Energy Agency in the 2000s, it was learned that a 344-centrifuge cascade was used extensively in Pakistan's gas centrifuge plants to make low enriched uranium (LEU). This cascade is typically organized into four rows of 86 centrifuges each. Khan admitted in his 2004 confession that he knew North Korea was interested in producing LEU.[11] Based on information obtained in North Korea in 2011 by one of the authors from a senior North Korean nuclear official, the Yongbyon centrifuge plant contained 2064 centrifuges in six cascades. This meant that each centrifuge cascade at Yongbyon contained 344 centrifuges, identical to the number in the Pakistani design. Since cascade designs vary widely in terms of the number of centrifuges they contain, it is likely that the North Korean cascade is based on the Pakistani design and is dedicated to making LEU.

It is suspected that KRL provided other centrifuge cascade designs, particularly the designs needed to make WGU. Khan and his associates used the 344-centrifuge cascade as part of a

[9] "A Return Trip to North Korea's Yongbyon Nuclear Complex."
[10] The reported height is more consistent with P1 centrifuges which also are deployed in cascades with two rows of centrifuges. KRL also provided North Korea with a P1 centrifuge design. However, Hecker stated that a North Korean told them that the visible centrifuges were not P1 centrifuges.
[11] *Peddling Peril;* and "2004 Statement."

four-step process to enrich from natural uranium to weapon-grade uranium.[12] This cascade design can be used in the first and second step, enriching from natural to less than five percent and then separately from five percent to 20 percent enriched uranium. Cascades with fewer centrifuges would be involved in the two final steps. The location or design of the centrifuges in the two other steps is not identifiable in the images (but see below).

The length of each LEU cascade, which is needed to compare the dimensions of the enrichment halls with dimensions of the buildings measured in satellite imagery, can be estimated. Each P2 centrifuge is about 20 centimeters in diameter. Side by side, 86 P2-type centrifuges would be about 17.2 meters long. However, there is space between successive centrifuges, taken on average as half the width of a centrifuge. Adding these spaces to the row would add an additional 8.5 meters, for a total of 25.7 meters. This value could be larger by several meters, if more space between centrifuges is assumed.

Other information about the Pakistani 344-centrifuge cascade can provide additional insights into the North Korean cascades. For example, there should be about 15 enrichment stages in this cascade, consistent with the Pakistani design. The stages and numbers of centrifuges in each stage are on the table below.

A P-2 Cascade in Kahuta Plant in Pakistan and Yongbyon Plant in North Korea that makes 4-5% enriched uranium

Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Cent. per stage	2	6	8	12	16	20	24	30	38	46	42	36	30	22	12	344
	↑ Product									↑ Feed					↑ Tails	

The large number of centrifuges in this type of cascade explains but also complicates the assessment of the complex, visible piping. The images show a variety of piping and equipment expected in any gas centrifuge plant based on Urenco designs (see Figure 6). Three small pipes are visible emanating from each centrifuge, with each one connecting to a different centrifuge or a nearby, larger pipe. These three small pipes are for the feed, product, and tails entering

[12] *Peddling Peril*.

and leaving the centrifuge. There are four large pipes running along the cascade and stacked vertically; these appear to be feed, product, and tails header pipes with a dump line at the top. In addition, each stage should have an electro-pneumatic valve connected to the dump line; they are visible in the North Korean cascade and identified by colored tubing carrying compressed air from a pipe (see Figure 6).

Pakistani centrifuge cascades are known to use an emergency gas evacuation system to prevent a failing, or "crashing," centrifuge rotor from sending a pressure spike, destroying the rest of the centrifuges in the cascade. In case of a sudden increase in pressure, the dump line valves would open automatically and evacuate uranium hexafluoride gas from a centrifuge stage, reducing the chance of neighboring centrifuges being destroyed, often called fratricide of other centrifuges. Possibly as part of this system, each centrifuge in Figure 6 appears to have a vibration detector affixed to its top that can trigger a response if excessive vibration occurs, potentially indicating a crashing centrifuge. Such a vibration sensor would also serve to monitor vibrations during the startup and shut down of a centrifuge as it traverses critical resonant frequencies that a P2-type centrifuge will experience. In addition, the emergency evacuation system could be activated by sharp pressure spikes measured in pressure measuring gauges, typically Pirani gauges, able to withstand corrosive uranium hexafluoride, or pressure transducers. Such devices look to be attached to the top of many centrifuges. There is expected to be at least one per stage in the cascade.[13]

Not identified in Figure 6, but likely present, are recycle pipes connecting the product and tails headers to the feed header, allowing for the cascade to run on the same process gas by continuously recycling it. Such recycling allows a cascade to reach its desired flow rate and product and tails enrichment concentrations prior to starting the accumulation of product and tails, and these pipes also permit a cascade to have a standby mode.

Not visible are fast-acting microvalves on each of the small pipes coming out of the individual centrifuge, part of an Urenco emergency system also acquired by Khan but perhaps not shared with North Korea. It was shared with Iran, and these valves are incorporated into Iranian centrifuge cascades, along with pressure transducers. Absent this more effective Urenco system, North Korea may lose more centrifuges due to crashing and fratricide.

In Figure 6 and in several other images, many short, black, flexible tubes, with clamps, can be seen on many of the small cascade pipes connecting individual small feed, product, and tails pipes with the header pipes. The black tubing is particularly visible in the Yongbyon images and the Kangsong annex. Interestingly, they are not visible in the cascade piping of the main Kangsong hall. In that sense, the black piping may be an innovation after Kangsong was first built.

[13] A variety of pressure gauges are visible in the images. They could be either Pirani gauges or pressure transducers. A dominant shape is block-like or rectangular. Many are attached to the top cap adjacent to the three small-diameter feed and withdrawal pipes. One design of KRL's 344-centrifuge cascade used Varidyne pressure gauges, namely its uranium hexafluoride resistant Pirani gauges.

These tubes could be related to absorbing vibrations in the cascade generated during centrifuge operation or breakage. As such, it would suggest an earlier problem in the original cascades, since excessive vibrations can damage welded piping.

The lack of black piping on all cascades raises another possibility, namely they are related to easing the task of replacing centrifuges, whether broken or improved.

Because gas centrifuges break, the operators need a way to replace them efficiently. These black tubes may be related to replacing broken centrifuges. If so, after a centrifuge breaks, North Korean operators would disconnect (or cut on older models) each of the three small feed, product, and tails pipes coming out of the top of the centrifuge near a header pipe and remove the centrifuge and remaining small pipes. A new centrifuge's piping would be joined to the old piping with this black tube.

If this is correct, the black tubes provide an indication of the extent of centrifuge replacement due to breakage. In some cases, the images suggest that almost an entire cascade has black tubes. This could reflect fratricide, requiring the replacement of all the centrifuges in the cascade. It could also mean that a new centrifuge was designed to fit into the existing pipework, accepting height limitations and some operational restraints.

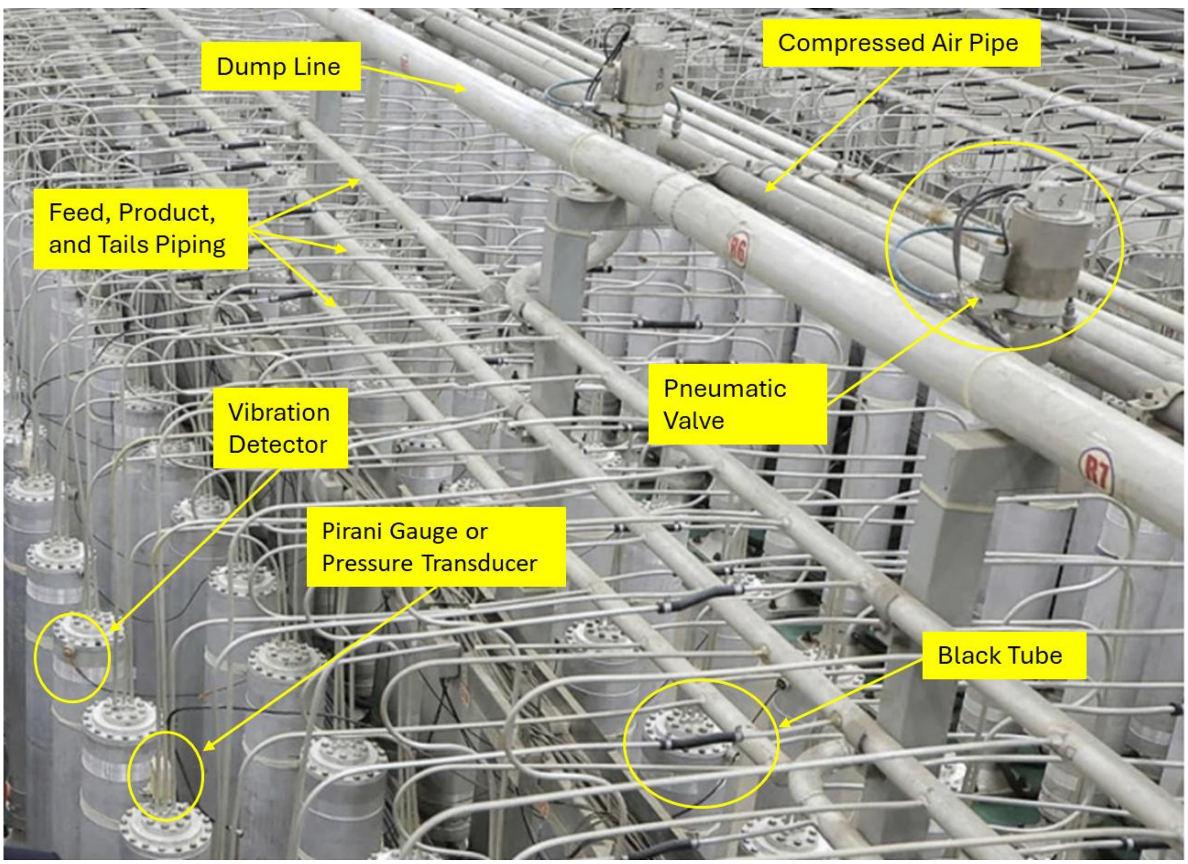

Figure 6. An annotated view of parts of the cascade as seen in a January 2025 image, showing various equipment and piping.

The images of the bridge show piping attached to each cascade, likely ending in feed and withdrawal stations positioned in another room, as well as gas flow meters, additional pressure gauges, and larger electro-pneumatic and possibly motorized or manual valves of various sizes to control uranium hexafluoride gas flow into and out of each cascade.

Centrifuge improvement

In its September 13, 2024, statement accompanying the images, North Korea announced its intention to increase the number of installed centrifuges and deploy a new type of centrifuge, which has "already reached the completion stage."[14] As is typical with many North Korean announcements, there are ambiguities. It is not clear whether the new centrifuges have been installed or are awaiting deployment; the images included with the announcement do not clarify this question.

The images and the announcement do not provide any insight into the output of a new type of centrifuge. Output could be increased simply by replacing the rotor assemblies with those with a higher grade of maraging steel, allowing the rotor to spin faster and thus have a larger enrichment output that is proportional to the square of the velocity of the rotor assembly. Moreover, the new centrifuge type may be longer but spin at the same rate as the older one, with an increase in enrichment output proportional to its increase in length. However, none of the centrifuges, except for possibly a single centrifuge in the far back of one image (see Figure 12), appear longer than P2 centrifuges.

One improvement likely within North Korea's technical capability, albeit challenging, is to use carbon fiber in a way that allows speeds greater than those achievable with maraging steel but not so high as to require a major redesign of the internal parts of the centrifuge, which is likely beyond North Korea's abilities. Iran has pursued such a strategy. For example, an increase in rotor speed to 500 meters per second would increase the separative work per centrifuge by about 25 percent compared to a similar one utilizing 350 grade maraging steel. This would translate to an output of 6.25 swu per year per centrifuge, comparable to Iran's IR-6 centrifuge. A wall speed of 550 meters per second would have an enrichment output 50 percent greater than a similar one spinning at 450 meters per second, or 7.5 swu per year. However, a speed of 550 meters per second or greater may not meet the above conditions for continuing to use the other, traditional P2 internal parts.

One new question is whether Iran provided North Korea technology on making carbon fiber rotor assemblies or help in procuring carbon fiber.[15] Available procurement data, provided by a European country, do not indicate that North Korea in recent years has imported large quantities of carbon fiber of sufficient quality for use in a large-scale centrifuge deployment.

[14] KCNA, "Respected Comrade Kim Jong Un Inspects Nuclear Weapons Institute and Production Base of Weapons-Grade Nuclear Materials," KCNA, September 13, 2024, http://www.kcna.kp/en/article/q/69c852101729d6055a771219d3f0a8fd.kcmsf.

[15] Iran uses carbon fiber in several centrifuges, most successfully in the IR-4 and IR-6 centrifuge. Moreover, these two centrifuges use carbon fiber bellows, which Iran spent years developing.

Moreover, North Korea is judged as unable to make such carbon fiber.[16] Nonetheless, imports could have been missed or covertly received from Iran, which has illicitly acquired large quantities of carbon fiber for its gas centrifuge program.

The topic of the enrichment output of North Korea's centrifuges will be discussed further in a follow-on report dedicated to estimating the size of North Korea's stock of nuclear explosive materials and the size and composition of its nuclear arsenal.

Kangsong Enrichment Plant

The available information supports that the September 2024 images show significant portions of the Kangsong enrichment plant. This is also the view expressed by the International Atomic Energy Agency (IAEA). In reference to the September 2024 images, the IAEA stated in late November 2024, "The depicted centrifuge cascades and infrastructure are consistent with the layout of a centrifuge enrichment facility and with the structure of the main building at the Kangsong Complex and its newly constructed annex."[17]

Centrifuge Hall Images from September 2024

Large Cascade Hall. Figures 7 and 8 show one side of the cascade hall filled with large, identical looking centrifuge cascades, while Figures 9 and 10 show Kim Jong Un on a bridge which runs through the middle of the cascade hall containing piping and other equipment associated with gas centrifuge operation. Importantly, the bridge images confirm there are cascades on both sides of the bridge, even if ground images are only available for the cascades on one side. Figure 11 is a schematic of the cascade hall observed in the images.

Each cascade has four interconnected rows of what look like P2-type centrifuges, with two slightly staggered rows on each side of the cascade piping and associated cascade equipment. Based on ground images of the hall, and considering the width of the building, it is likely that there are a total of six cascades on each side of the bridge. The images from the bridge (see below) suggest a wide hall that could contain this number of cascades.

Counting the number of centrifuges in each row is difficult, at best about 70 are visible in an outside row. But the blurring of the photo and the angle at which it was taken make this count likely an undercount. However, these cascades are likely similar or even the same design as those seen at the Yongbyon enrichment plant in the January 2025 images. Thus, in this case, each of the four rows in the images contains 86 centrifuges, consistent with the above count of centrifuges in the images.

[16] It is possible that North Korea buys PAN from a Chinese supplier and finishes it into carbon fiber domestically.
[17] "IAEA Director General's Introductory Statement to the Board of Governors," International Atomic Energy Agency, November 20, 2024, https://www.iaea.org/newscenter/statements/iaea-director-generals-introductory-statement-to-the-board-of-governors-20-november-2024.

One potential discrepancy regarding Kangsong is that the satellite images of the Kangsong building show rows of skylights that are not visible in any of the September images. In addition, Kim's shadow in Figure 7 suggests that no skylights are present in the room. The shadow is produced from a light on the back wall shining down the centrifuge row. Skylights would provide alternate angles of light.

However, a possible explanation for the lack of skylights would be the existence of another floor above the cascade hall. In one image from the bridge, vertical piping is visible, which may extend through the hall's ceiling. It is possible that some or all of the second, third, or fourth step feed and withdrawal stations or support equipment would be on this floor. It is unknown if there are additional centrifuges on this floor, and if so, whether it would entail 5000 to 6000 more centrifuges, as some have claimed, although European centrifuge experts who are knowledgeable about Urenco centrifuge plant designs have assessed that the upper floor would not contain this number of centrifuges. Nonetheless, the second floor could hold centrifuge cascades for steps 3 and 4 and perhaps those of step 2; these three steps would be expected in total to contain about 1500 centrifuges with most being in step 2 (see below).

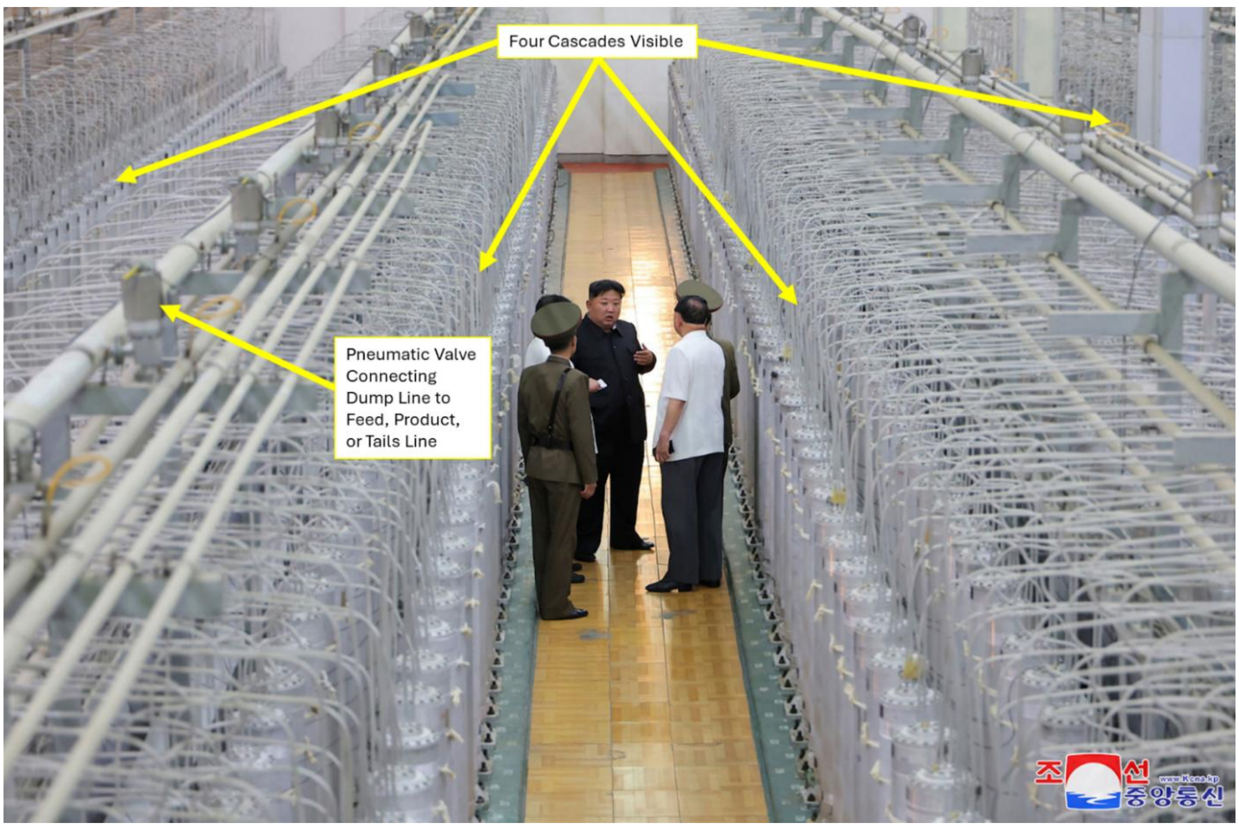

Figure 7. An image of Kim Jong Un among our visible centrifuge cascades on one side of a larger centrifuge hall. Noticeably, the columns are on the right-hand side of the image. Pneumatic valves are visible on top of the dump line, likely one per stage.

Figure 8. An image of Kim Jong Un ascending the stairs to the bridge; four centrifuge cascades can be seen, with three on one side of the columns. Noticeably, the columns are on the left-hand side of the image, suggesting the three cascades in Figure 7 are on the other side of the columns, for a total of at least six cascades on one side of the bridge.

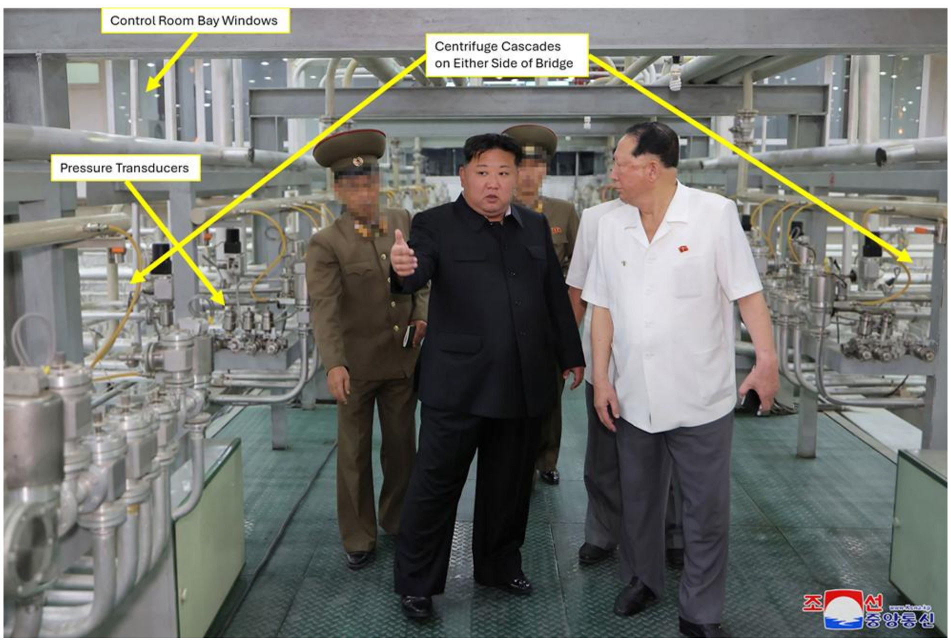

Figure 9. An image of Kim Jong Un on the middle bridge in between the centrifuge cascades. Centrifuge cascades can be seen on either side of the bridge. Windows can be seen behind Kim Jong Un and on the sides. Some of these windows may be for observation of the cascade halls or from the control room of the facility.

Figure 10. Another image of Kim Jong Un on the middle bridge.

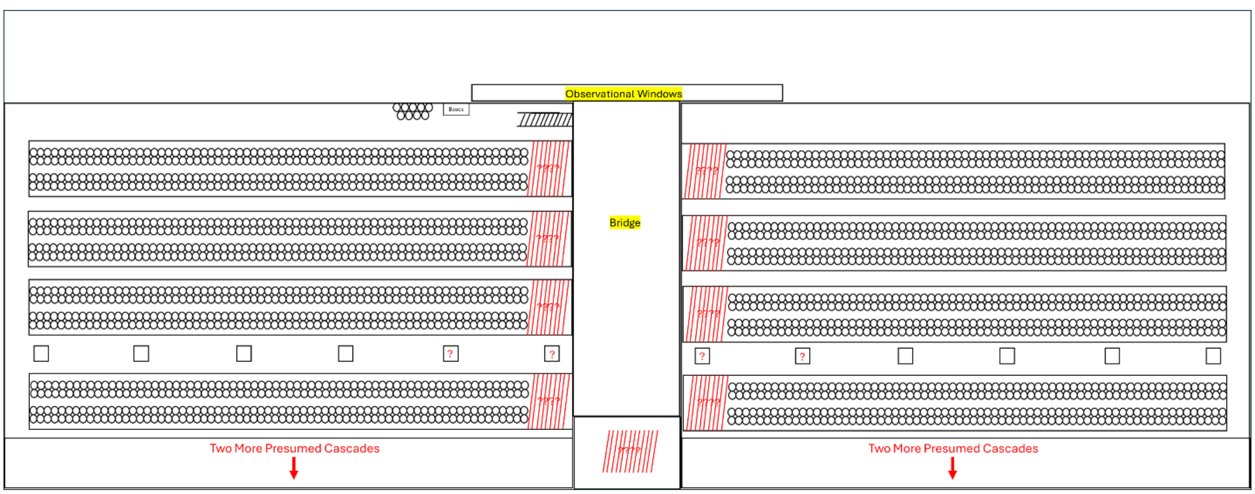

Figure 11. Schematic diagrams of the cascade hall observed in the images released by KCNA. Please note that the schematics are not to scale and do not include the entire building. Moreover, only 70 circles are in each row, as this is the number estimated visually from the images. In fact, the number is likely 86 per row.

Low Roofed, Long Hall. Figure 12 shows Kim Jong Un and his entourage inside a long hall under a slanted roof (slanting from right to left in the image). The truss design supports the roof. An electrical infrastructure bay can be seen to the left of Kim. On the right side of the image there appears to be a cascade with four rows and possibly another cascade of indeterminate shape, based on seeing two sets of overhead piping, where the back one is only partially installed. It is this back cascade where one centrifuge appears taller than the others, but the entire centrifuge is not visible, making it impossible to confirm whether the centrifuge is taller than a P2 centrifuge.

The image also shows in the foreground two rows of outer casings, some with top coverings and some open, and no evidence of piping. Some believe these outer casings are different from outer casings in older halls. The lack of piping over the cascade closest to Kim suggests that it is in the process of being installed, perhaps with piping to be installed to the right of the lines of outer casings, prior to placing the centrifuges in their final position under the new piping.

One plausible location for the image is a new auxiliary building constructed next to the main Kangsong building. The building is long; it is one story tall with a slanted roof, and it has an protruding bay structure attached to it, consistent with the electrical infrastructure bay seen in the image.

Commercial satellite imagery of Kangsong shows that a new auxiliary building was constructed between late February and September 2024, consistent with it not being fully finished compared to the Yongbyon Annex (see below). This building consists of a structure roughly 115 to 122 meters long, running the length of the primary Kangsong building with a bay protruding from it at one end (see Figure 13). It is not as tall as the main building. The installation of the slanted blue metal roof began around March 15 and was completed by April 1, 2024.

The KCNA image of a long centrifuge hall does not show the full room. However, given the many dozen centrifuges installed in a row, their relative size, and the number of support posts, the hall appears to be more than a hundred meters long, consistent with the Kangsong auxiliary building. However, this estimate is uncertain since it is difficult to tell from the image exactly how many support posts there are and what the precise distance is between each beam.

Satellite imagery also shows several support posts installed. However, the roof support posts in the satellite imagery do not appear as numerous as those seen supporting the roof in Figure 14. Nonetheless, the roof slant is similar to that of the roof observed in Figure 14.

The auxiliary building is about 10 to 11 meters wide. Considering a one-to-two-meter gap between each cascade, and that each cascade is at least two to three meters wide, the auxiliary building would likely only be wide enough to contain two cascades if each contained four rows of centrifuges. See Figure 15.

However, it is long enough to contain three sets of two such cascades, for a total of six, four-row cascades. Moreover, it may contain smaller cascades next to the wall nearest the main building. Alternatively, the installation is too incomplete to allow an accurate count of the centrifuges in the auxiliary building. However, the former estimate is further developed below to show the WGU production potential of this site.

Figure 12. A second, very long enrichment hall visited by Kim Jong Un. Electro-pneumatic valves on the dump line can be seen that look new. Pressure gauges are not visible, but they may be on the opposite side of the four-row cascade.

Figure 13. A satellite image of Kangsong from November 22, 2024, showing the recently built auxiliary building.

Figure 14. A satellite image of Kangsong from March 13, 2024, showing the auxiliary building under construction.

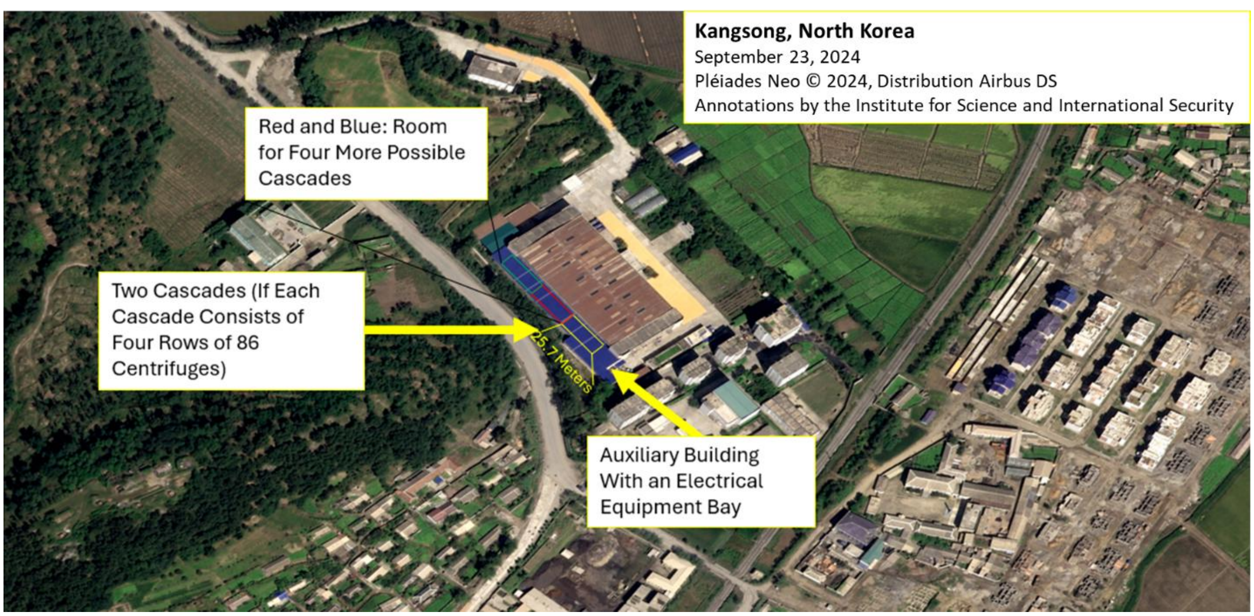

Figure 15. This figure shows a configuration of six cascades fitted into the auxiliary building, organized as three pairs of 344-centrifuge cascades.

Cascade Layout at Kangsong Based on the Images

The images provide a method to better understand the Kangsong plant, including deriving an estimate of the number of centrifuges in it and a nominal scoping estimate of the amount of WGU it could produce in a year.

If Kangsong is accepted as the centrifuge plant shown in the images, the statement accompanying the September 2024 images makes clear that the purpose of the unidentified site is to make weapon-grade uranium, implying that the site is designed to do so. While it cannot be excluded that another, unknown enrichment facility would enrich LEU from Kangsong up to weapon-grade, that possibility is not treated here.

The images, however, do not appear to show where weapon-grade uranium is produced inside Kangsong. The cascades shown appear to make only low enriched uranium.

If North Korea copied Khan's four-step approach to making WGU, a reasonable assumption given the type and level of support provided by KRL, the large hall would comprise the first step, going from natural uranium to three to five percent enriched uranium.

A model is a turn-key centrifuge plant, codenamed Ginco Steel LLC, that was being designed by the Khan network for Libya and found in data seized by Swiss and other prosecutors of Khan network members in the 2000s. This design has a physical separation between step 1 and steps 2, 3, and 4. One room was designed to contain 30 P2 cascades, each with 164 centrifuges, labeled to enrich uranium from 0.71 percent to 4.5 percent. A separate room was designed to hold eight 164-centrifuge cascades, labeled 4.5 to 20 percent, four 114-centrifuge cascades, labeled 20 to 60 percent, and two 64-centrifuge cascades, labeled 60 to 90 percent. The facility would contain a total of 6816 centrifuges.

This design is for a centrifuge plant larger than Kangsong, but the Kangsong arrangement could be similar. The main difference would be the use of larger cascades for steps 1 and 2.

Scaling from the number of centrifuges in the Ginco design, the main hall at Kangsong would contain twelve 344-centrifuge cascades that would comprise the first step and make three to five percent enriched uranium. There would be another area, possibly one large hall with three cascades, also 344-centrifuge cascades making 20 percent enriched uranium, and several other cascades with less than half the number of centrifuges, namely three 114-centrifuge cascades, going respectively from 20 to 60 percent enriched uranium, and two 64-machine cascades enriching from 60 to 90 percent, or WGU.

The total number of centrifuges in this approximation is 5630 centrifuges. Converting this number into an annual WGU production value is complicated by inefficiencies in the four-step approach, uncertainties over the true value of the enrichment output of the P2 centrifuges, and inefficiencies in operating production-scale cascades. Accounting for these factors conservatively, and assuming a nominal single centrifuge value of five swu per year, the original

Kangsong plant could produce about 100 kilograms of WGU per year. This serves as a higher end scoping estimate.

How big is the hall containing step 1? The main cascade hall is estimated to contain 12 cascades with space left to account for possible hallways between the long walls of the cascade hall and the outer walls of the buildings, which have windows.[18] With 12 cascades, and an estimated cascade length of 25.7 meters as calculated earlier, the necessary floor area is roughly 61 meters long and 40 meters wide. This area includes the cascades and a bridge running down the middle of the cascade hall. There is space allocated between the outer walls, and space is left to account for the control room, feed and withdrawal stations, and other support functions. The bridge is assumed to take up four meters of floor space with no centrifuges installed underneath it. The flat-roofed sections on either end of the long side are assumed not to hold any cascades but are for shipping and receiving.

The estimated area left over for the enrichment from up to five percent enriched uranium to weapon-grade is 33 meters long by 40 meters wide. This space is sufficient to hold the cascades comprising steps 2, 3, and 4 and their feed and withdrawal stations. Figure 16 shows the relative placement inside the building of these two separate areas. The estimated width and length of the visible cascade hall would suggest that the LEU cascades run parallel to the length of the building. (Alternatively, as discussed above, the cascades comprising these three steps could fit on the second floor.)

Figure 16. A potential configuration of Kangsong cascade halls showing steps 1, 2, 3, and 4, enabling the production of weapon-grade uranium.

[18] The inclusion of outer windows is also a feature of the Radiochemical Laboratory, North Korea's plutonium separation plant. Images taken by the IAEA in 1992 from inside the plant show outer windows on one side of a hallway and hot cells on the other side. The inclusion of windows on this building caused confusion in the U.S. intelligence community in the late 1980s, parts of which assumed a plutonium separation plant would not have windows and thus the building was not a plutonium separation plant.

Kangsong Auxiliary Building.

As discussed above, the auxiliary building was not fully set up when the pictures were taken, and its purpose is uncertain. Is it to expand the capacity of Kangsong? Is it to test new centrifuges?

At most, the building is estimated to be able to hold six cascades of 344 centrifuges each, where each cascade is 25.7 meters long, as estimated above, for a total of 2064 centrifuges. In this case, the space could be dedicated to making LEU for further enrichment to WGU in the HEU section of Kangsong, perhaps also expanded in capability or at another unknown site. This would lead to about 50 kg of WGU per year.

If the auxiliary building is to independently increase WGU production, then it would have fewer centrifuges assuming a four-step design is implemented. In this case, there could be four 344-centrifuge cascades making LEU, one 344-cascade making 20 percent enriched uranium, one 128-centrifuge cascade making 60 percent HEU, and one 64-centrifuge cascade making WGU. The two cascades in the 3rd and 4th steps would fit in one cascade location. The auxiliary building would have in total 1912 centrifuges. If the centrifuges are a P2-type, and assuming standard inefficiencies, the auxiliary building could make about 35 kilograms of WGU per year.

These values are uncertain. Without additional information, this scoping estimate uses a range of 35 to 50 kg of WGU per year. In terms of the total centrifuge estimate discussed above and below, the value of 1912 centrifuges is used for simplicity's sake (see Table).

Yongbyon Enrichment Plant

Centrifuge Hall Images from January 2025

The January images show three halls holding centrifuge cascades and a bridge spanning two main halls. These images likely convey the inside of the Yongbyon enrichment site. The IAEA issued a similar assessment. In reference to the January 2025 images, the Director General of the IAEA stated in early March 2025, "The depicted centrifuge cascades and infrastructure are consistent with the layout of a centrifuge enrichment facility and with the structure of the Yongbyon Uranium Enrichment Plant."[19]

Figure 17 shows a hall that may be the original hall of the Yongbyon centrifuge plant. If so, this hall was likely the one shown to Hecker and his colleagues, although the cascades may be shorter in length and wider than what they saw, with four rows of centrifuges instead of two.

Figure 18 shows a different hall, likely the addition built in 2013. In this image, four rows of cascades can be discerned, three readily visible and the fourth partially visible in the top right

[19] "IAEA Director General's Introductory Statement to the Board of Governors," International Atomic Energy Agency, March 3, 2025.

corner of the image. These cascades appear more tightly packed than the ones in the original hall.

Figures 19, 20, and 21 show various views along a bridge spanning both cascade halls. Kim Jong Un and his entourage appear to be photographed sequentially as they progress toward the control room, starting at the far end of the bridge at a window overlooking the cascades in the annex building (note sloping roof), passing above the cascades in the hall added in 2013, walking through a passage separating this hall from the original section of the Yongbyon enrichment plant, and stopping above the original hall. This also explains why the control room and any associated observational windows are not visible in the images.

As is the case with the September images, a limitation is that the images show only full cascades on one side of the bridge. Only very partial views are shown of the other side of the halls, revealing only the beginning of the cascades as seen from the bridge

Annex Hall

Figure 22 shows two views of a long cascade hall. This hall appears to be the one visible from the observation window on the bridge in Figure 19. Satellite imagery shows the construction of an addition in recent years adjacent to the main centrifuge halls at Yongbyon (see Figure 23). This structure is consistent with the January 2025 images.

The annex structure is roughly 50 meters long and 23 meters wide and has a slanted roof. It is constructed between two taller buildings, although the internal structure of those buildings is unknown. A May 2022 Google Earth image shows that during the construction of the annex structure, two roof support pillars were present, in line with what is seen in the January 2025 image (see Figure 24).

With each P2 centrifuge cascade being about 25.7 meters in length, the annex structure plus an adjacent building, suggested in the January image in Figure 24, is long enough to hold the six cascades present in the January image. At 23 meters wide, the annex should be wide enough to hold the six cascades next to each other, which are estimated to be about 21 meters wide.

Figure 17. A partial view of a narrow cascade hall, likely the original Yongbyon hall. This image shows the full width of the room, i.e. both walls, if not its full length. A door is visible on the left. Two rectangular block-shaped pressure gauges, with Pirani gauges or pressure transducers, can be seen in the middle-right lower part of the image.

Figure 18. Another narrow cascade hall (top image), likely the 2013 addition, adjacent to the hall in Figure 17. A fourth cascade is visible in the top right of the image (see also the bottom image, which is a close up of the top right corner).

Figure 19. A view from the bridge into another cascade hall, likely the annex discussed above.

Figure 20. Two views on the bridge, likely overlooking the 2013 addition, showing the observation window in the background.

Figure 21. Two additional images along the bridge, which appears to cross over both cascade halls shown in Figures 17 and 18. In this image, Kim Jong Un and his entourage appear to be in the original Yongbyon enrichment hall.

Figure 22. Two views of a long cascade hall in a low-roofed building, likely the Yongbyon Enrichment Plant Annex built in about 2022. The silver cabinets have wires running from them. Wire conduits are visible with wires running to individual centrifuge motors. Electro-pneumatic valves are visible on the dump line. Also visible are pressure gauges and vibration detectors. In addition, on the upper image the feed and product pipe can be seen exiting the cascade and returning to a central station. The feed point(s) cannot be identified. The pressure gauges in the images, which are on the top caps, look more cylindrical and could be pressure transducers.

Figure 23. A January 2025 image of the annex structure built adjacent to the main enrichment halls at Yongbyon.

Figure 24. A Google Earth image of the construction of the annex at Yongbyon. The image shows the internal structure of the room. Two roof support pillars are visible, as seen in a January 2025 ground image.

Cascade Layout at Yongbyon Based on Images

The following attempts to use the images to construct a better understanding of the Yongbyon enrichment plant, including an estimate of the number of centrifuges installed and the amount of WGU the plant could make. It is useful to explain the images by sketching out a history of the plant, although this history is not unique. This history leads to a higher end scoping estimate of WGU production. An alternative one is discussed below that leads to a lower end estimate.

History of Yongbyon. North Korea rapidly built this enrichment plant at Yongbyon in the late 2000s in secret but with the expectation of declaring it during post-Six Party talks involving the United States, among others. The visit by the Americans in 2010 is consistent with this view, as are discussions in 2011 between North Korean officials and U.S. and NGO officials.

It is reasonable to conclude that this facility was designed to make LEU for the LWR; at the time, North Korea expected to finish the LWR in 2012 or 2013. The estimated enrichment output of the six cascades in the original building, containing 2064 centrifuges, is consistent with a plant designed to produce the initial core load of enriched uranium fuel and subsequent annual partial core refueling. These six cascades would be sufficient to make 1.8 tonnes of four percent enriched uranium per year, which is more than sufficient to satisfy the estimated nominal annual need of the 100 MWth LWR. It has an estimated core size of 3.5 tonnes of LEU and refuels about one-third of the core each year, requiring about 1.2 tonnes of LEU per year.[20]

Despite significant efforts, no nuclear deal emerged after North Korea undertook some provocative steps in early 2012, collapsing the effort to obtain what came to be called the Leap Day Agreement. Subsequently, the Obama administration decided not to try to negotiate any further.

In 2013, North Korea roughly doubled the facility's floor space. This expansion can be explained by North Korea deciding to focus on increasing its stock of WGU, while maintaining the six cascades in the original hall dedicated to making LEU. With unexpected delays in procuring critical reactor equipment internationally for the LWR, both halls could be operated to maximize WGU production.

With the LWR nearing completion by about 2022, North Korea may have decided to add an annex to Yongbyon to make LEU for this reactor while preserving the plant's WGU output.

Centrifuges in Main Yongbyon Halls and a WGU Output Estimate. Yongbyon has changed considerably since the visit in 2010 by Hecker and his colleagues. It also cannot be excluded that the Americans saw an incomplete set of cascades; namely four rows were

[20] "A Return Trip to North Korea's Yongbyon Nuclear Complex." According to this report, "The average enrichment level is 3.5% and the tails are 0.27%. The reactor designers told him to target enrichment levels from 2.2 to 4%." The upper bound of a product of four percent enriched uranium was used to estimate annual LEU production. Hecker states that the fuel in the core has a mass of four tonnes. The uranium mass is 3.5 tonnes.

planned for each cascade but only half cascades were installed by the time of the visit. Alternatively, the two-row cascades may have failed and were replaced with four-row ones.

Under the estimated historical recreation above, and consistent with the January 2025 images, the first hall holds six cascades, and the new hall built in 2013 contains eight cascades, for a total of 14 cascades in the main facility.

A reasonable, although not the most efficient, four-step configuration of the cascades in the two main halls in a four-step arrangement is:

1. Nine 344-centrifuge cascades going from natural uranium to less than 5 percent enriched uranium
2. Three 344-centrifuge cascades going from less than 5 percent enriched uranium to 20 percent enriched uranium
3. Three 114-centrifuge cascades in one cascade area going from 20 to 60 percent enriched uranium
4. One 80-centrifuge cascade going from 60 to 90 percent enriched uranium

This arrangement involves 4550 centrifuges and can produce about 80 kilograms of WGU per year, assuming all the uncertainties about these centrifuges discussed above, the same output of the P2 centrifuge, and an additional one driven by an additional inefficiency in this particular four-step design.

Additional configurations are possible. For example, both main halls may produce uranium enriched up to five percent, with steps 2, 3, and 4 in other sections of the building. This would increase WGU production by about 35 percent to about 110 kg WGU per year.

This model assumes that LEU for the LWR is not produced in these halls but instead in the annex in six cascades each with 344 P2 centrifuges, able to make 1.8 tonnes of four percent enriched uranium per year. This assumption is arbitrary but LEU production for the LWR is necessary if it is operated. Determining exactly in which cascades North Korea would make this LEU requires more knowledge than available.

This estimate neglects the capability needed to make enriched uranium for a reactor in a nuclear-powered submarine. This assumes that construction of the reactor and its deployment is several years away.

Alternative Scenario: Lower End WGU Estimate. Some have suggested that Yongbyon is not producing WGU. Instead, it will make LEU for the 100 MWth reactor operating in a mode to make weapon-grade plutonium and additional LEU for the nuclear reactor to be inserted into a submarine nearing completion. In this case, the Yongbyon enrichment plant would have only LEU cascades. There would be 20 of them with 6880 centrifuges.

In this case, the 100 MWth reactor produces weapon-grade plutonium in the enriched uranium itself. This requires that the LEU must be withdrawn from the LWR much sooner than the nominal timeframe of about one-third core per year. In one estimate, the core is reloaded twice a year, resulting in the production of 20 kgs of weapon-grade plutonium per year. This mode of operation would use 3.5 percent enriched uranium, requiring about 25,000 to 30,000 swu per year to make sufficient enriched uranium.[21] A total of 6880 P2 centrifuges with an output of five swu per year would nominally produce 34,400 swu per year. So, this level of enriched uranium production is possible with spare capacity of 4400 to 9400 swu per year. This spare capacity is enough to make LEU for a submarine reactor as well.

Kangsong would be the plant dedicated to making WGU and undergoing expansion. When completed, it could produce 135 to 150 kgs of WGU per year, as above. This serves as a lower end scoping estimate.

Placement of Cascades in Yongbyon Enrichment Plant. Figure 25 shows the relative placement of the cascades in the three halls at Yongbyon. The images are used to line up the halls with the bridge and observation window of the annex.

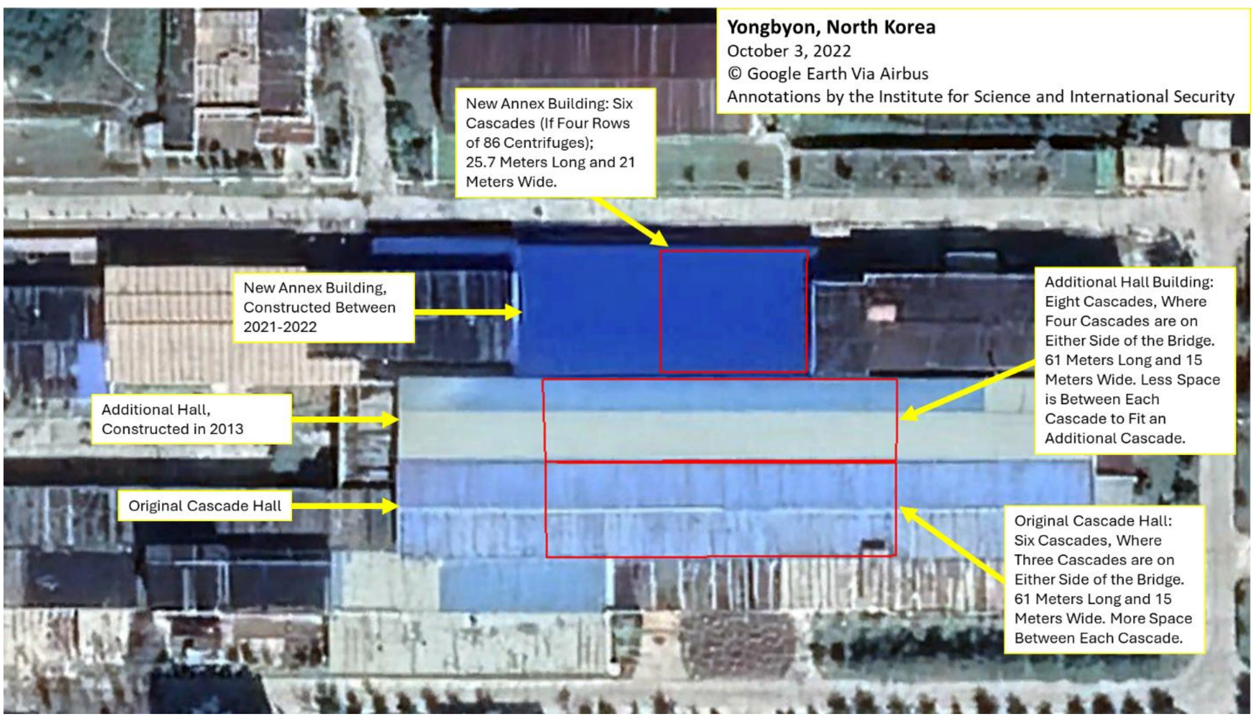

Figure 25. An image of Yongbyon from October 2022 showing the cascade halls. An overlay shows the suspected placement of the cascades seen in the January images.

[21] The range varies due to different choices of tails assay, from 0.3 to 0.4.

Table Summary of Centrifuges and Annual WGU Production Potential, Higher End Estimate

Facility	Number of Centrifuges	Enriched Uranium Production, Type and Amount
Kangsong		
Original Halls	5630	WGU, 100 kg/year
Annex, when done	>1912	WGU, 35-50 kg/year
Subtotals	**7542**	**WGU, 135-150 kg/year**
Yongbyon		
Original Hall & 2013 Addition	4550	WGU, 80 kg/year
Annex	2064	4% LEU, 1.2-1.8 tonnes/year, nominal operation
Subtotals	**6614**	**80 kg WGU per year**
Totals	**14,156**	**215-230 kg WGU/year**

Appendix

Commercial satellite imagery of Kangsong taken in early and mid-September shows the laying of yellow surface padding in several areas of the complex. The yellow surface padding appears just before the release of the images by KCNA in early September 2024 (see Figure A1). One explanation is that the surface padding was laid for the visit to the site by Kim Jong Un, yet another indication that the images released in September were taken at Kangsong.

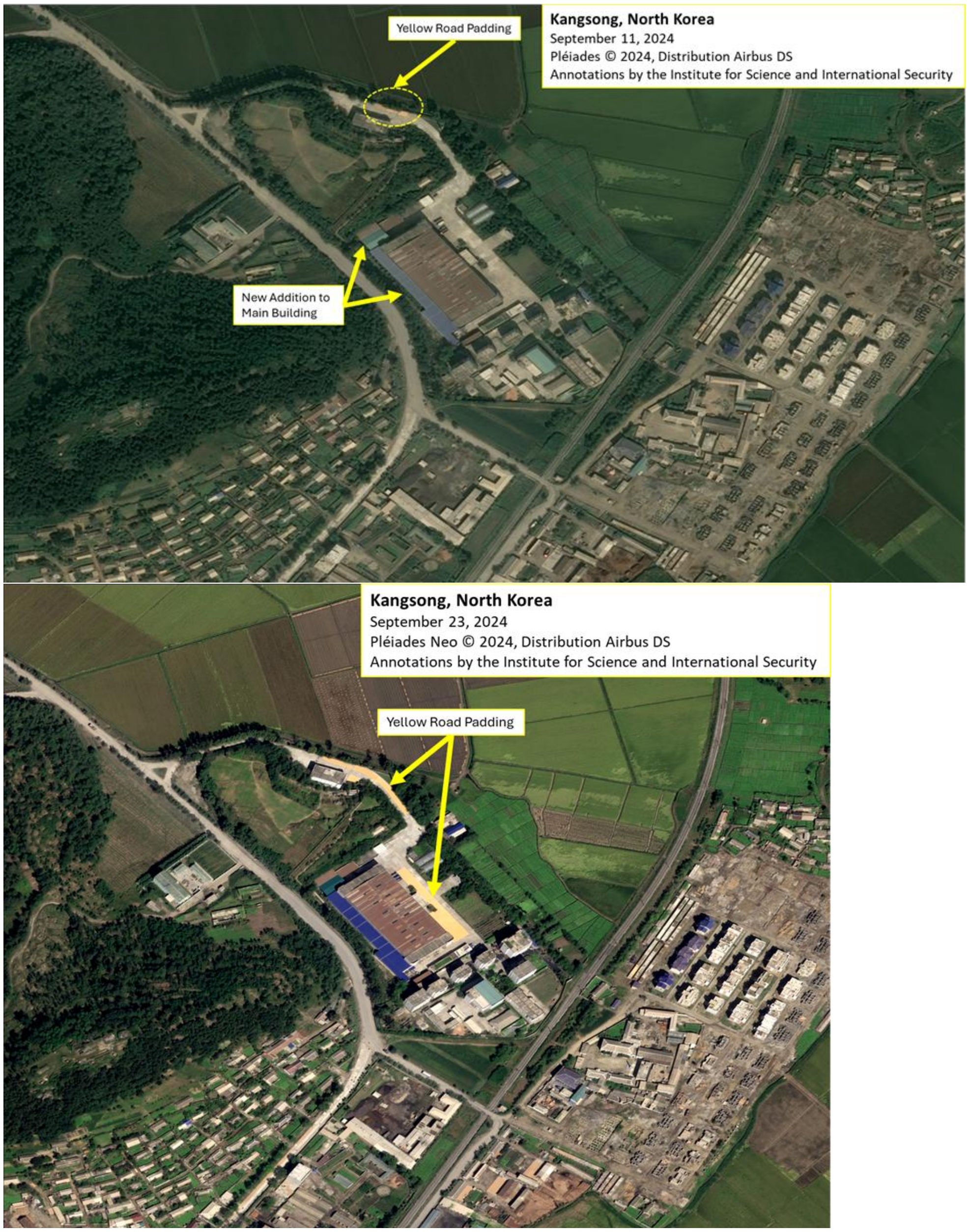

Figure A1. Two high resolution satellite images showing Kangsong and the installation of yellow surface padding on the road inside the complex. It is unclear when the padding was fully installed, as no clear satellite imagery from September 12th or 13th was available, although it is plausible the surface padding was fully installed in time for a visit to the site by Kim Jong Un.