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Indicators of nuclear weapon pit production and North Korea

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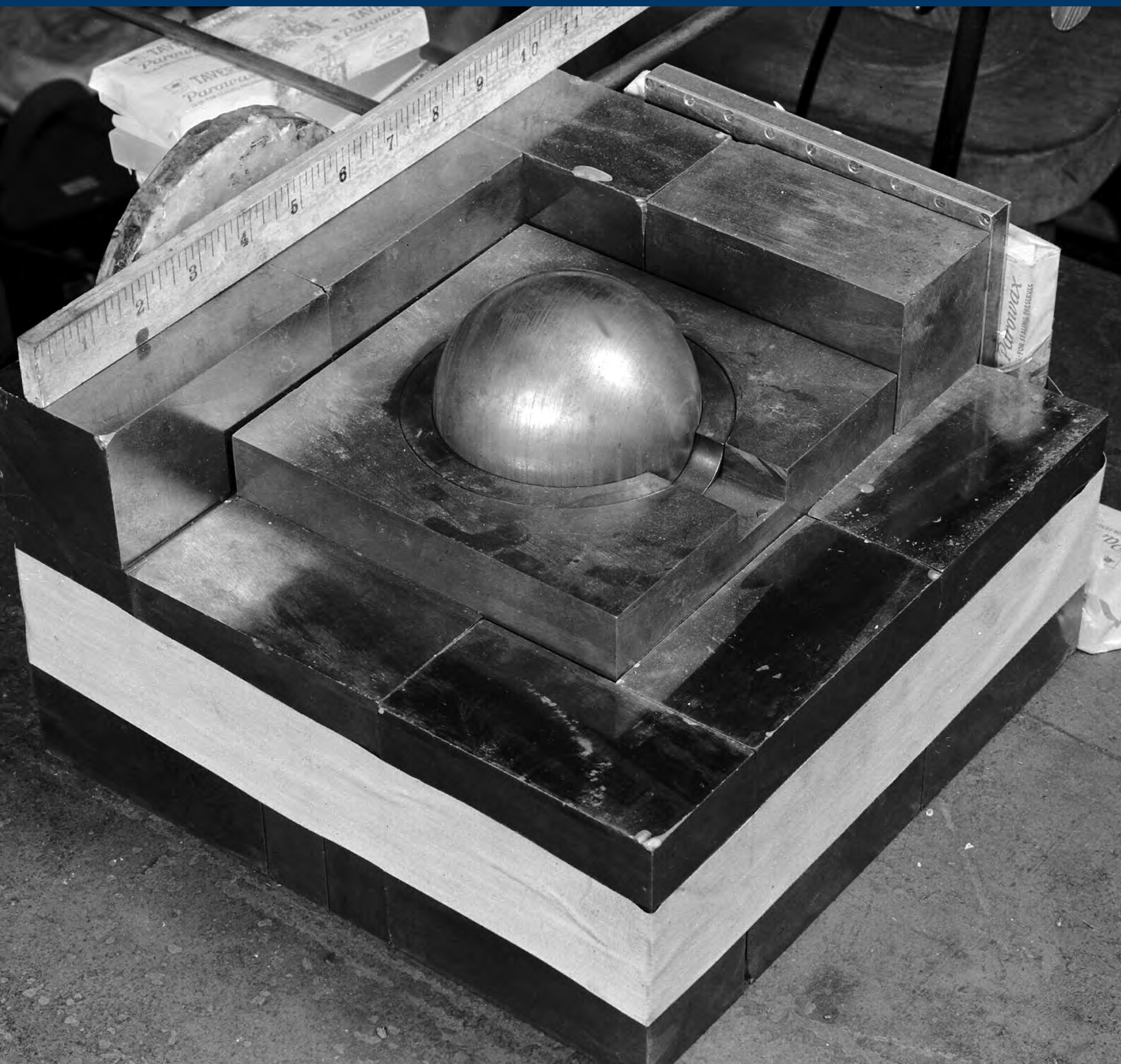

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Credits

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Chapter 1

Introduction

North Korea's nuclear weapon programme has been the subject of intense scrutiny since its inception in the early 1990s through to today. The nature of that scrutiny has evolved as North Korea's transparency and willingness to host international inspectors has waxed and waned. Today public discourse on the topic draws on opaque public statements, imperfect open source satellite imagery, anonymous hints from national intelligence apparatus, and coverage of occasional visits by Kim Jong Un to nuclear facilities. The subject of that discourse also focuses on those aspects of the programme that are most visible and transparent. Those aspects of North Korea's nuclear weapon programme that are hardest to observe are – understandably – talked about less frequently.

The core of North Korea's nuclear weapons – their 'pits' – is one aspect that has not received much attention, despite the central role they play in the weapon programme. There is very little publicly available information on pit production in most nuclear-armed states, and even less emerging from the highly secretive North Korean regime. Detailed information on the precise tools and techniques involved in fashioning the core of a nuclear weapon is rightly protected to prevent the further proliferation of nuclear weapons. The challenges of controlling the equipment and expertise required to fashion fissile material into nuclear weapons was also recognised early in the development of the nuclear non-proliferation regime, which was developed instead to provide assurance that fissile material – which is harder to acquire covertly – was not diverted to feed pit production.

It is understandable that while international efforts have focussed on preventing and constraining North Korea's access to fissile material the public discourse has similarly focused on that topic rather than how North Korea turns that material into nuclear weapons. However, pit production is not straightforward and North Korea's freedom to produce whichever and however many pits it wants is not a given.[1] North Korea has pointed to security concerns as highlighting "the importance and necessity of a mass-producing of tactical nuclear weapons and calls for an exponential increase of the country's nuclear arsenal."[2] To satisfy this demand North Korea needs to do more than produce sufficient fissile material,[3] it also needs a pit production capability that can convert that material into weapons. That capability must also be reliable, sophisticated, and large enough to produce pits that meet North Korea's various goals for weapon design and arsenal size.

1 At the time of writing, the US nuclear weapon establishment is struggling to expand its pit production capacity to meet Congressionally mandated targets of producing 80 pits per year by 2030, starting with 10 pits in 2024. By the end of that year, it had produced only one pit that was certified for use. Dylan Spaulding, *Plutonium Pit Production: The Risks and Costs of US Plans to Build New Nuclear Weapons* (Union of Concerned Scientists, 2025), https://doi.org/10.47923/2025.15875.

2 'DPRK Calls for Exponential Increase in Nuclear Arsenal', *Xinhua*, 1 January 2023.

3 VERTIC, in collaboration with RUSI, CNS, and ONN have carried out significant work to model the production of fissile material in the DPRK. These estimates drew upon open sources of information (such as satellite imagery and DPRK media sources) and fuel cycle modelling to generate estimates of how much highly enriched uranium and plutonium the DPRK may have produced to date. These estimates have since been updated in response to an analysis of open source imagery of North Korea's enrichment facilities and satellite imagery analysis of a new reactor at the Yongbyon Nuclear Scientific Research Centre. It is estimated that North Korea could have produced 2160kg (+/- 390kg) of HEU up to 2025, and 50-70kg of plutonium by the end of 2024.

It is not publicly known how and where North Korea makes its pits, and there has been little public discussion on how this might be remedied. This report addresses this by explaining how nuclear weapon pits are made and by identifying process features that could give rise to indications of pit production that are visible through publicly available satellite imagery.[4] It also highlights some of the equipment and materials that are relevant to the pit production process and discusses how trade controls on such items may or may not constrain the scale and sophistication of North Korea's pit production enterprise. It also explores how North Korea's pit production capabilities might be verifiably disabled in any future nuclear freeze or disarmament agreement.

This report develops and tests a list of visible satellite indicators that are associated with the chemical, radiological and security features of known and suspected pit production facilities. It applies these indicators to three known and suspected nuclear-weapon related sites in North Korea – Yongbyon, Yongdoktong, and Wollo-ri – and finds it unlikely that North Korea's pit production capability is housed there. While the report does not identify a likely location of North Korea's pit production capability, it establishes a foundation for further investigation of pit production activities in North Korea and elsewhere.

The report also finds the Nuclear Suppliers Group Dual-Use list is not (and perhaps cannot be) broad enough to subject the types of rudimentary equipment that can be used to make basic nuclear weapon pits to international trade controls. While tighter restrictions on relevant equipment and materials were introduced under UN Security Council Resolution 1718, they may have been too little, too late to derail North Korea's pit production. Nevertheless, these restrictions could still constrain the further evolution and development of that capability if they are properly implemented and enforced.

The report also turns to the historical precedents set by the verified dismantlement of nuclear weapon programmes in South Africa and Iraq to demonstrate that the pit production equipment can be verifiably disabled and removed from nuclear weapon use. It highlights the challenges of completely and irreversibly disabling a pit production capability that arise from the general availability and loose trade controls of equipment relevant to pit production. However, it also argues that identifying pit production sites and verifiably disabling the equipment found there could build valuable confidence in nuclear disarmament in the short term and support broader efforts to completely, verifiably, and irreversibly keep fissile materials in peaceful uses.

4 To do this it draws from the extensive archive of open information regarding the facilities at the US Rocky Flats plant that is held in the US Library of Congress and was collected as part of the plant's registration in the Historic American Engineering Record.

Chapter 2

What is a pit?

A nuclear explosion is generated by the rapid creation of a sufficiently dense mass of fissile material. Fissile materials – namely the isotopes uranium-233, uranium-235, and plutonium-239 – split (or 'fission') when they absorb neutrons, releasing a burst of energy, energetic fission fragments, and further neutrons. In a sufficiently dense mass of fissile material, those fission-generated neutrons can go on to cause further fission reactions, creating a self-sustaining ('critical') chain reaction.

If 50kg of uranium-235 were collected into a spherical mass, at normal densities, without any other materials to slow, reflect or contain its neutrons, it would be sufficient to create a critical chain reaction. A critical chain reaction could be created in these conditions with just 10kg of plutonium-239. In both cases, the critical chain reaction would release a large amount of energy, but not sufficiently quickly to be explosive. Instead, the kinetic energy generated would quickly disassemble the mass (reducing its density) and stop the chain reaction.

To create an explosive chain reaction, a highly critical mass must be assembled very quickly, and the density of fissile materials and neutrons in that mass must be sustained for as long as possible to allow the chain reaction to race through the material before it is blown apart. Nuclear weapons achieve this by using explosive lenses to rapidly compress the mass (increasing its density) or by accelerating subcritical masses into one super-critical mass. They also maximise the neutrons available for fission by providing an initial burst of initiating neutrons and by containing those neutrons with reflectors around the core. Heavy tampers are also used to momentarily sustain the high density of the exploding core to maintain the fissile chain reaction for as long as possible. These augmentations allow nuclear weapons to create an explosive fission chain reaction with far smaller quantities of fissile materials than the bare spherical critical masses described above.[5]

The 'pit' of a nuclear weapon is its fissile material core, ready to be compressed into a critical mass. To maximise the density of fissile material in the pit, the material is typically contained in its purest metallic chemical form. The commonly held image of a nuclear weapon pit is therefore one of a small, shiny, metal sphere. This is sufficient for mental illustration but disguises some complexity.[6] The fissile material components may be hollow or solid hemispheres welded together into a spherical whole and may incorporate nested shells of fissile materials and other materials that can boost the chain reaction. The centre of a pit may also contain additional non-fissile components, such as neutron initiation devices, and pits may have machined features to integrate the finished pit with external components. At its periphery a pit may also be coated or plated to contain and protect the fissile material (which is chemically reactive), reflect neutrons back into its core, and tamper the nuclear explosion on detonation.[7] This completed, discrete, contained pit is then subsequently assembled with other components such as high explosives,

5 In the right circumstances, a successful pit could contain 4kg or less of weapons-grade plutonium or 12kg or less of highly enriched uranium (HEU). *Global Fissile Material Report 2013*, n.d. P.92

6 There is no universally held definition of a pit, and the terms 'nuclear charge' and 'physics package' are also used to describe a subset of warhead components including the fissile material at its heart.

7 A tamper may or may not be directly bonded onto the surface of the pit. If not, it may be attached to the surrounding explosive lenses, separated from the pit by a small gap that allows it to accelerate under detonation before impacting and compressing the pit.

arming/fusing/firing systems, fusion 'secondaries', and ultimately an external casing to create a deployable nuclear weapon that can survive the rigours of delivery.

What pits might North Korea be producing?

It is not clear what type of pits North Korea has produced for its nuclear weapons. A literature analysis by the Open Nuclear Network (ONN) demonstrates that opinions differ on the designs that North Korea may have tested or developed, with suggestions including HEU pits, plutonium pits, and composite pits incorporating a solid core of plutonium and an outer shell of HEU.[8] That literature analysis, combined with analysis of open-source imagery of DPRK's nuclear weapons led ONN to argue that "the six nuclear devices tested and incorporated into North Korea's arsenal are likely one of the following designs:

- Implosion-based single-stage device with a levitated pit made of plutonium, HEU or a composite of plutonium and HEU. [9]
- Two-stage thermonuclear device that incorporates a version of its single-stage device as the primary."[10]

While this argument implies that North Korea's nuclear arsenal is built around a common single-stage device, it is not clear whether that device in turn relies on a common single pit design.[11] Depending on the design tolerances of the device, it may be able to incorporate pits of the same material produced to different specifications, and perhaps even pits produced from different or composite fissile materials. It is also unknown whether North Korea integrates any additional internal components to its pits (such as neutron initiators) or machines features into its pits to integrate it with additional external components (such as tritium boost-gas systems), both of which complicate pit production to varying degrees. For the purposes of this report it is assumed that North Korea's nuclear arsenal incorporates pits of a relatively rudimentary design, without incorporating more advanced features such as tritium gas boosting and single-point safety. However, this report does not assume that North Korea is not pursuing more advanced design features that may come to place new demands on its pit production capabilities.

8 Sarah Laderman et al., *Fissile Material and Nuclear Force Structure in North Korea*, Occasional Paper (Royal United Services Institute for Defence and Security Studies (RUSI), 2024), https://www.rusi.org/explore-our-research/publications/occasional-papers/fissile-material-and-nuclear-force-structure-north-korea. Pp 15-16.

9 The US and the Soviet Union both explored composite pits in the past. The US incorporated composite pits into the first mass-produced US nuclear weapons. See Robert S. Norris et al., 'History of the Nuclear Stockpile', *Bulletin of the Atomic Scientists* 41, no. 7 (1985): 106–9, https://doi.org/10.1080/00963402.1985.11456011. P. 107. The Soviet Union's third nuclear weapon test used a composite core. See David Holloway, *Stalin and the Bomb: The Soviet Union and Atomic Energy, 1939-1956* (Yale University Press, 1994), 219, https://doi.org/10.2307/j.ctvf3w23z.

10 Laderman et al., *Fissile Material and Nuclear Force Structure in North Korea*. P.24

11 Early US nuclear bombs were compatible with a number of different pits. 'History of the Custody and Deployment of Nuclear Weapons – July 1945 through September 1977', Office of the Assistant to the Secretary of Defense (Atomic Energy), February 1978. Pg. E-2

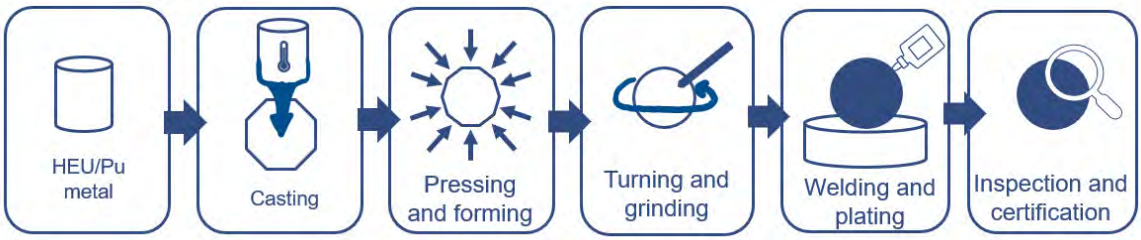
Chapter 3

How are pits produced?

At its most simple, the pit production process involves shaping metallic fissile material into the precise geometries required by nuclear weapon designs, while maintaining the desired chemical purity and mechanical form of the material. This broad process can be broken down further into six more detailed steps, as illustrated in Figure 1.

Pit production is not a continuous process that consistently feeds in a steady stream of material to produce a steady stream of products. It is carried out in staged batches, allowing for process steps to be cleaned out and maintained between batches. This also allows production lines to be adapted to different pit production missions, which could vary between different pit designs, and between experimental production or stockpile production. As such, even with knowledge of the scale or sophistication of any production line, it is hard to hypothesise about production rates – which may depend more on a varying mission schedule than purely on physical capacity.[12]

Figure 1: Six steps of pit production



Step 1: Producing HEU/Pu metals

The first step in the pit production process is the acquisition of fissile materials such as plutonium or highly enriched uranium (HEU) in metallic forms that are suitable for further processing. This involves chemically converting these fissile materials away from the forms in which they are typically produced in the nuclear fuel cycle.

HEU is produced by separating the non-fissile isotope uranium-238 from the fissile isotope uranium-235. This 'enrichment' process is carried out in North Korea through gas centrifuges. These spin a gaseous form of uranium – uranium Hexafluoride (or UF_6) – at high rotational speeds and exploit the slight differences in the resulting centrifugal and axial forces between the two isotopes to separate them into enriched product and depleted 'tails' streams. UF_6 is used because it forms a gas very easily at normal pressures and temperatures and can be stored relatively easily. However, it is neither pure, stable nor machinable enough to be suitable for producing nuclear weapon components. To this end, UF_6 can be reacted with hydrogen to strip some of the fluorine into a hydrogen fluoride byproduct, 'reducing' the UF_6 to UF_4. The rest of the

12 This is in contrast to uranium enrichment processes, which are ramped up to a stable production state and maintained in that steady state continuously producing material for as long as practicable. The scale of a gas centrifuge enrichment plant relates more directly to its production capacity than the scale of a weapon component facility.

fluorine can be further stripped by reducing UF_4 with magnesium or calcium at high temperatures (>1130°C) to separate a molten form of pure uranium metal from a calcium/magnesium fluoride byproduct, which can be cleaned off to leave a pure uranium metal 'button'.[13]

Plutonium is generated through the irradiation of uranium fuel in a nuclear reactor. The Purex process (which the DPRK is believed to use) dissolves spent reactor fuel in Nitric acid, and the resulting plutonium Nitrate is separated from uranium Nitrates and other dissolved fission products by solvent extraction.[14] While this process can generate very pure plutonium Nitrate liquid, this chemical form is unsuitable for pit production. By weight it is only approximately 50% plutonium, and it cannot be formed into solid weapon components. Plutonium is typically 'precipitated' out of a liquid plutonium Nitrate solution by reacting it with other chemical compounds to produce solidified plutonium compounds that can be physically filtered from the Nitrate solution, dried, and then heated to produce a final product. This final product is typically in the form of plutonium Oxide (PuO_2), whose chemically stable powder form makes it useful for onward storage and transport.[15] However, the Oxygen (which makes up roughly 12% of the total PuO_2 molecule by weight) represents an impurity that makes plutonium Oxide undesirable for weapons purposes. As a powder, it is also very difficult to press PuO_2 into a dense enough form and then machine that form into precise nuclear weapon component shapes.[16] A purer, denser and more workable form of plutonium can be generated by bonding plutonium oxides with highly reactive fluorine ('fluorination') and then reducing the resulting plutonium fluoride through a process similar to the uranium fluoride reduction process, reacting it with Calcium at high temperatures. This separates a molten form of metallic plutonium from the Calcium and fluoride byproducts, which can be cleaned off to leave a 'button' of pure plutonium metal.

Step 2: Casting rough shapes

Once the fissile materials have been reduced to their pure metallic forms, the resulting buttons are heated again. At roughly 640°C, plutonium metal melts and once brought above this temperature it can be cast into rough shapes for weapon components. Uranium metal has a higher melting point and must be brought beyond roughly 1130°C before it can be cast into rough shapes. In both cases, the heating and casting must avoid introducing impurities into the finished product. This can be accomplished by using heating crucibles and casting dyes that are fabricated from or coated with materials that are chemically resistant to plutonium or uranium metals, such as tantalum, yttrium or magnesium oxide.[17] Carrying out this process in a vacuum also prevents the metals reacting with atmospheric oxygen, which would react with the metal – reversing the fluorination and reduction steps described above. Uranium metal shrinks as it cools, so additional material must be fed into casting dies to ensure the desired shape is maintained as it cools.[18] A vacuum induction furnace used for this purpose can be seen in Figure 2.

This heating process is also used to alloy the pure fissile material metals with selected elements to improve their chemical stability and mechanical properties. The atoms in both uranium and plutonium metals

13 Producing a 100% 'pure' product is not straightforward and depends on the chemical and atmospheric conditions at the point of reduction, often giving variable yields of final pure products. There are other reduction methods for producing uranium metal, such as the electrolytic reduction. However, these methods are typically fed with other chemical forms of uranium other than UF6 (such as uranium Dioxide, or UO_2), making them a less direct route from HEU UF6 to HEU metal.

14 David Albright and Institute for Science and International Security, eds, *Solving the North Korean Nuclear Puzzle* (Institute for Science and International Security, 2000). P.154

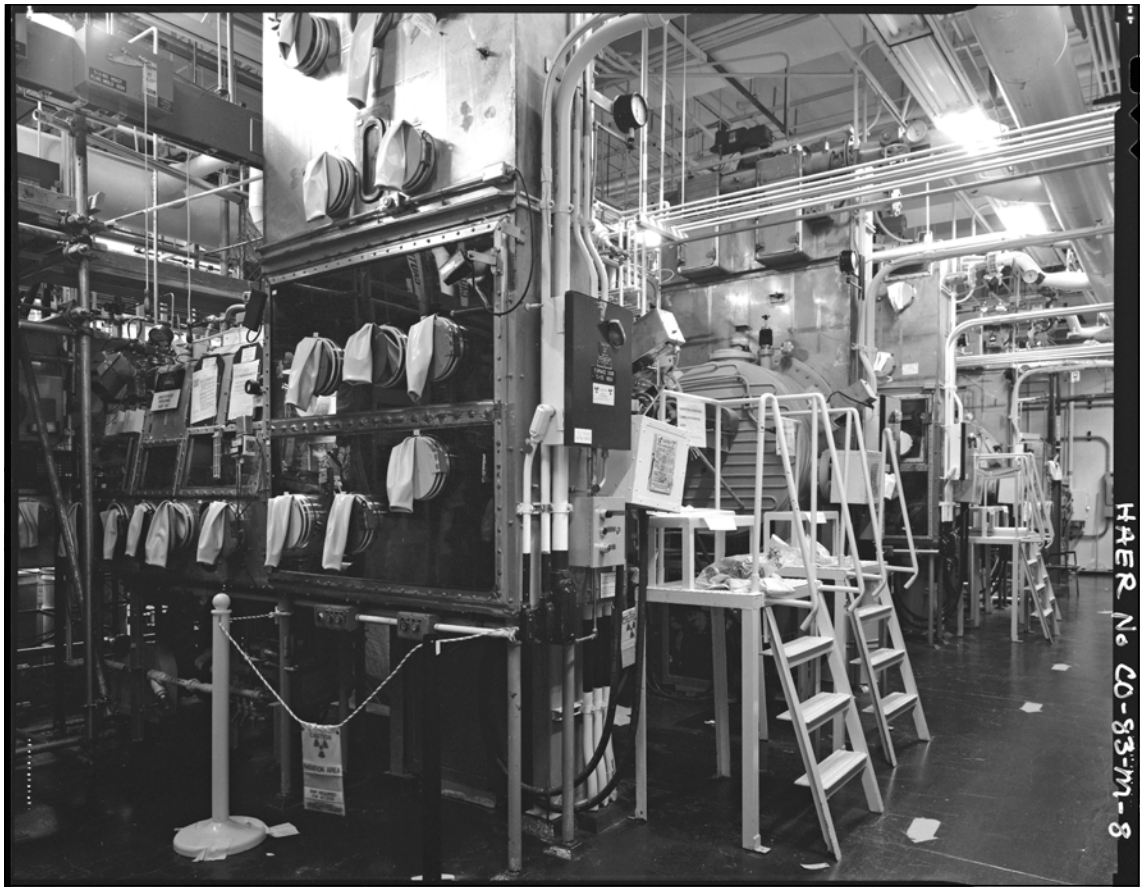
15 As discussed below, plutonium Oxide is not without its hazards and must still be handled carefully.

16 PuO_2 powder can theoretically reach a density of 11g/cm^3, which is much lower than the roughly 16-20g/cm^3 density of various phases of plutonium metal.

17 'Guidelines for Transfers of Nuclear-Related Dual-Use Equipment, Materials, Software, and Related Technology, as Amended.', International Atomic Energy Agency, 26 January 2021, https://www.nuclearsuppliersgroup.org/index.php/en/guidelines/nsg-guidelines/guidelines-part-2. Section 2.A.1.

18 This is not the case for plutonium, which expands under cooling.

Figure 2: A vacuum induction furnace (background) for casting plutonium metal ingots at the Rocky Flats pit production site in the US, with gloveboxes in the foreground[19]



settle into different configurations at different temperatures, and the metals behave differently in each phase as temperatures change and as they are subjected to different mechanical forces (such as machining or implosion). Pure uranium metal at room temperature exists in a phase that is 'anisotropic': it responds to heat and mechanical forces differently depending on the angle and direction of those forces, making it prone to warping.[20] The 'alpha' phase of plutonium is strong but very brittle, making it hard to machine without fracturing. The 'delta' phase of plutonium is very malleable and can be easily machined, but it eventually transitions back to the 'alpha' phase causing extreme changes in density that can fracture and warp any machined shapes.[21]

In both cases, introducing small quantities of alloying agents during the casting process can 'fix' the fissile material metals into phases that are more amenable for the following pit production steps.[22] For plutonium, this is commonly accomplished by alloying it with a small amount (as low as 1% by atomic weight) of gallium.[23] While this introduces impurities that are undesirable from the perspective of producing an

19 HAER COLO,30-GOLD.V,1M—8, Library of Congress Prints and Photographs Division Washington, D.C. https://www.loc.gov/pictures/item/co0854.photos.316894p/

20 Nathan R. Gubel et al., 'Introduction to Uranium', in *Uranium Processing and Properties*, ed. Jonathan S. Morrell and Mark J. Jackson (Springer New York, 2013), https://doi.org/10.1007/978-1-4614-7591-0_1.2013

21 Siegfried S. Hecker and Michael F. Stevens, 'Mechanical Behavior of Plutonium and Its Alloys', *Los Alamos Science* 2, no. 26 (2000): 336–55.

22 This alloying step can also be carried out during the reduction process if the alloying agent is introduced as a fluorinated compound alongside the plutonium/uranium fluoride at the reduction phase. N. L. LaHaye and D. E. Burkes, 'Metal Fuel Fabrication Safety and Hazards', Pacific Northwest National Laboratory, June 2019, https://www.nrc.gov/docs/ML1919/ML19193A057.pdf. Pg. 4.1.

23 Aluminium and Nickel may also be used to fix plutonium in its face-centred cubic phase but may have a negative impact on the behaviour of neutrons required for sustaining the fissile chain reaction.

efficient fission chain reaction, the benefits of fixing plutonium in its delta phase far outweigh any costs in fissile purity.[24] Uranium can be alloyed with niobium and molybdenum for similar purposes, but it is not clear whether the mechanical gains from doing so outweigh the costs in terms of fissile purity. Alloying may not be necessary for producing uranium pits.

Step 3: Pressing and forming more precise shapes

Depending on the design of the weapon component and the casting process above, the shape and volume of cast metals may need further refining before they can be useful. For example, cast metal may need to be formed into uniformly thin sheets by extruding it into hollow tubes and then flattened, or rolled directly into thin sheets. These thin sheets can then be pressed around a target die to accurately recreate its shape. Where uranium metals are used to fuel civilian nuclear reactors (such as in the gas-graphite reactor used by North Korea at Yongbyon), cast metal may be rolled or extruded into rods or tubes before cladding. Directional pressing may also take place at the casting stage described above, where an inert gas can be fed into the vacuum casting chamber to force the molten metal into a more precise and consistent cast shape at the desired densities.

Some of these pressing and forming operations may take place at a high temperature to improve the malleability of the material but kept below the melting points of the materials as described above. This heating again introduces the risk of oxidizing the metal with any surrounding oxygen, so are often carried out in an oxygen-free environment.

Step 4: Turning, grinding, and milling

The final nuclear weapon component shapes are achieved through the subtractive machining processes of turning, grinding, and milling. Turning (or lathing) involves using a fixed cutting edge (see Figure 3 and Figure 4) to shave material off a rotating component and is well-suited to producing shapes with accurate rotational symmetry hemispheres or hemishells. Grinding involves passing a rotating abrasive tool over a fixed surface to achieve highly smooth finishes and to prepare surfaces for welding. Milling involves using a rotating cutting tool to cut features (such as grooves, holes, or slots) into a fixed component.[25] While these operations do not need to be carried out at high temperatures, they do generate significant heat and release fine shavings and chips of fissile material metal. These are liable to ignite if exposed to moist air. Any lubricants used to manage the generation of friction heat must be carefully selected to reduce any chemical contamination of the finished product. As discussed in greater detail below, chemical and criticality hazards require these operations to be carried out in carefully controlled environments and through carefully controlled processes.

24 Siegfried Hecker, 'Plutonium and Its Alloys: From Atoms to Microstructure', *Los Alamos Science* 2, no. 26 (2000): 290–335. P.319. For a broader overview of the metallurgical properties of plutonium see Hecker and Stevens, 'Mechanical Behavior of Plutonium and Its Alloys'.

25 For example, holes in an otherwise solid hemishell may need to be drilled to accommodate tubes for the insertion of tritium boost gas into the core of an imploding pit during detonation.

Figure 3: A lathe used for the final machining of weapon components at the Rocky Flats pit production site in the US[26]

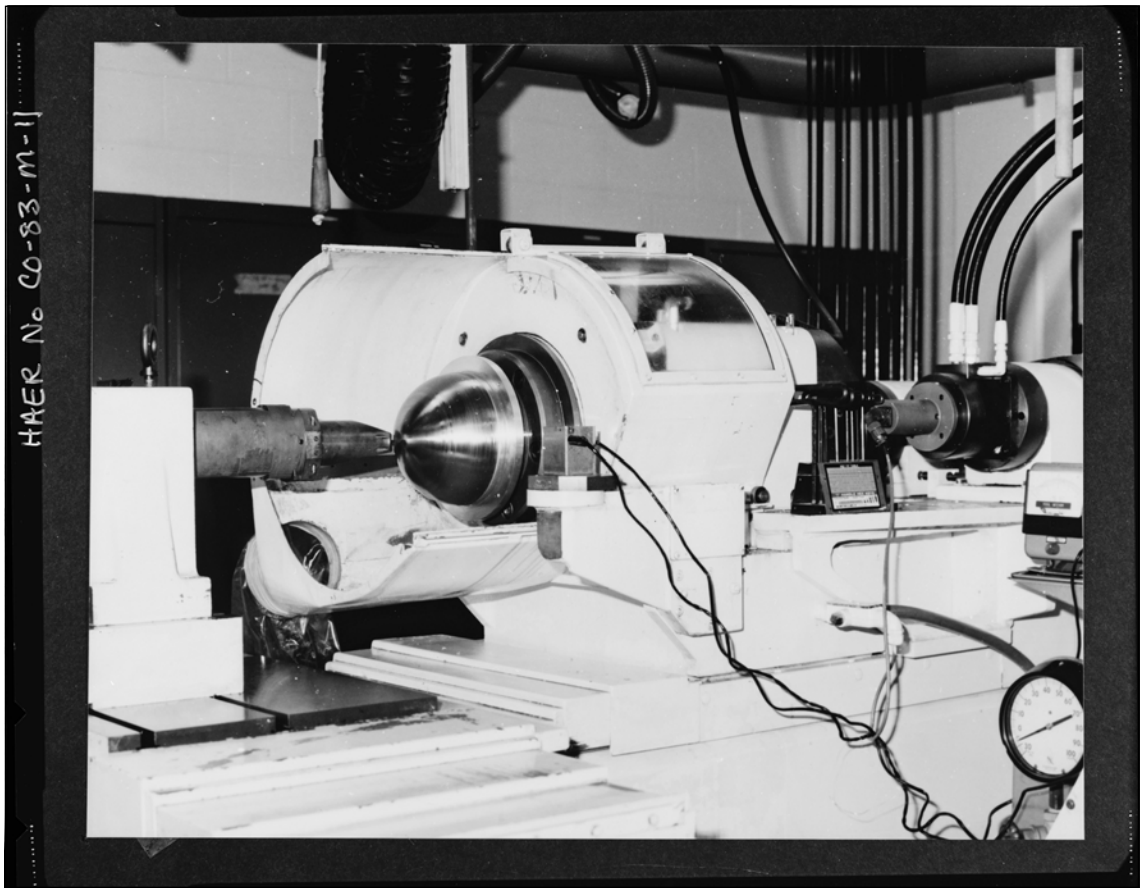


Figure 4: A lathe used for the machining of uranium metal weapon components at the 404 Plant within the Jiuquan Atomic Energy Complex in China[27]

26 HAER COLO,30-GOLD.V,1M—11, Library of Congress Prints and Photographs Division Washington, D.C. https://www.loc.gov/pictures/item/co0854.photos.316897p/

27 A still captured from a video on the 404 Plant, posted on the video sharing site 'BiliBili' by the China National Nuclear Corporation (CNNC), available here: https://www.bilibili.com/video/BV1cV411377a/

Figure 5: A vacuum chamber containing remotely operated welding equipment at the Rocky Flats pit production site in the US[28]

Step 5: Welding and plating

The final stage of pit production involves welding various pit components together. This may include welding concentric hemishells of different fissile materials together in layers (for a composite pit), welding the faces of hemishells together into a spherical whole, and welding other pit components (such as tampers and tritium boost gas tubes) to produce a finished product.[29] These operations must be carried out carefully to ensure the welds are sound without introducing anomalies or asymmetries that would disrupting the uniform and predictable implosion of the weapons components under detonation.

Both uranium and plutonium metals can be welded to themselves or a variety of other metals by heating them (directly or indirectly) to their melting points, joining them to its target component, and carefully allowing them to cool and solidify.[30] This can be accomplished through inert gas arc welding, which heats the components to be joined through an electrical arc, enveloped in a jet of inert gas (such as argon) to avoid oxidizing and weakening the weld. As with preceding process steps, oxidization can also be avoided by welding in a vacuum (see Figure 5). Other welding techniques such as resistance welding (which exploits high electrical resistance at joins to focus heat onto those joins), electron beam welding

28 HAER COLO,30-GOLD.V,1M—13, Library of Congress Prints and Photographs Division Washington, D.C. https://www.loc.gov/pictures/item/co0854.photos.316899p/

29 Tampers may be fabricated from materials such as Tungsten or natural (unenriched) uranium metals, machined into hemispherical shells using many of the same techniques described here. Tampers may not be welded directly onto the face of the pit and may be welded into a 'levitated' position separate from the pit.

30 Anderson, 'Welding of plutonium'. 'uranium: Properties, Processes, Controls'.P.44

(for small, highly precise joins), and solid-state bonding (which exploits atomic-level bonding forces to join metals at temperatures below their melting point) have been explored for this purpose too.[31]

Once weapon components have been fabricated and assembled into their near-final forms, they can be coated or plated in an outer layer. This prevents the fissile material metals from reacting with the atmosphere and oxidizing, which would weaken the bonds holding components together and raise the risks that plutonium/uranium oxides might ignite or contaminate people or objects. Nickel may be used as a coating/plating material for this purpose as it is relatively unreactive, hard, and durable.

These outer layers can be applied in a variety of ways. In the civilian nuclear power sector, cladding materials are pressed onto the exterior of metal fuel elements of both uranium and plutonium through techniques like isostatic pressing, as described in preceding subsections. During the Manhattan Project, both electroplating and chemical vapour deposition were used to protect fissile material components. The former technique involves immersing fissile material components in an electrolyte bath and subjecting them to an electrical charge that pulls coating materials from the bath onto the surface of the fissile material components. It was used to protect the components of the Trinity test device with nickel, with mixed success.[32] It is not straightforwardly applied to fissile material metals, whose surfaces must be carefully prepared to accept and bond to the coating materials.[33] The latter technique involves reacting a gaseous form of the coating material with the fissile material component, causing it to deposit a solid coating on the component. It was used, with greater success than electroplating, to coat the core of the Fat Man device in nickel.[34]

Step 6: Inspection and certification

The chemical composition, density, shape and integrity of a final pit must conform to certain standards set by the overall design of a nuclear weapon. These standards may be higher or lower – and may have to be met with greater or lesser accuracy – depending on the design of the weapon.[35] A variety of destructive and non-destructive tests and measurements of the evolving pit component may therefore be taken throughout the production process. Samples of fissile material metals emerging from the casting process may be analysed in a laboratory to confirm the chemical composition and phase of an alloyed product. The shape of a component could be confirmed with a variety of dimensional inspection tools, ranging from hand-operated gauges to more sophisticated laser systems. Radiographical examination (for example by X-ray) can identify cracks, voids, and gaps in components. Inducing and measuring electrical 'eddy currents' around component welding spots can help identify any cracks, pits, or weld failures.[36] If the completed components pass these various tests, they would likely be marked with a unique identifier that certifies them for onward use and associates it with its inspection records and results.[37]

31 'Historic American Engineering Record: Rocky Flats Plant', US Library of Congress, n.d.P.91

32 Some electrolyte solution was absorbed by a porous spot on the metal component and subsequently reacted with the metal, causing the Nickel coating to blister. See Martz et al., 'The Taming of plutonium'. P.279

33 Weirick and Lynch, 'Corrosion Resistant Coatings for uranium and uranium Alloys'. P.20

34 *Ibid.*

35 A conservative and unsophisticated weapon design which is unconcerned with efficient usage of fissile material or augmenting design features may accept lower material densities, less uniform density, and less accurate measurement of that density in comparison to a tightly controlled, efficient and sophisticated weapon design.

36 For a broader description of the pit inspection techniques used at the US Rocky Flats Plant, see 'Rocky Flats Plant, Plutonium Manufacturing Facility, North-Central Section of Plant, Just South of Building 776/777, Golden, Jefferson County, CO', Historic American Engineering Record, n.d., HAER CO-83-M, Library of Congress Prints and Photographs Division Washington, D.C. 20540 USA, accessed 2 December 2025, https://www.loc.gov/pictures/collection/hh/item/co0854/. p.8

37 For example, the US National Nuclear Security Administration marks certified pits with a diamond stamp. Whitney Spivey, '"We Have Commenced War-Reserve Pit Production"', Los Alamos National Laboratory, 9 December 2024, https://www.lanl.gov/media/publications/national-security-science/1224-we-have-commenced-war-reserve-pit-production.

Chapter 4

Externally observable indicators of pit production arising from features of the process

Criticality

The propensity of uranium-235 and plutonium to undergo fission in the presence of neutrons creates a significant risk that if sufficient fissile material is collected under the right conditions, a critical fission chain reaction can start. This risk can be particularly high during the pit production process if rudimentary weapon designs demand large quantities of fissile materials or if procedures are poorly designed or executed such that critical masses are accidentally created. The primary defence against this risk is maintaining strict limitations on the quantities and geometries of fissile materials, and on the presence of any neutron moderating materials that amplify criticality risks. This defence does not obviously generate any indicators that might be visible from satellite imagery.[38]

Security arrangements

Plutonium and HEU (in the quantities and forms that are involved in pit production) are considered as Category 1 nuclear materials for the purposes of nuclear security requirements under various multilateral arrangements.[39] This categorisation typically requires national authorities to implement security arrangements for such material that include constant surveillance, physical barriers, protection by guards in close contact to appropriate security response forces, and restriction of access to persons whose trustworthiness has been certified.[40] Some domestic regulatory regimes build on these requirements to expect multiple, layered and complementary barriers, perimeter and interior intrusion detection systems, and on-site rapid response forces.[41]

> **Proposed indicator of pit production visible through satellite imagery:** multiple, layered and complementary perimeters, including secondary perimeters around individual buildings, with strict access control.

Heat

The pit production processes described above demand heating fissile materials to very high temperatures. Casting and alloying uranium metal requires heating it up to (and sometimes beyond) its melting

38 Rather it significantly restricts the scale of individual pit production process steps, and the equipment involved in those steps, allowing them to take place in smaller facilities than those used for other activities such as uranium enrichment and spent fuel reprocessing.

39 For example, the amended Convention on the Physical Protection of Nuclear Materials. See 'Amendment to the Convention on the Physical Protection of Nuclear Material', International Atomic Energy Agency, 18 October 2021, https://www.iaea.org/sites/default/files/publications/documents/infcircs/1979/infcirc274r1m1c.pdf. Annex II

40 *Ibid., Annex I*

41 For example, US guidance assigns pure fissile material metals and completed nuclear weapon pits to the second-highest "Attractiveness Level" (which described the relatively utility of the material for assembling a nuclear weapon), after completed nuclear weapons. Part 73 of Section 10 of the US Code of Federal Regulations requires such material to be protected by barriers, access controls, surveillance and intrusion detection systems, alarm systems, and detailed response plans to neutralize or respond to any theft or sabotage of the material.

point of 1130°C and rolling or pressing it requires temperatures only a few hundred degrees lower. While plutonium metal has a lower melting point and does not require such high temperatures, it still requires considerable heat to cast and work. This heat is often generated electrically, with standard industrial vacuum melting systems typically requiring 225kW-325kW of electricity. Depending on the scale and throughput of these hot works (and other competing electrical demands), transformers or transformer switchyards may therefore be visible. This heat must also be dissipated somehow, and any byproducts from chemical reactions (which are minimised but not eliminated entirely) must also be safely dispersed.

Proposed indicator of pit production visible through satellite imagery: a nearby electrical transformer switchyard that can convert high voltage / low current electricity provided by typical grid systems to a low voltage / very high current required for electrical heating (for example, arc/ induction furnaces).

Proposed indicator of pit production visible through satellite imagery: heat exchangers, including cooling towers and fan-driven ventilation systems.[42]

Proposed indicator of pit production visible through satellite imagery: tall exhaust stacks for venting off gases with chemical or radiological hazards.

Radiological hazards

The primary radiological hazards presented by the pit production process is the radioactive emission of alpha particles from uranium-235 and plutonium-239.[43] plutonium-239 is by far the more hazardous material in this regard.[44] Alpha particles do not penetrate through materials and something as thin as paper can serve as a barrier to external sources of alpha particles. However, they deposit a large amount of energy when they are absorbed, making the absorption (via open wounds) or inhalation or ingestion of alpha emitters particularly hazardous.[45] Plutonium and HEU particles in the lungs can be transferred to the blood or lymphatic systems, and then on to other parts of the body where the alpha decay can cause significant damage.[46] As discussed below, HEU and plutonium can chemically react with their environment to form powdery coating, particularly if they are finely divided and exposed to moisture. These coatings can easily become airborne. Machining activities also throw large quantities of material contamination into the environment that must be carefully contained and filtered.

Suppressing the release of plutonium and HEU contamination (in the form of dusts, aerosols, and other particulate matter) and preventing the inhalation or absorption of such contamination protects against these radiological hazards. Workers can be protected from such contamination by extracting it through negative air pressure fume hoods or down-draft tables (see Figure 6), containing it within sealed glove boxes (see Figure 7), or by equipping workers with respirators and safety overalls.

Proposed indicator of pit production visible through satellite imagery: air handling units to provide negative air pressure for contamination control, particularly with High Efficiency

42 Many fan-driven heat exchangers are challenging to identify without access to high resolution optical satellite imagery.

43 Weapons-grade uranium and plutonium also emit Beta, Gamma, and Neutron radiation to varying degrees depending on the quantity of material and the in-growth of various decay products, again with plutonium presenting greater hazards than uranium. However, the arrangements for protecting against this radiation (namely shielding and quantity controls) do not present indicators visible through satellite imagery. As such these hazards are not considered in more detail here.

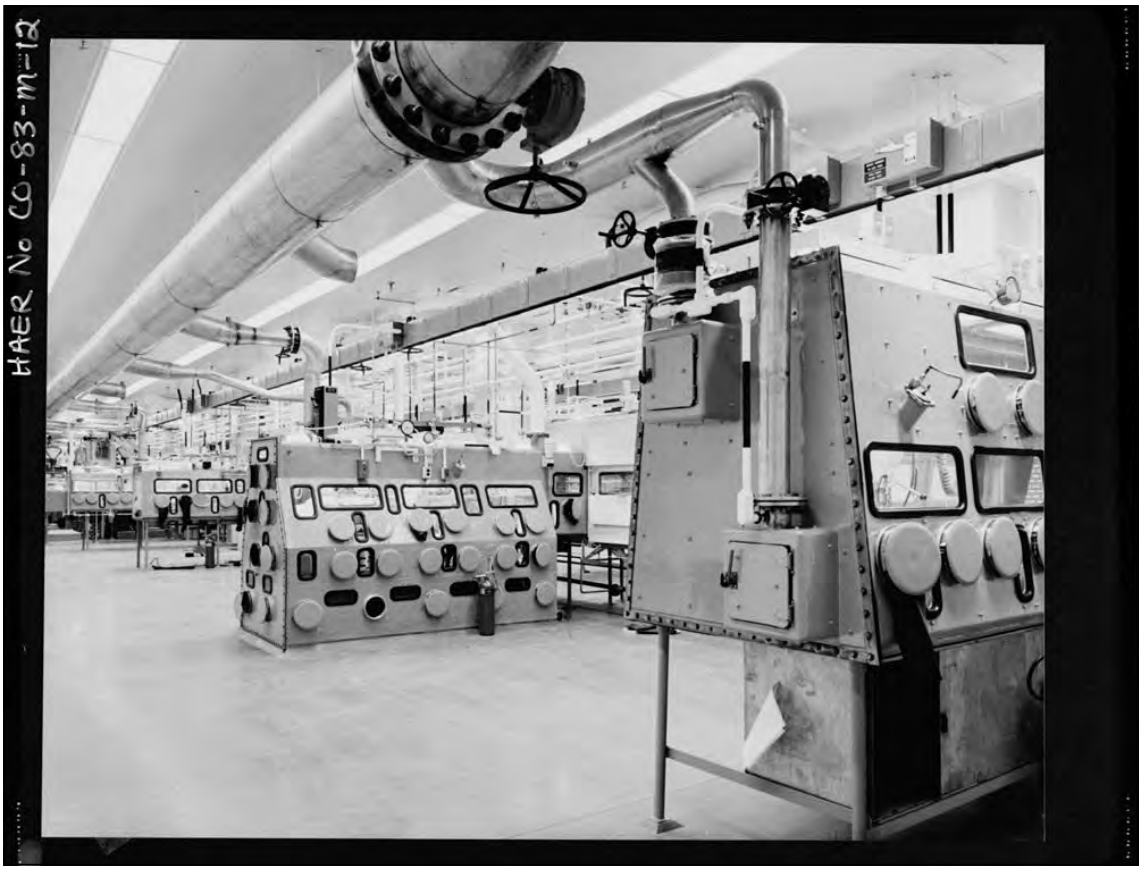
44 The half-life of plutonium-239 (the time it takes for half of the atoms present to decay) is roughly 30,000 times shorter than the half-life of uranium-235.

45 Alpha particles have a 'radiation weighting factor' of 20, meaning they cause roughly 20 times the damage to human tissue on absorption than gamma rays or beta radiation (electrons).

46 Uranium is deposited primarily in the kidneys, hones, and livers. Plutonium is primarily absorbed by bone surfaces and the liver, and lingers in the body far longer than HEU. See Cournoyer et al., 'Why Is Weapons Grade plutonium More Hazardous to Work with than Highly Enriched uranium?' p.15

Figure 6: View of a downdraft table at the Rocky Flats pit production site in the US[47]

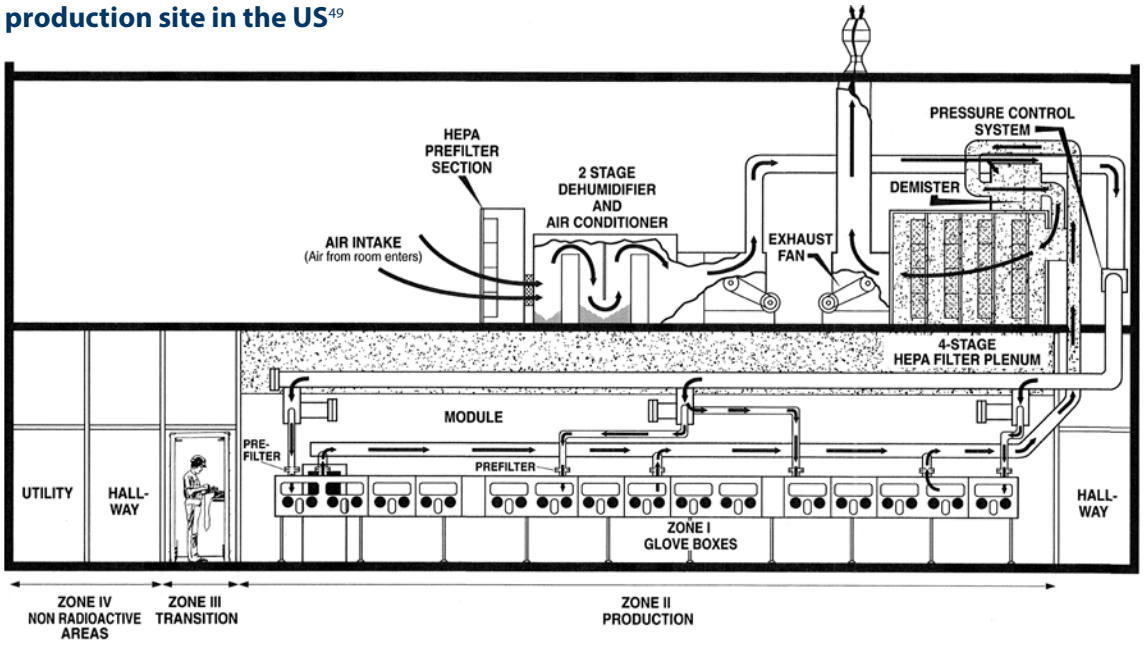
Figure 7: Gloveboxes at the Rocky Flats pit production site in the US, used in this instance for machining and inspecting weapon components[48]



47 HAER COLO,30-GOLD.V,1M—14, Library of Congress Prints and Photographs Division Washington, D.C. https://cdn.loc.gov/service/pnp/habshaer/co/co0800/co0854/photos/316900pv.jpg

48 HAER COLO,30-GOLD.V,1M—12, Library of Congress Prints and Photographs Division Washington, D.C. https://www.loc.gov/pictures/item/co0854.photos.316898p/

Figure 8: Drawing of a notional glove box and HEPA system at the Rocky Flats pit production site in the US[49]



Particulate Air (HEPA) filter systems to prevent the release of radioactive materials to the environment (see Figure 8). As HEU presents a lesser radiological hazard than plutonium, the requirements for such air handling arrangements may be less where only HEU is processed. Exhaust stacks – as discussed above – can also be used in combination with HEPA filter systems to control radioactive contamination.

Pyrophoricity

Plutonium metal readily reacts with hydrogen from atmospheric moisture and other sources to produce plutonium hydrides. If these plutonium hydrides are fine enough, they can spontaneously ignite (they are 'pyrophoric') at room temperatures.[50] The heat generated by plutonium hydride fires can then prompt the ignition of plutonium metal itself.[51] This causes the metal to rapidly oxidize and melt, dispersing plutonium oxides and risking the coagulation of liquid plutonium metals into forms that risk criticality (discussed above). Uranium is similarly ignitable if it is stored in fine shavings or pieces in the presence of moisture, but the combustion happens at higher temperatures and at a slower rate than plutonium.[52] Plutonium fires were unfortunately a common feature in the history of pit production, with serious fires causing significant harm, environmental contamination, and infrastructural damage at the Rocky Flats pit production plant in the US and at 'Plant 20' at the Mayak Chemical Combine in Russia.[53]

49 Extracted from HAER COLO,30-GOLD.V,1- (sheet 16 of 17), Library of Congress Prints and Photographs Division Washington, D.C. https://www.loc.gov/pictures/item/co0471.sheet.00016a/

50 The ease at which plutonium Hydrides can spontaneously ignite depends on their surface areas: finely divided Hydrides (such as in powders or shavings) ignite much more readily than bulky Hydrides. See Jim Bisker and Tom Christman, 'Primer on Spontaneous Heating and Pyrophorocity', U.S. Department of Energy, February 2018, https://www.standards.doe.gov/standards-documents/1000/1081-bhdbk-2014-cn1/@@images/file. P. 28-30.

51 As above, this is dependent on the surface area of the metal, with finely divided plutonium metal igniting far more easily than bulky plutonium.

52 Cournoyer et al., 'Why Is Weapons Grade Plutonium More Hazardous to Work with than Highly Enriched Uranium?'. P.8

53 For accounts of plutonium fires and their human impact at these sites see T. R. Mongan et al., 'Plutonium Releases from the 1957 Fire at Rocky Flats', *Health Physics* 71, no. 4 (1996): 510–21, https://doi.org/10.1097/00004032-199610000-00009. Mira M. Kosenko, 'Where Radiobiology Began in Russia: A Physician's Perspective', US Defense Threat Reduction Agency, September 2010, https://apps.dtic.mil/sti/tr/pdf/ADA535346.pdf. And Vladislav Larin, 'Mayak's Walking Wounded', *Bulletin of the Atomic Scientists* 55, no. 5 (1999): 20–27, https://doi.org/10.1080/00963402.1999.11460370.

The risks presented by the pyrophoricity of plutonium and uranium metals are most acute when they are being machined and when wastes from other process stages are being collected, where fine scraps, flecks, and dusts are accumulated. These risks can be reduced by minimizing the presence of moisture by drying environments, removing air entirely with a vacuum, or displacing moist air with inert gases (like argon). Air handling equipment – as discussed above for contamination control purposes – can also be used to control atmospheric temperatures and moisture levels to minimize chemical reactivity. Any plutonium or uranium metal fire must be extinguished quickly and carefully. Water exacerbates the chemical reactions in any fire and moderates (slows down) the neutrons that are emitted by these materials, increasing the chances they could initiate a critical chain reaction in the fissile material, so it is typically used only as a last resort. Instead, such fires are better smothered by inert gases and Magnesium Oxide sands.[54]

Proposed indicator of pit production visible through satellite imagery: chemical tanks suitable for storing inert elements, such as gaseous argon and liquid nitrogen.

Proposed indicator of pit production visible through satellite imagery: the presence of on-site emergency fire-fighting capabilities.

54 Cournoyer et al., 'Why Is Weapons Grade plutonium More Hazardous to Work with than Highly Enriched uranium?' p.9

Chapter 5

Testing indicators of pit production through satellite imagery analysis

The aspects of pit production above imply there may be the following indicators of pit production that may be visible through satellite imagery:

- Multiple, layered and complementary perimeters, including **secondary perimeters around individual buildings**, with strict access control;
- **Electrical transformers or switchyards**;
- **Heat exchangers**, including cooling towers and fan-driven ventilation systems;
- **Tall exhaust stacks** for venting off gases with chemical or radiological hazards;
- **Air handling units** to provide negative air pressure for contamination control, particularly with High Efficiency Particulate Air (HEPA) filter systems;
- **Chemical tanks** suitable for storing inert gases, such as Argon and Nitrogen; and
- On-site emergency **fire-fighting capabilities**.

The presence or absence of these indicators would not conclusively prove that pit production is or is not taking place. Other processes involve tackling similar hazards to pit production and generate similar indicators. Non-nuclear chemical industries, civilian nuclear fuel reprocessing, and nuclear weapon production processes unrelated to pit production (such as tritium handling) may look a lot like pit production. On the other hand, pit production may take place without obviously presenting these indicators. Chemical reagents may be stored under cover and firefighting capabilities may be housed at a distance from the facilities in question. Pit production may be carried out entirely underground, with only air handling and exhaust systems that connect the processes to the outside world providing a clue towards the activities within.

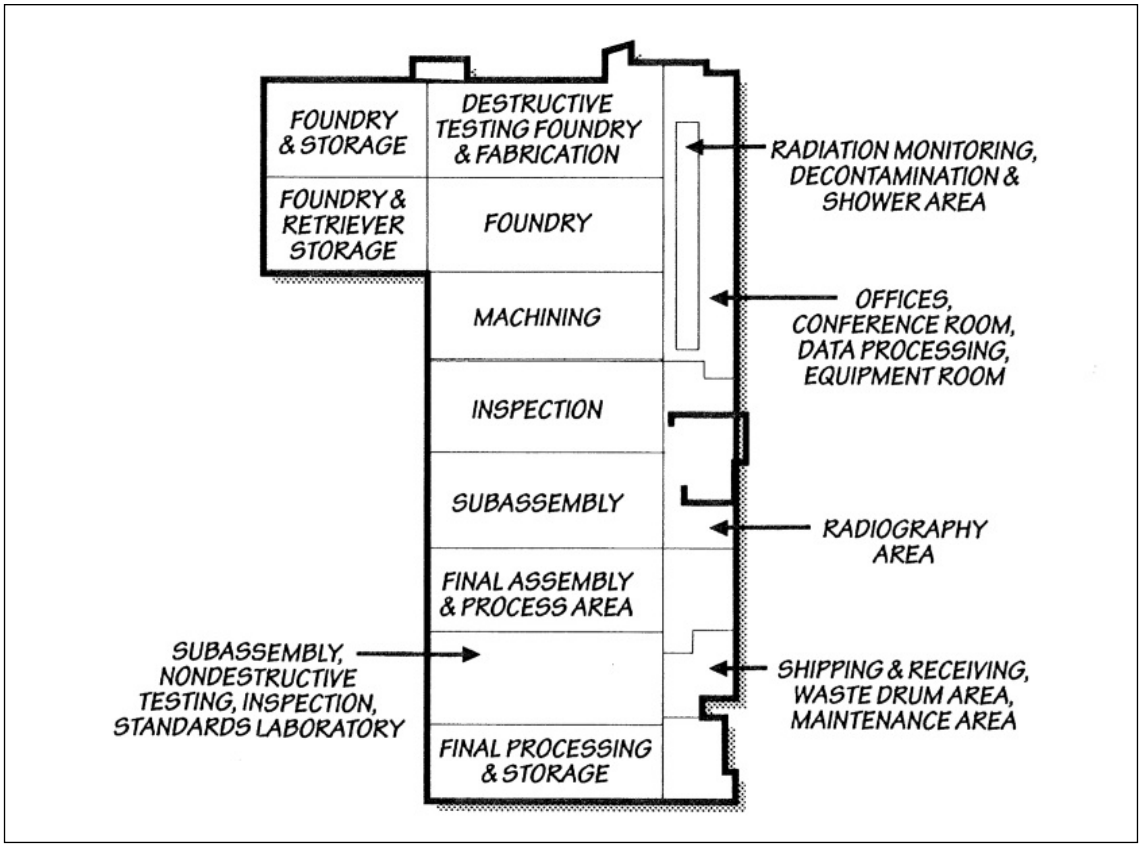
Nevertheless, these indicators may be a useful tool for analysing possible nuclear weapon and pit production sites when applied alongside other open sources of information – such as government reports and statements, declassified intelligence reports, and trade data. The applicability of these satellite imagery indicators alongside other sources of information can be tested by examining facilities in other states that are known to (or may be) involved in pit production:

- Building 707 plutonium Manufacturing Facility, Rocky Flats Plant, US.
- PF-4 Plant, Los Alamos National Laboratory, US.
- A90 Building, Atomic Weapons Establishment, UK.
- Valduc Site, France.
- Tatysh Facilities, Mayak Production Association, Russia.
- Possible Special Parts Factory, Pingtong Nuclear Facility, China.

Building 707 plutonium Manufacturing Facility, Rocky Flats Plant

The Rocky Flats Plant was established in 1951 and swiftly grew to become by 1964 the sole producer of nuclear weapon triggers in the US. At its peak, the site was producing plutonium pits at a rate of 1,000-

Figure 9: Schematic floor plan of Building 707 plutonium Manufacturing Facility[55]



2,000 pits per year.[56] Production at the site ceased abruptly in 1988 following a raid by the US Federal Bureau of Investigations (FBI) for alleged environmental violations. Building 707 (see Figure 9) was the primary plutonium manufacturing and assembly facility at the site from 1970, following a plutonium fire at its predecessor (Building 776/777) that forced its early closure. All the buildings on the site (including Building 707) have since been fully decommissioned and demolished, but an inventory and evaluation of all the buildings on the site was carried out in 1997 as part of the site's registration in the Historic American Engineering Records.[57] This publicly-available record includes detailed reports, charts, diagrams, and photos of the site which provide confirmation of many of the proposed indicators above.

Operations at Building 707 included metallurgy, pit fabrication, inspection, testing, assembly and storage. Plutonium metal ingots were cast in vacuum induction furnaces, rolled to a specific thickness, cut and pressed into hemishells, machined, welded, assembled, and subjected to inspection and certification before being stored or sent to other facilities for further weapon assembly.[58] The layout of these operations can be seen in Figure 9. The Building 707 complex included a cooling tower, an electrical distribution station, outside storage tanks for inert gases, and air handling/HEPA units, some of which can be observed from freely available overhead imagery (see Figure 10 and Figure 11 below).[59]

55 Schematic extracted from HAER COLO,30-GOLD.V,1- (sheet 9 of 17), part of 'HAER No. CO-83'.

56 'Final Environmental Impact Statement for Plutonium Pit Production at the Savannah River Site in South Carolina', US National Nuclear Security Administration Savannah River Site, September 2020, https://www.energy.gov/sites/default/files/2020/09/f79/final-eis-0541-srs-pit-production-summary-2020-09.pdf. S-1. At various times the site was also involved in fabricating uranium and beryllium weapon components and handling stainless steel reservoirs for tritium gas. Finished pits were then shipped to the Pantex Plant in Texas for final assembly into nuclear weapons.

57 'HAER No. CO-83'.

58 For a detailed discussion with images of the plutonium Manufacturing Facility see 'Building 707'.

59 Those indicators not shown in Figure 11 and Figure 12 are known to exist near Building 707. Tall exhaust stacks are visible in the proximity of Buildings 771 and 776/777, predecessors of Building 707. A 25-person fire department was stationed on site, though its precise location is unknown. See 'Building 707'.

Figure 10: Open source image of Building 707 with indicators of pit production highlighted[60]

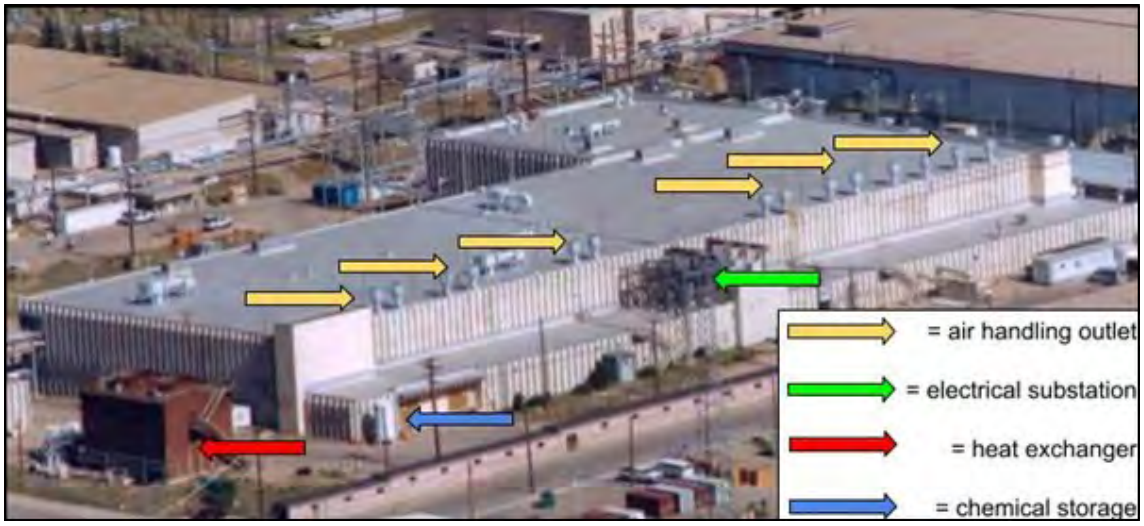


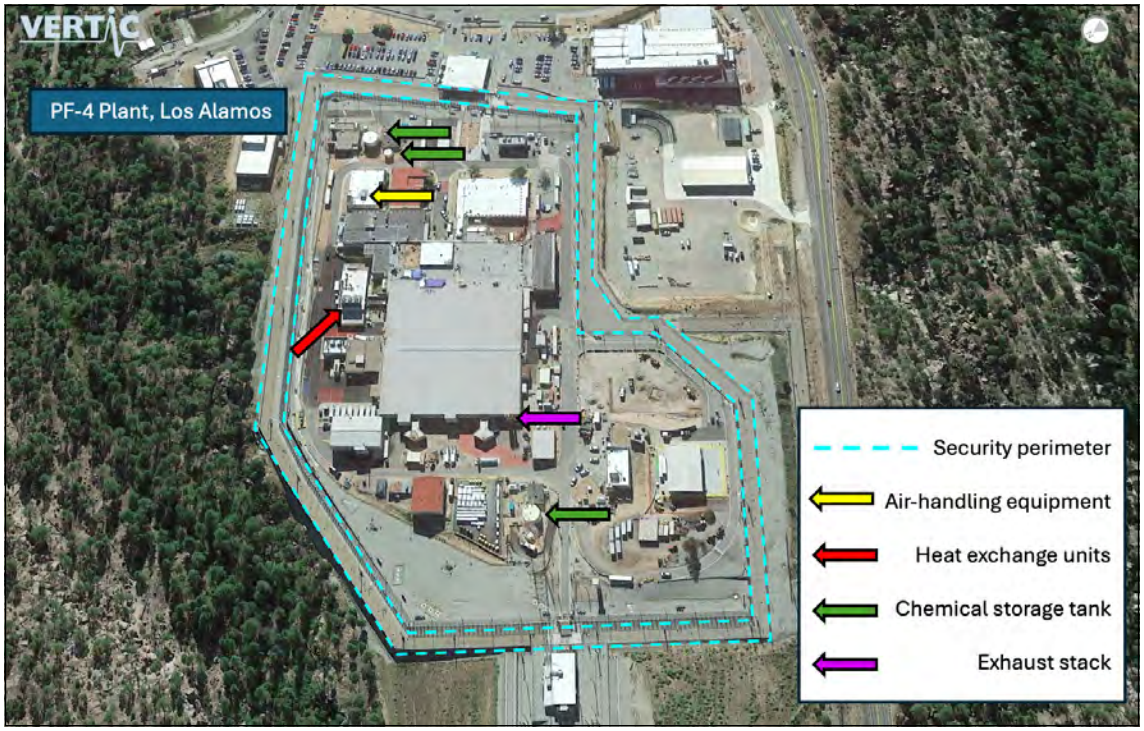
Figure 11: Satellite image of Building 707 with indicators of pit production highlighted. Image via U.S. Geological Survey, taken 1 January 2002, 39.891932 N, 105.201746 W

60 Image extracted and modified from Slide 13 of Scott Surovchak, 'Rocky Flats Overview', Northern New Mexico Citizens Advisory Board, 20 August 2014, https://www.energy.gov/sites/prod/files/2015/07/f24/Rocky_Flats_Overview_082014.pdf.

PF-4 Plant, Los Alamos

Following the closure of the Rocky Flats site, the US shifted pit production to Los Alamos National Laboratory in 1993. The PF-4 facility within Technical Area 55 was chosen as the only fully functional plutonium handling facility in the US Department of Energy Defence Programmes complex at the time. Unlike Building 707 above, the pit production mission at PF-4 sits alongside a number of other plutonium-related activities, including nuclear material separation, research chemistry, and the production of plutonium-238 heat sources.[61] Reflecting the challenges of integrating a new pit production mission into a plant not designed for such activities, alongside other competing missions, PF-4 currently produces fewer than its target of 30 pits per year.[62] Many of the proposed indicators of pit production can be observed at this facility (see Figure 12).[63]

Figure 12: Satellite image of PF-4 with indicators of pit production highlighted. Image via Google Earth, taken 20 September 2017, 35.863644 N, 106.302665 W



A-90, Atomic Weapons Establishment, UK

The A-90 facility was constructed in the late 1980s at the Aldermaston site of the UK's Atomic Weapons Establishment. The site also houses other facilities related to stockpile stewardship, fundamental science, and the handling and fabrication of other non-explosive weapon components. Finished pits are transferred to another nearby site where they are mated with explosive components for final assembly into operational warheads. The A-90 facility was designed in a similar way to the PF-4 facility at Los Alamos.[64] Like PF-4, its missions include both nuclear weapon component production and broader R&D, and early in its

61 Similarly, PF-4 sits alongside a broad array of other facilities at the Los Alamos site involved in broader nuclear weapon stewardship activities, national security research, and shared civil-military scientific missions.

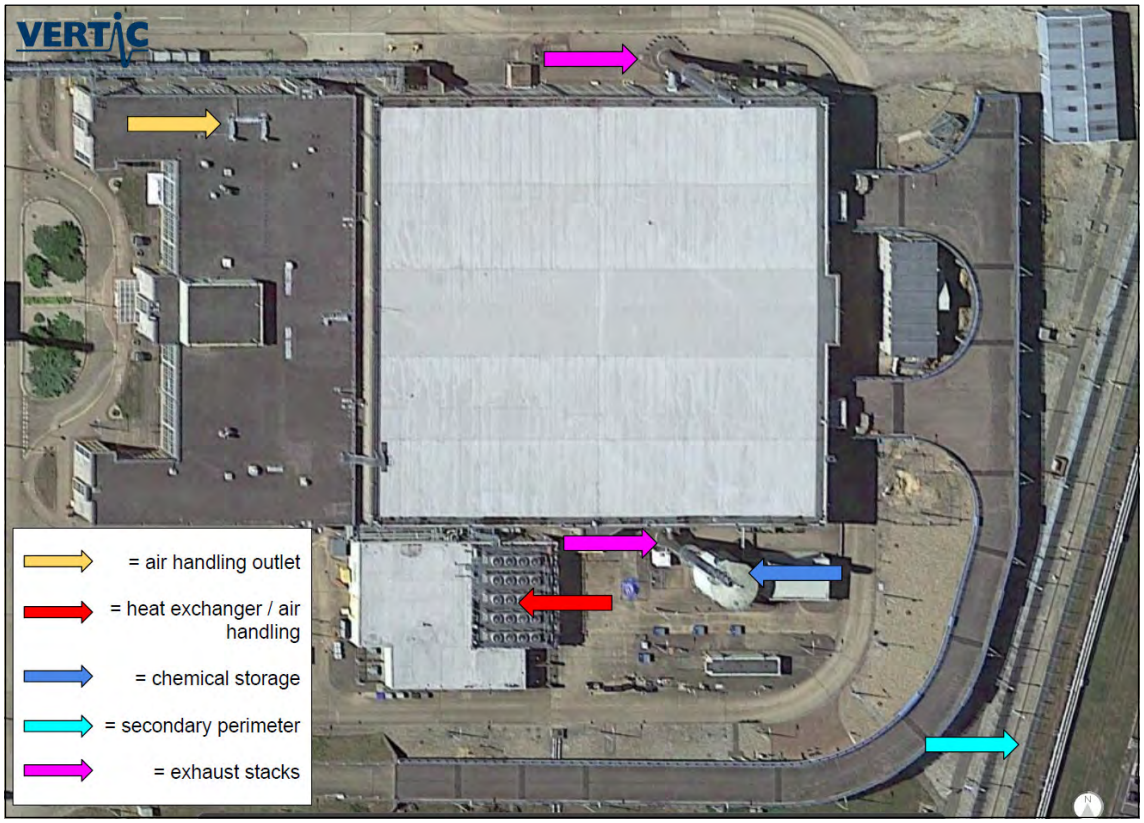
62 The Associate Laboratory Director for Weapons Production at Los Alamos stated that they dedicated 19 operational weeks to pit production in 2021, less than half of the roughly 52 weeks in a year. This increased more recently to about 33 weeks, but to reach their target capacity they would need to achieve 40 weeks. See: Spivey, '"We Have Commenced War-Reserve Pit Production"'.

63 Those indicators not highlighted in the Figure have been identified in other proximate imagery. An electrical substation is visible 2km south-east of PF-4.

64 Siegfried Hecker, 'U.S.-UK Stocktake', The Inside Story, Los Alamos National Laboratory, 22 July 1997, https://www.nuclearinfo.org/wp-content/uploads/2023/03/Sig_Hecker_US_UK_Stocktake_22_July_1997.pdf.

life it was expected to have a similarly limited capacity.[65] It is thought to carry out all the primary stages of pit production, including casting, alloying, forming, machining, welding, and inspection. Reflecting its distant relationship with the PF-4 facility, the A-90 facility presents many of the same visible indicators of pit production (see Figure 13).

Figure 13: The A90 facility with pit production indicators highlighted. Image courtesy of Google Earth, taken 20 July 2020, 51.368541 N, 1.142419 W



The Valduc site, CEA-DAM, France

Located 45km from Dijon in the east of France, the Valduc site undertakes the design, manufacturing, maintenance, and dismantling of nuclear weapon components for the French nuclear weapon programme.[66] It is not clear precisely which facilities on the site are involved in pit production, however it is possible to exclude some facilities that are known to be involved in hydrodynamic testing (the "EPURE" facility) and those storing explosive materials. Within the remaining site area there are some candidate facilities that display a number of the pit production indicators described above, including possible air-handling equipment, piping between buildings, exhaust stacks and chemical storage tanks (see Figure 14).[67]

Tatysh Facilities, Mayak Production Association, Russia

As of October 1999, pit production in Russia was believed to be taking place at the chemical and metallurgical "Plant V" / "Plant 20" in the Tatysh compound at the Mayak fissile material production site, near

65 *Ibid.*

66 See the website of the Commissariat à l'énergie atomique et aux énergies alternatives, at https://www.cea.fr/Pages/le-cea/les-centres-cea/valduc.aspx (accessed 2 December 2025).

67 These indicators were identified using higher resolution imagery which cannot be published in this report. The resolution of that imagery precluded the identification of possible heat exchangers on the candidate pit production facilities. Both primary and secondary security perimeters are visible on Figure 14.

Figure 14: Overview of the Valduc site, with an area of likely pit production and assembly buildings surrounded by a secondary security perimeter. Image courtesy of Yandex, 2017, 47.575833 N, 4.871726 E

the city of Ozersk (Chelyabinsk Oblast).[68] The plant was opened in 1949 to produce plutonium metal and to manufacture warhead components, and was later expanded to include the manufacture of HEU warhead components. It is also possible that tritium and possibly beryllium components were handled and fabricated at the site.[69] A decision was made in 2009 to close this plant and move all processing of fissile material metals to a different site (known as Seversk),[70] but this decision was reportedly cancelled a year later.[71] An additional pit production facility at the Seversk site was (as of 2002) thought to have been closed.[72] Satellite imagery of the Tatysh compound to the South West of the Mayak site reveals two areas of interest, either of which are highly likely to incorporate Plant V.[73] Both present all the indicators of pit production discussed above (see Figure 15, Figure 16, and Figure 17).

68 Oleg Bukharin et al., *New Perspectives on Russia's Ten Secret Cities* (1999), https://nuke.fas.org/norris/nuc_10019901a_208b.pdf. P.23. The Mayak site also includes Russia's first plutonium-producing reactors and spent fuel reprocessing plants. It also houses some new reactors under development and a storage site (constructed jointly with the US) for fissile materials removed from dismantled weapons considered surplus to requirements.

69 Thomas B. Cochran et al., *Making the Russian Bomb: From Stalin to Yeltsin*, 1st edn (Routledge, 2019), https://doi.org/10.4324/9780429039256. P.68.

70 'Metallurgical Plant at Mayak to Close by 2014', *IPFM Blog*, 4 May 2009, https://fissilematerials.org/blog/2009/05/metallurgical_plant_at_mayak_t.html.

71 'plutonium Processing to Remain at Mayak'.

72 'A Breakdown of Breakout: U.S. and Russian Warhead Production Capabilities | Arms Control Association', accessed 1 August 2025, https://www.armscontrol.org/act/2002-10/features/breakdown-breakout-us-and-russian-warhead-production-capabilities. The author cites a presentation by Lev Ryabev, former Director of the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) and former Deputy Minister of Atomic Energy, in March 2000. This does not rule out the presence of pit production capabilities elsewhere in Russia at facilities (like PF-4 at Los Alamos National Laboratories) currently or previously primarily oriented towards examination, surveillance, and R&D into nuclear weapons components.

73 Construction of a new buildings in Areas A and B is visible in satellite imagery from 2010-2014 (the period after the cancelled move to the Seversk site), reinforcing the likelihood that the Tatysh site retains an important plutonium handling mission. The functions of these new buildings have not been confirmed.

Figure 15: The Tatysh compound with buildings of interest highlighted. Image courtesy of Airbus and Google Earth, taken 4 June 2025, 55.664303 N, 60.686018 E

Figure 16: Area A at the Tatysh compound, with indicators of pit production and facility construction highlighted. Image courtesy of Google Earth, taken 25 May 2025, 55.666784 N, 60.681515 E

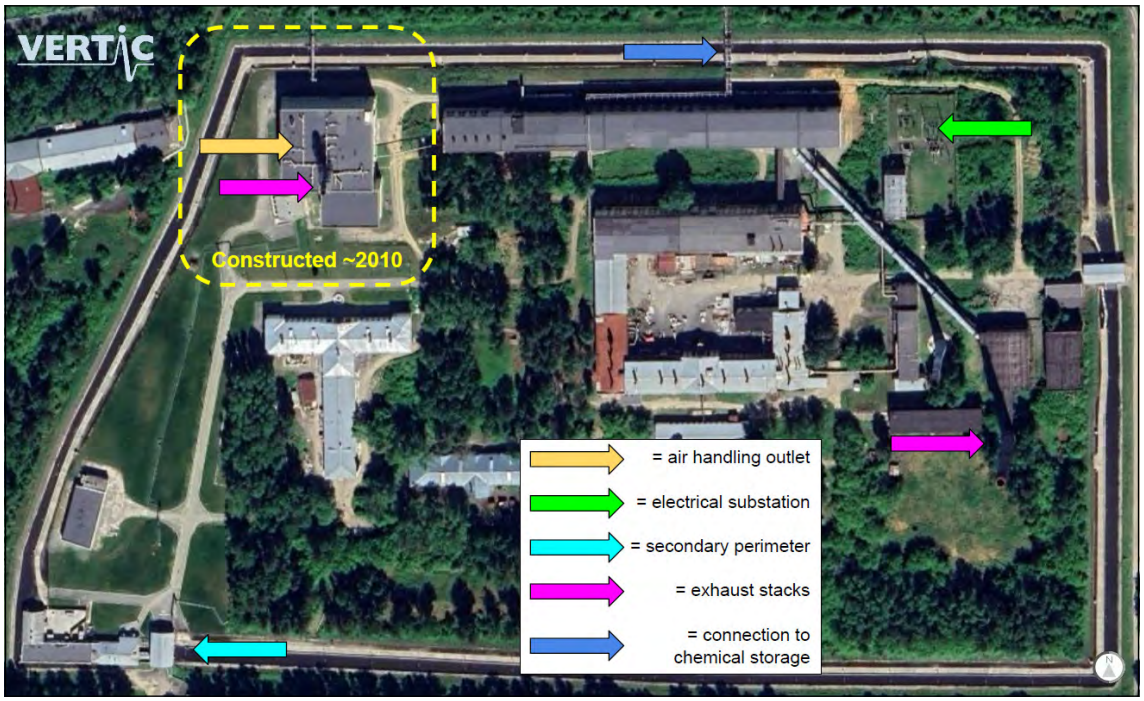
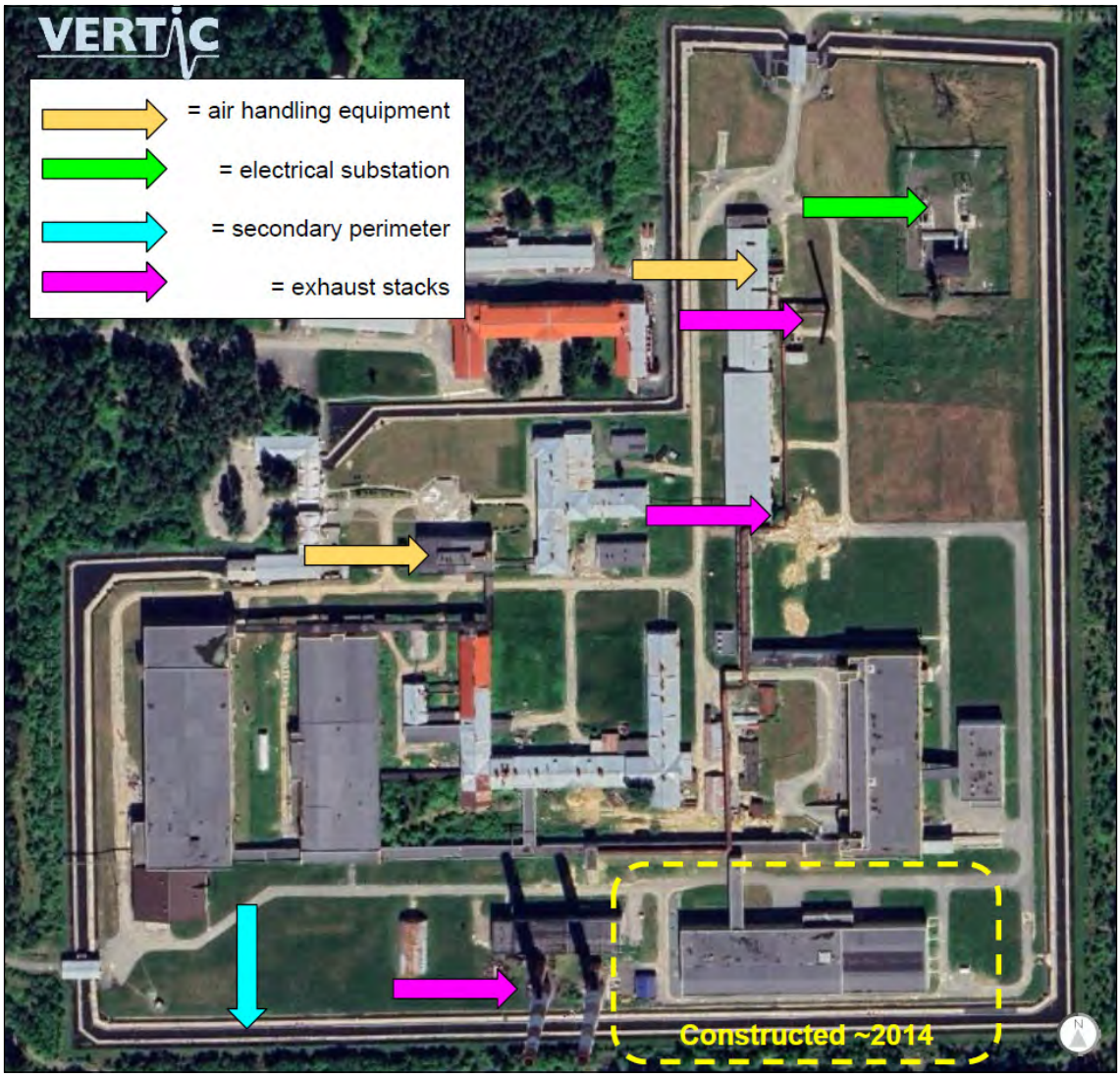


Figure 17: Area B at the Tatysh compound, with indicators of pit production and facility construction highlighted. Image courtesy of Google Earth and Airbus, taken 04/06/2025, 55.662232 N, 60.697252



Possible Special Parts Factory, Pingtong Nuclear Facility, China

The Pingtong Nuclear Facility is located in China's Sichuan province, in a narrow mountain valley roughly 75km north/northeast of Mianyang and 15km northeast of Pingtong. Declassified satellite imagery indicates that construction of the facility began no later than December 1973,[74] and its association with the China Academy of Engineering Physics led some to suggest that it is associated with the fabrication of China's nuclear weapons.[75] Satellite imagery shows the construction of a facility during 2013-2015 that has been termed a "Special Parts Factory",[76] whose features align with the indicators described above (see Figure 18) – suggesting that this facility may be used to fabricate pits.[77] There are a number of other facilities on the site, including a secured underground facility and other separately secured facilities, but their functions are unknown.

74 Renny Babiarz, *Expansion at China's Pingtong Nuclear Facility, 2002-2020*, IR 20201113-CH (AllSource Analysis, 2020), https://allsourceanalysis.com/wp-content/uploads/2025/11/VTN-20N01AD1327432-Expansion-at-Chinas-Pingtong-Nuclear-Facility.pdf.

75 Thomas C. Reed and Danny B. Stillman, *The Nuclear Express: A Political History of the Bomb and Its Proliferation*, Softcover ed (Zenith Press, 2010).

76 Babiarz, *Expansion at China's Pingtong Nuclear Facility, 2002-2020*.

77 Renny Babiarz, *Pingtong Nuclear Facility Assessment: 2021-2025*, AllSource Analysis, 2025.

Figure 18: Pingtong Special Parts Factory, with indicators of pit production highlighted. Image courtesy of Airbus, taken 11 June 2025, 32.135548 N, 104.846328 E

Assessment of possible pit production indicators

The analysis of known or suspected pit production sites demonstrates that many of the proposed indicators of pit production can be observed through satellite imagery (see Figure 19). However, as discussed above, seeking out these indicators does not guarantee that a pit production site will be successfully identified. These indicators may be presented by other nuclear and non-nuclear processes. The analysis of the Pingtong facility (Figure 18) incorporated a comparative check against other Chinese nuclear and non-nuclear facilities,[78] confirming that indicators like chemical storage tanks, exhaust stacks, and multiple security perimeters can be observed at such facilities. However, that check also confirmed that such facilities do not appear at such facilities as consistently as they do at known pit production facilities.

Nevertheless, pit production processes may not obviously display these indicators. Chemical reagents may be stored under cover and firefighting capabilities may be housed at a distance from the facilities in question.[79] Pit production may be carried out entirely underground, with only air handling and exhaust systems that connect the processes to the outside world providing a clue towards the activities within.

The indicators observed at analysed sites may reflect an approach to tackling the features of pit production that is common among those sites but is not adopted in North Korea. If North Korea is less concerned

78 Including civilian and military high explosive production facilities, rocket propellant facilities, a beryllium machining facility, nuclear fuel reprocessing facilities, and Benzene production facilities.

79 It is unlikely that the analysed facilities have no access to specialised fire-fighting services, despite no such services being observed.

Figure 19: Summary of pit production indicators at analysed sites

Possible pit production indicator	Presence of pit production indicators at analysed sites					
	US: Building 707, Rocky Flats	US: PF-4, Los Alamos	UK: A90, Aldermaston	France: CEA-DAM, Valduc	Russia: Tatysh complex, Mayak	China: Special Parts Facility, Pingtong Complex
Multiple, layered and complementary security perimeters	Yes	Yes	Yes	Yes	Yes	Yes
Heat exchangers	Yes	Yes	Yes	Unclear	None observed	Yes
Tall exhaust stacks	Yes (at Building 771)	Yes	Yes	Yes	Yes	Yes
Air handling units	Yes	Yes	Yes	Yes	Yes	Yes
Chemical tanks	Yes	Yes	Yes	Yes	Yes (Area A)	Yes
Electrical transformer substation	Yes	Yes (2km southeast)	None observed	None observed	Yes	Yes
Fire-fighting capabilities	None observed	None observed	None observed	None observed	None observed	None observed

than other nuclear-armed states about the safety of its workers and the chemical purity of its pits, it may not need to store inert gases and install air handling equipment. If North Korea relies more on secrecy and ubiquitous state policing to secure its facilities, it may not need multiple, layered and complementary security perimeters for this purpose. Assuming North Korean pit production is categorically similar to pit production in other nuclear-armed states may exacerbate the risk that candidate sites are overlooked purely because they do not look like other pit production sites.

While these indicators cannot serve as irrefutable proof of pit production, their observation in the cases described above demonstrates the value of seeking them out in North Korea – in combination with other open sources of information indicating the presence of possible nuclear or military activities at sites of interest.

Chapter 6

Where might pit production take place in North Korea?

Step 1: the production of HEU/plutonium metal

The **Yongbyon Nuclear Science Research Center** is one such site of interest. It is the heart of North Korea's nuclear enterprise, serving to convert uranium, enrich it, fabricate it into fuel, irradiate it in reactors, and reprocess the spent fuel. It is also relatively well understood, having been subject to international inspection by the International Atomic Energy Agency (IAEA) up until 2002, and having hosted a number of visits by nuclear experts from 2002 to 2010 once IAEA inspectors were ejected.

In one such visit to the reprocessing facility at the Radiochemical Laboratory (RCL) in 2004, North Korea presented the visitors with 200g of plutonium metal that appeared to have been alloyed into its delta phase, making it ready to cast and machine into plutonium pits.[80] However, they were told at the time that further weaponisation work took place off site. Visiting again in 2007, they were shown three of four plutonium laboratories located "in a two-story annex" to the RCL (see Figure 20) and they were able to characterise their possible functions and safety arrangements:

Figure 20: Yongbyon Radiochemical Laboratory (RCL) with plutonium Laboratories highlighted. Image courtesy of Google Earth and Maxar Technologies, taken 25 September 2014, 39.781425 N, 125.753236 E

80 Chaim Braun et al., *North Korean Nuclear Facilities After the Agreed Framework* (Center for International Security and Cooperation, Stanford University, 2016), https://fsi-live.s3.us-west-1.amazonaws.com/s3fs-public/khucisacfinalreport_compressed.pdf. P.42

Figure 21: A visiting delegation are shown gloveboxes used for plutonium metal production at the RCL, 2007. Image courtesy of Siegfried Hecker's Hinge Points: An Inside Look at North Korea's Nuclear Programme

> *"plutonium metal was produced, purified, and allowed […]. The glovebox labs [see Figure 21] were quite primitive, but functional, and the interiors of the boxes were remarkably clean considering they did not have sophisticated glovebox atmosphere controls. The lack of radiation monitors at the gloveboxes and general layout of the labs indicated they had only the most basic safety practices […]. The size of the labs and the equipment I saw indicated a limited throughput capacity for producing plutonium metal […]. The labs did not contain sufficiently large furnaces for casting plutonium weapon components or the requisite capabilities to machine the final parts […] these operations were conducted outside the Yongbyon complex."*[81]

The visitors were never shown equivalent facilities for producing HEU metal for weapons purposes. While North Korea may have been enriching uranium since the early 2000s, it only demonstrated its ability to do at the end of that decade when it presented a complete gas centrifuge enrichment plant to visitors on their last trip in 2010. At the time the visitors were told that the plant was configured to produce low enriched uranium for the light water reactor that was then under construction,[82] and not for producing HEU for weapon purposes. Nevertheless, it is possible that North Korea has been producing high enriched uranium for this purpose for some time at a separate site, raising the question of whether and where they are also converting it to metal for the same purpose.

Prior to the disablement actions taken by North Korea in 2007 under the Six Party Talks, it was known that North Korea could convert unenriched natural uranium Tetrafluoride (UF_4) to metal – via reduction with Magnesium as described above. It was also known that North Korea alloyed that metal with aluminium

81 Siegfried S. Hecker, *Hinge Points: An Inside Look at North Korea's Nuclear Program* (Stanford University Press, 2023). P. 177-178.

82 Braun et al., *North Korean Nuclear Facilities After the Agreed Framework*. P.23

Figure 22: Lathes previously used to machine natural uranium metal fuel rods, under storage during 2008 disablement measures. Image courtesy of Siegfried Hecker's Hinge Points: An Inside Look at North Korea's Nuclear Programme

Figure 23: Uranium metal reduction furnaces, under storage during 2008 disablement measures. Image courtesy of Siegfried Hecker's Hinge Points: An Inside Look at North Korea's Nuclear Programme

and machined that alloyed metal into fuel rods for the 5MWe gas-graphite reactor.[83] The conversion, casting, and machining equipment associated with uranium fuel fabrication were removed under the 2007 disablement measures (see Figure 22 and Figure 23) but these measures have since been reversed and North Korea can still produce unenriched natural uranium metal fuel for the 5MWe gas-graphite reactor.[84]

Having mastered the production of unenriched uranium metal, it is safe to assume that North Korea has also mastered the production of HEU metal. The primary differences between the two processes are the criticality risks presented by HEU (which can be addressed by strictly limiting batch sizes and geometries), the demands for chemical purity presented by pits, and the balance that must be struck in that regard with machineability. All these differences are easily surmountable.[85] If the new Light Water Reactor is indeed fuelled with low enriched uranium, it is also safe to assume that North Korea has mastered the chemistry behind reducing enriched UF6 to UF4 – a precursor both for UO_2 reactor fuel and uranium metal.[86]

Drawing on the accounts of the visitors to Yongbyon between 2002 and 2010, and the likely uranium conversion activities taking place there to support North Korea's reactor programme, it is reasonable to assume that the first stage of pit production – the production of plutonium/HEU metals – takes place today to some extent at the Yongbyon facility.[87]

Steps 2-6: from casting to final inspection and certification

The accounts from visitors to Yongbyon between 2002 and 2010 suggest that is unlikely that the remaining steps of pit production were happening at Yongbyon at that time. North Korea's nuclear weapon programme was only finding its feet in this period (with two tests conducted in 2006 and 2009), and international inspectors were often present at Yongbyon but found no evidence of past or current pit production.

It is possible that North Korea established other aspects of pit production at Yongbyon after this period. Doing so could take advantage of the various security, electrical, chemical, air handling and transport infrastructures already in place at Yongbyon and allow the efficient processing of any wastes arising from pit production at the RCL. There has been significant refurbishment and redevelopment of facilities around the Yongbyon complex that could in theory incorporate aspects of pit production. This includes the refurbishment in late 2015/early 2016 of the building in the fuel cycle area that prior to 2007 was used to cast and machine unenriched uranium metal to fuel the 5MWe graphite-moderated reactor at Yongbyon. However, the benefits of introducing these steps at Yongbyon may also be outweighed by the fear that in co-locating such a sensitive military capability alongside many other nuclear capabilities at a site subject to so much external scrutiny they would be putting 'too many eggs in one basket'.

A search of the Yongbyon site for the pit production indicators described above through contemporary open source satellite imagery does not paint a clear picture of pit production. Satellite imagery of the main reactor and administrative area reveals the security and heat management arrangements for the two reactors, but no other buildings in the reactor area demonstrate indicators of pit production. Imagery

83 Albright and Institute for Science and International Security, *Solving the North Korean Nuclear Puzzle*. P.144

84 Braun et al., *North Korean Nuclear Facilities After the Agreed Framework*. Pp-32-33. It is assumed by many that this takes place somewhere in Yongbyon.

85 Criticality risks can be addressed by strictly limiting batch sizes and geometries (perhaps demanding different furnaces to those used in natural uranium fuel production). Chemical purity could be improved by suppressing undesirable chemical reactions (tightening vacuums and adjusting equipment coatings) or improving the reduction agent. A balance between purity and machineability could be struck by adjusting the alloying process away from the aluminium used for natural uranium fuel production.

86 Braun et al., *North Korean Nuclear Facilities After the Agreed Framework*. P.33. It is also assumed that this also takes place in Yongbyon.

87 This does not imply that Yongbyon is the only place in North Korea that produces alloyed plutonium/HEU metals for weapons purposes.

of the fuel cycle area towards the south reveals exhaust stacks, chemical storage tanks, and possible air handling equipment present at different buildings, but these may be explained by other fuel fabrication and enrichment activities, and no one building presents significant indicators of pit production. Imagery of the RCL area between the reactor and fuel cycle areas demonstrates the overlap between indicators of spent fuel reprocessing and possible pit production, with additional perimeter security, numerous exhaust stacks, heat exchangers, and chemical storage tanks all visible. However, no air handling arrangements were observed on available imagery and there has been little obvious major construction or external refurbishment to suggest that a new mission has been introduced to the area. It is therefore unlikely that the pits for North Korea's nuclear arsenal are currently produced at Yongbyon.[88] It is possible that a pit production capability has been established at Yongbyon, but if so, it is unlikely to be the primary source of pits for the arsenal, which is likely somewhere else.[89]

Another site of interest in this regard is the **Yongdoktong site**, which is located approximately 46km northwest of the Yongbyon Nuclear Research Center. According to an unnamed senior US intelligence official, this facility is "a suspected North Korean nuclear weapons storage facility."[90] Others have described the site as "a critical component in the research, development, test, and evaluation […] of North Korea's nuclear warheads."[91] In particular, it is likely involved in producing and storing the high explosives that detonate a nuclear warhead pit.[92] It is reasonable to question whether the site is also involved in the fabrication of pits for North Korea's nuclear warheads. However, a search through available satellite imagery of the Yongdoktong site for indications of pit production suggests that is unlikely. While multiple buildings around the site are encircled by enhanced secondary security perimeters, there are no indications of hot or radioactive work taking place there. No exhaust stacks, air handling arrangements, heat exchangers, or chemical storage tanks were observed. However, satellite imagery does raise the possibility that there are a number of underground facilities on the site that could conceal pit production work.[93] It is considered more likely that if nuclear warheads are stored at this site, then their pits are fabricated elsewhere.[94]

Another site of interest for possible pit production is the **Wollo-ri** site. It is believed that parts of the US intelligence community have assessed that this site is involved in the manufacture of nuclear warheads, and in particular "the machining of fissile material pits for use in nuclear weapons."[95] However, available satellite imagery of the site does not obviously demonstrate any of the pit production indicators described above and it is considered unlikely that pit production takes place at Wollo-ri. As with Yongdoktong, there are indicators of possible underground facilities at the site that may conceal pit production work and it is still possible that such work is concealed at this site.[96]

88 Only one of the analysed pit production facilities in other nuclear-armed states was co-located with other nuclear fuel cycle facilities: the Tatysh complex at Mayak. For the majority of its lifetime the capability housed there was not unique in Russia, who could call on other pit production facilities that are now thought to be inactive.

89 'North Korea's Kim Jong-Un Agrees to Shut Missile Site', *BBC News*, 19 September 2018, https://www.bbc.co.uk/news/world-asia-45569924.

90 Zachary Cohen and Atwood, 'New Satellite Images Reveal North Korea Took Recent Steps to Conceal Nuclear Weapons Site', News, *CNN Politics*, 2 March 2021, https://edition.cnn.com/2021/03/02/politics/north-korea-satellite-images-yongdoktong-nuclear-site.

91 Joseph S. Bermudez Jr et al., 'Yongdok-Tong Nuclear High Explosive Test Facility: Part 1', Center for Strategic and International Studies, *Beyond Parallel*, 22 April 2025, https://beyondparallel.csis.org/yongdok-tong-nuclear-high-explosive-test-facility-part-1/.

92 Elin Bergner and Laderman, *High-Explosives Testing In Nuclear Weapons Programmes*, ONN, 2026.

93 *Ibid*. While no air handling or heat exchange arrangements have been observed around the sites of possible underground facilities, these may be present but not visible through satellite imagery.

94 This would match the approach adopted by the US and the UK.

95 Ankit Panda, 'Wollo-Ri: Nuclear Warhead Storage Area, Manufacturing Site, or Military Academy?', *NKPro*, 10 July 2020, https://www.nknews.org/pro/wollo-ri-nuclear-warhead-storage-area-manufacturing-site-or-military-academy/.

96 Jeffrey Lewis, 'Wollo-Ri Nuclear Facility', *Arms Control Wonk*, 8 July 2020, https://www.armscontrolwonk.com/archive/1209644/wollo-ri-nuclear-facility/.

The search for North Korea's pit production can extend beyond the three sites of interest considered above. There are potentially many sites of interest that may warrant examining for the indicators described above. The search could be prioritised first by those sites thought to be associated with the North Korean military and its Munitions Industry Department and Nuclear Weapons Institute (rather than those associated with the Ministry of Atomic Energy such as Yongbyon), and then by those that demonstrate the highest levels of visible security arrangements – such as suspected underground facilities.

However, expanding the search for the indicators described above may be making a category error. The indicators rest on an assumption that North Korea addresses the hazards and issues presented by pit production with the same high standards and infrastructure as other nuclear armed states. This may not be the case. North Korea's weapon designs may place few demands for chemical purity, precision engineering, and efficient use of material. Its approach to security may rely more on secrecy than overt physical protection measures. It may be willing to absorb losses of personnel and equipment from unsafe practices. In this case, there may be few visible indicators of pit production to observe from satellite imagery.

If this is the case, it may not always be so. North Korea may not be able to satisfy its ambitions for the scale of its nuclear arsenal with inefficient use of scarce fissile materials, or its ambitions for warhead sophistication with imprecise and impure pit production processes. If the standards to which its pits must be produced get tighter, it may be less willing to absorb losses caused by unsafe practices. The history of the US Rocky Flats site demonstrates that new pit designs (and/or damage caused by safety failures) may demand the construction of new pit production buildings.[97] However, it also demonstrates that buildings can be refurbished and upgraded from within without many obvious external indicators.[98] An evolution in North Korea's approach to pit production may demand new or refurbished facilities that display more observable indicators than more small-scale approaches to pit production. Such an evolution may be presaged by public statements by the North Korean regime regarding new, enhanced, or improved nuclear warhead designs and by any return to nuclear explosive testing to validate such designs. Pit production activities may also be relocated by choice (perhaps to place them closer to fissile material production or weapon fabrication activities) or by necessity (perhaps due to fires or other accidents).

97 Building 776/777 (the predecessor to Building 707 discussed above) was constructed in response to a new pit design that demanded tighter production standards and a higher throughput. A plutonium fire in the building eventually forced the unanticipated transfer of some of its activities to its successor Building 707. 'Building 707'.

98 Following its construction, Building 776/777 was upgraded and altered a number of times without major changes to its footprint.

Chapter 7

What equipment and materials are used in pit production and how is their trade controlled?

The United Nations has established trade embargoes to prevent the transfer of equipment, technology and materials to North Korea that might support its nuclear weapon programme, including its pit production capabilities. UN Security Council Resolution 1718 (2006) provides the foundation for this embargo by prohibiting UN Member States from "the direct or indirect supply, sale or transfer to the DPRK, through their territories or by their nationals, or using their flag vessels or aircraft" of certain items, materials, equipment, goods and technology that might contribute to North Korea's nuclear weapon programme. The scope of these prohibitions has steadily grown from a foundation of all items on the Nuclear Suppliers Group (NSG) Trigger List and Dual-Use List to include a much broader array of items that are relevant to pit production, including:[99]

- Fluorine and electrolytic cells for fluorine production, which could support the fluorination of plutonium for its subsequent reduction to metal;[100]
- Especially designed or prepared systems for the production of uranium and plutonium metals;[101]
- Glove boxes, which could be used throughout the pit production process to control radioactive contamination and provide controlled atmospheres;[102]
- Controlled atmosphere (vacuum or inert gas) metallurgical melting and casting furnaces of certain powers and capacities;[103]
- Crucibles which are either made from or coated in materials that are unreactive to uranium and plutonium (such as tantalum, yttrium or magnesium oxide);[104]
- Reduction agents, such as calcium;[105]
- Isostatic presses, including dies, mould, and controls for such presses;[106]
- Machining tools of certain capabilities and accuracies, including those for turning (lathing), milling, and grinding;[107]
- Metal inert gas welders;[108]
- Coating and plating equipment, including for electroplating and chemical vapour deposition;[109] and
- Dimensional inspection machines, systems, or instruments of certain capabilities and accuracies.[110]

99 See UN Security Council Resolution 2087 (2013), paragraph 5(b).
100 S/2017/822 Annex and INFCIRC/254/Rev.12/Part 2, sections 3.B.1.
101 INFCIRC/254/Rev.14/Part 1, sections 7.1.6 and 7.2.2.
102 S/2017/822 Annex.
103 INFCIRC/254/Rev.12/Part 2, sections 1.B.4. and 1.B.7.
104 INFCIRC/254/Rev.12/Part 2, section 2.A.1.
105 INFCIRC/254/Rev.12/Part 2, section 2.C.5.
106 S/2017/822 Annex and INFCIRC/254/Rev.12/Part 2, section 1.B.5.
107 INFCIRC/254/Rev.12/Part 2, section 1.B.2 and S/2017/829 Annex.
108 S/2017/822 Annex.
109 Ibid., and S/2017/829 Annex.
110 INFCIRC/254/Rev.12/Part 2, section 1.B.3. and S/2017/829.

The impact of these controls on North Korea's pit production is limited by their specificity, the time-frames of their adoption, and the extent to which they are adopted and enforced. Many of the relevant items in the NSG Dual Use List are captured only when their capabilities and accuracies exceed a certain threshold. For example, only lathes with accuracies at or below 1 micrometre (one thousandth of a millimetre) are captured by the NSG Dual Use List.[111] Rudimentary pit production is still possible with equipment that falls far short of these standards. The scope of these restrictions was subsequently expanded both with more explicit general restrictions passed by the Council,[112] and with a binding "catch-all" provision that requires States to prohibit the transfer of *any* item that to a person that may be linked to North Korea's nuclear programme.[113] However, many transfers that would otherwise have been prohibited by these expansions may have been made prior to their implementation.[114]

Despite expanding trade controls, a combination of North Korean evasion techniques (such as the use of front companies in intermediary states) and weak trade controls in intermediary states have likely allowed North Korea to continue acquiring equipment, technology and materials related to pit production.[115] There is also evidence indicating that domestic North Korean entities have developed indigenous equipment and technologies relevant to pit production, including computer-numerically controlled (CNC) machine tools such as lathes and mills (see Figure 24).[116]

The limitations of international trade controls in constraining North Korea's pit production are therefore severe. The equipment and technologies required to produce pits is relatively less sophisticated than those required for other nuclear-related

Figure 24: A pamphlet advertising different CNC lathes marketed by a North Korean entity[117]

111 In many cases these thresholds are set according to the standards required by other nuclear activities unrelated to pit production. For example, the accuracy standards for machining equipment may relate more to the fabrication of uranium enrichment centrifuges than the production of pits.

112 Such as on *all* isostatic presses (S/2017/822), not just those with certain pressures and capacities (INFCIRC/254/Rev.12/Part 2).

113 S/RES/2087 (2013) article 9

114 For example, data from the Japan External Trade Organization (JETRO) demonstrates that Japan exported hundreds of thousands of metric tons of metalworking machine tools to North Korea, including lathes and milling machines, from 1964 to 2006. See Jenny Moss, 'Machinery of Juche: How Japanese Tech Catalyzed North Korean Industry', NK Pro, 11 September 2025, https://www.nknews.org/pro/machinery-of-juche-how-japanese-tech-catalyzed-north-korean-industry/?t=1757950998.

115 Examples of North Korean trade control evasion techniques can be found in the reports of the Panel of Experts established pursuant to UN Security Council Resolution 1874 (2009). It is otherwise challenging to identify specific examples of illicit trade in equipment related to pit production via trade data reported to the UN Comtrade Database. The categories in that Database do not easily align with the definitions of restricted items. For example, while the export of all metal inert gas welders to North Korea is prohibited via S/2017/822, reportable codes under HS Parent Code 8515 (Electric soldering, brazing, welding machines and apparatus) do not distinguish inert gas welders from other welders.

116 See for example the discussion of Ryonha Machinery Corporation and its advertised products in Annex XXI of the 2013 Report of the Panel of Experts established pursuant to resolution 1874 (2009).

117 *Ibid*. While the machines advertised here may not provide or be compatible with the controlled atmosphere environments required when machining plutonium and uranium, it indicates that North Korea may be able to produce machine tools that can be used in such controlled atmosphere environments.

activities, such as the manufacturing of uranium enrichment centrifuges. Despite the strengthening of international trade controls to cast the net more broadly over pit production equipment and technology, the challenges of implementing, monitoring, and enforcing these restrictions remain. The weakness of the constraints that have been put on North Korea's pit production capabilities are perhaps best demonstrated by the six nuclear weapon tests that North Korea has been able to carry out, and by the claims it has made regarding the readiness and reliability of its nuclear arsenal.

Nevertheless, if North Korea seeks to significantly improve the design of its nuclear weapons this may place new demands on its pit production capabilities that cannot be met with the equipment and materials it has at its disposal. Supporting and strengthening the implementation of international trade controls on equipment and materials related to pit production could therefore constrain the evolution of North Korea's nuclear arsenal.

Chapter 8

Can pit production be verifiably and irreversibly disabled?

While North Korea's nuclear weapon programme (and possibly its pit production capability) continues to grow, UN Security Council resolutions still call on North Korea to abandon its nuclear programmeme in a complete, verifiable, and irreversible manner. Efforts to refine precisely what this would involve have ebbed and flowed over time, responding to the perceived likelihood of any concessions by North Korea in this regard. The focus of these efforts has also evolved in line with North Korea's nuclear weapon programme, with discussion of disabling specific weaponization capabilities receding further into the background as more immediate problems (such as North Korea's nuclear weapon tests and the number of deployed weapons) occupy the foreground. Nevertheless, any route to *complete*, verifiable, and irreversible disarmament of North Korea must eventually address its pit production capability, and it is worth considering how to do this.

In theory, addressing North Korea's pit production capability in this manner would require it to declare all the sites that house this capability and provide access to international inspectors who can observe the disablement of that capability. This could involve taking an inventory of key equipment (such as machining lathes, presses and their dies, and furnaces), applying unique identifiers to that equipment, and retaining that equipment under secure monitored storage. Two practical examples demonstrate how this could happen: the verification of South Africa's nuclear disarmament and the verified dismantlement of Iraq's nascent nuclear weapon programme.

South Africa produced six nuclear weapons but voluntarily dismantled them and disarmed itself in the early 1990s. It subsequently invited inspectors from the IAEA to confirm its disarmament. As part of this confirmation, the IAEA were provided with a list of all the equipment that formed part of the nuclear weapons programme, including the machining and milling equipment used to make the HEU cores of their weapons. The IAEA tagged this equipment with unique identifiers and required South Africa to keep the IAEA informed of their location once they were transferred into peaceful uses within the civilian industry in South Africa.[118] For almost a decade the IAEA inspectors regularly visited these civilian locations to confirm the equipment was still used for peaceful purposes, until South Africa adopted an Additional Protocol to its safeguards agreement with the IAEA in 2002.[119] This equipment is now no longer being routinely and regularly monitored by the IAEA.

Prior to 1991, Iraq was pursuing capabilities to produce, cast and machine fissile material metals as part of its covert nuclear weapon programme. According to the IAEA's reporting to the UN Security Council on the verified dismantlement of Iraq's nuclear programme following the Gulf War, Iraq had successfully

118 Neville Whiting and Nic von Wielligh, 'Chapter 4: Implementation of Safeguards in South Africa: An Assessment of the Preparedness, Implementation, Issues, Incidents and Events Associated with the Two Phases of Verifying the Correctness and the Completeness of South Africa's Declared Nuclear Inventory and Ensuring the Irreversibility of the Programmes' Dismantlement', in *From Swords to Ploughshares: The Dismantlement of the South African Nuclear Weapons Programme* (VERTIC, n.d.). P.85.

119 Johann Kellerman, 'Chapter 10: Towards an Understanding of "irreversibility" in the Context of Nuclear Disarmament', in *From Swords to Ploughshares: The Dismantlement of the South African Nuclear Weapons Programme* (VERTIC, n.d.). P.148. The broader information and access provided to the IAEA by the Additional Protocol may have convinced the IAEA that it was no longer necessary to monitor the machining and milling equipment.

experimented with uranium metal casting, including into hemispheres.[120] It was preparing to convert highly enriched uranium research reactor fuel into metal.[121] Iraq was also constructing a uranium metal plant dedicated to the production and processing of uranium metals that had a "sophisticated air handling system" and was anticipated to produce 20kg of high purity uranium metal per day.[122] It was also constructing another facility that would have accommodated equipment for machining uranium metals.[123] It had also successfully carried out laboratory-scale experiments for producing plutonium metals but as of 1991 had not progressed beyond those experiments.[124] All related buildings and production equipment was either destroyed, removed or rendered harmless under IAEA supervision. Cold and hot isostatic presses, furnaces, machine tools and vacuum pumps were destroyed by flame cutting and demolition with explosives.[125] A coordinate measuring machine (that could have been used to inspect finished weapon components) was removed by the IAEA. Other machine tools were examined to determine whether they should be subject to ongoing monitoring and verification, and if so, they were inventoried, tagged, sealed, and move to locations where they were kept under surveillance.[126]

Both cases demonstrate that equipment relevant to pit production has been verifiably and irreversibly disabled under international supervision in the past, and similar techniques could be deployed in North Korea in the future. However, the cases also reveal a limitation: much of the equipment is dual use and ubiquitous in civilian industries, raising the risks that disabled equipment once used in a nuclear weapon programme could be easily replaced with similar equipment from elsewhere. The South African nuclear weapon-related machine tools placed under ongoing monitoring were very unsophisticated, and more sophisticated tools remained uncontrolled – including alongside those that were controlled in the same facility. In Iraq, the IAEA spent a significant amount of time evaluating more than 50 CNC machine tools at a conventional munitions plant to determine whether or not they should be subject to ongoing monitoring and verification, only to find that they were not of sufficient quality to be worth monitoring.[127]

The experience of the IAEA in South Africa and Iraq demonstrates that declared equipment relevant to pit production can be destroyed or otherwise put beyond further use in a nuclear weapon programme. However, that experience also demonstrates the challenges of ensuring all relevant equipment has been addressed and that no other equipment is acquired to replace those that have been disabled. This reinforces the emphasis placed by the current nuclear non-proliferation regime, and particularly the system of IAEA safeguards, on the control of fissile material – which is harder to covertly acquire than pit production equipment.

Nevertheless, identifying and disabling North Korean pit production facilities can still serve to build confidence in the short term that North Korea is verifiably disarming. Locating and accessing these facilities would also play a valuable role in establishing an inventory of North Korea's weapons-usable fissile materials which may pass through, be stored alongside, or held up within pit production processes. This in turn would support longer-term assurance that all fissile materials are kept in peaceful uses and are not being diverted towards any covertly reconstituted pit production process.

120 'Fourth Consolidated Report of the Director General of the International Atomic Energy Agency under Paragraph 16 of Security Council Resolution 1051 (1996)', United Nations Security Council, 8 October 1997, https://nsarchive2.gwu.edu/NSAEBB/NSAEBB80/wmd07.pdf., p.30.

121 *Ibid.*, p.50.

122 *Ibid.*, pgs.30, 55.

123 *Ibid.*

124 *Ibid.*, p.54.

125 *Ibid.*, p.69.

126 *Ibid.*, pgs.30, 86.

127 Whiting and von Wielligh, 'Chapter 4: Implementation of Safeguards in South Africa: An Assessment of the Preparedness, Implementation, Issues, Incidents and Events Associated with the Two Phases of Verifying the Correctness and the Completeness of South Africa's Declared Nuclear Inventory and Ensuring the Irreversibility of the Programmes' Dismantlement', 4.P.89

Chapter 9

Conclusions

The pit production process presents hazards and issues relating to radioactivity, criticality, security, heat management, and chemical purity. The way these hazards and issues are addressed may present indicators of possible pit production that are observable through open source satellite imagery. These indicators are:[128]

- Multiple, layered and complementary perimeters, including secondary perimeters around individual buildings, with strict access control;
- Electrical transformers or switchyards;
- Heat exchangers, including cooling towers and fan-driven ventilation systems;
- Tall exhaust stacks for venting off gases with chemical or radiological hazards;
- Air handling units to provide negative air pressure for contamination control, particularly with High Efficiency Particulate Air (HEPA) filter systems; and
- Chemical tanks suitable for storing inert gases, such as Argon and Nitrogen.

These indicators are largely present at a sample of known or suspected pit production facilities in the US, the UK, France, Russia and China. However, they are not consistently or convincingly present at three North Korean sites of nuclear interest.[129] It is likely that the first step of pit production (the production of HEU/plutonium metals) is carried out at the Yongbyon Nuclear Scientific Research Center, but it is unlikely that the remaining steps are carried out there. If all the steps of pit production are carried out at Yongbyon (or the other two sites of nuclear interest) then it is carried out at such a small, unsophisticated scale that does not present the indicators described above.

Further satellite imagery analysis of other sites in North Korea may reveal a convincing pattern of indicators towards a possible pit production facility. Expanding the search to include sites thought to be associated with the North Korean military and its Munitions Industry Department may be a priority in this regard. However, North Korean pit production may not currently be carried out in a way that generates this pattern of indicators. It may be carried out in a small, unsafe and unsophisticated manner and it may be carried out underground or across multiple locations. Both approaches present few observable indicators.

If North Korean pit production processes present few observable indicators today, they may present more obvious indicators in the future. North Korea may soon follow the US, the UK, France, Russia and China into building more advanced (and more obvious) pit production facilities. The promise of more efficient, sophisticated, and advanced nuclear weapon pits (and a safer workforce) may come to outweigh the costs to security of moving away from small secret facilities. The web of trade restrictions woven by UN Security Council Resolutions, domestic trade control arrangements, and the Nuclear Suppliers Group are meant to prevent North Korea from accessing the equipment, technology and materials to support its pit production capability. However, the effect of this web is limited by the extent and timeliness of its implementation by states, and by North Korea's ability to circumvent its restrictions. Nevertheless, supporting

128 On-site emergency fire-fighting capabilities may also indicate pit production but are less visible through open source satellite imagery.

129 These are Yongbyon, Yongdoktong, and Wollo-Ri.

and strengthening the implementation of trade controls on equipment and materials relevant to pit production could constrain the evolution of North Korea's nuclear weapon design, keeping it at the rudimentary level it is currently assumed to be at.

This raises the question of whether and how North Korea's approach to pit production may evolve in the future. The history of other nuclear weapon programmes may be illuminating in this regard. The facilities that underpin nuclear weapon programmes have evolved as the ambitions and risk tolerances of those operating them have evolved. States that find themselves unable to deliver certain nuclear warhead goals (such as production throughput) or certain nuclear warhead capabilities (such as tritium gas boosting or fire-resistant pits) at old facilities may have produced new facilities. If these evolutionary phases can be delineated and characterized, any sign of evolution from North Korea – either through public statements or through further testing – could direct a search towards new indicators of construction or refurbishment.

It is unlikely that North Korea would unilaterally reveal the location of its pit production capability, and the prospect of disabling that capability in a complete, verifiable, and irreversible manner is distant. If it is located and incorporated into any agreement in that regard, there is historical precedent for the verifiable destruction, disablement, and long-term monitoring of the equipment that is relevant for pit production. If this precedent were to resurface in North Korea, its sustainability would depend on stronger implementation of international trade controls on such equipment. In the absence of that, the identification and disablement of North Korean pit production equipment could still build confidence in North Korea's nuclear disarmament in the short term, as an interim measure until credible control could be exerted on the inventory of fissile material that could be fed into reemerging pit production capability.

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