Uncovering China's Nuclear Warhead Production Cycle

～ FY 2025 Interim Research Report ～

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National Security and Japan-U.S. Program, The Sasakawa Peace Foundation

Study Group of the International Trends in the Nuclear Warhead Production Cycle

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Preface

The Significance of Elucidating China's Nuclear Warhead Production Cycle

This report presents the findings of the "Study Group of the International Trends in the Nuclear Warhead Production Cycle" (chaired by Yu Koizumi), established under the "Nuclear Warhead Production Cycle Study" conducted by The Sasakawa Peace Foundation's National Security and Japan-U.S. Program in fiscal year 2025.

This study was initiated with the aim of understanding China's nuclear strategy and deriving implications for Japan's security policy, through the elucidation and analysis of China's nuclear warhead production cycle.

Since the 2010s, China has been rapidly strengthening its nuclear capabilities, increasing not only the missiles, bombers, and nuclear submarines that serve as delivery vehicles for nuclear weapons, but also its stockpile of nuclear warheads. The number of deployed warheads is believed to have doubled over the past decade (with 600 deployed as of 2025),[1] and some past estimates have suggested it could reach 1,000 by 2030.[2] This represents nearly two-thirds of the deployed strategic nuclear warheads (1,550 units) for the United States (hereafter, "the U.S.") and Russia stipulated under the New Strategic Arms Reduction Treaty (New START: expired in February 2026). It will significantly impact the extended nuclear deterrence provided by the U.S., which forms the foundation of Japan's security policy.

However, much remains unknown about China's nuclear warhead production capabilities. In the case of the U.S. and Russia, a certain degree of information is publicly available, and knowledge has been accumulated regarding the entire cycle from the production of fissile materials to warheads, testing, loading onto means of transportation, and destruction after decommissioning (nuclear warhead production cycle). In contrast, the level of information disclosure regarding China's nuclear capabilities is very low, making it difficult to foresee the pace of China's nuclear capabilities buildup in the future. This fact creates an obstacle when formulating Japan's security strategy.

To overcome this situation, this study aimed to develop a methodology for elucidating the nuclear warhead production cycle. To achieve this aim, it is necessary to mobilize a wide range of fields, including military and security research, nuclear physics, and knowledge of uranium enrichment and reprocessing, which are essential for the production of nuclear materials, beyond the conventional framework of research on China. Therefore, we brought together 6 experts with expertise in these fields (see below) to establish the Study Group of the International Trends in the Nuclear Warhead Production Cycle and attempted to integrate their knowledge.

Specifically, with the cooperation of group members familiar with Chinese, we deciphered the official documents of the Chinese government and company websites. We also compared these with the nuclear warhead production cycles of the U.S. and Russia, striving to elucidate the facilities and regions where each cycle—from the production of nuclear material to its weaponization—is being carried out in China. We also used high-resolution satellite images, such as Vantor, to assess the actual state of these activities. In the final chapter of the report, based on the above analysis, we also examine the relationship between China's nuclear warhead production cycle and its nuclear strategy, future trends concerning China's nuclear capabilities, and the implications for

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[1] STOCKHOLM INTERNATIONAL PEACE RESEARCH INSTITUTE (SIPRI), "*Yearbook 2025,*" pp. 179-180.

[2] U.S Department of Defense, "*MILITARY AND SECURITY DEVELOPMENTS INVOLVING THE PEOPLE'S REPUBLIC OF CHINA 2024,*" Dec 2024, p. 101.

security in the East Asian region and Japan.

With the release of this report, we expect to obtain feedback from various quarters in the future, including areas that are still in the hypothetical stage, to establish a method for understanding, based on its nuclear warhead production cycle, the nuclear capability of the country in question, the speed of its buildup, and even the intent of its nuclear strategy. In addition, the above approach can be applied not only to China, but also to the nuclear capability assessment of states that are of security concern to Japan, such as North Korea.

In advancing our study with new perspectives and methodologies, we received generous cooperation from other research institutions and experts, including advice, materials, and satellite imagery. We recognize this as stemming from a shared interest in elucidating the nuclear warhead production cycle in China, which remains largely unexplained. We would like to take this opportunity to express our deepest gratitude for these kindnesses.

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Note: This report is the result of a study conducted as one of the independent activities under the National Security and Japan-U.S. Program of The Sasakawa Peace Foundation, and does not represent the views of the individual experts mentioned above.

Introductory Chapter Findings and Structure of the Report

Key Findings and Future Outlook of the Report

The key findings presented in this report are as follows.

- The production of nuclear warheads in China began amid the superpower rivalry of the Cold War. Initially, technological cooperation was provided by Soviet Union, but later, China developed its own technology, and after the Cold War, it has been actively stealing technology from the U.S. through cyber attacks.
- Currently, China National Nuclear Corporation (CNNC) plays a central role in the production of nuclear warheads in China. Many of its related facilities appear to be concentrated in Sichuan Province.
- Plutonium inventories in China, which constitute a bottleneck for nuclear weapons production, were significantly smaller compared to those of the U.S. and Russia, and nuclear weapons production had once been halted by the end of the Cold War. Therefore, given China's known plutonium inventory to date, its expansion of nuclear capabilities is likely to reach a ceiling at some point.
- On the other hand, China has not reported its inventory of fissile material to the International Atomic Energy Agency (IAEA) since 2017. Furthermore, since shortly before that, China has been working to enhance its plutonium production capacity, and the full-scale operation of its fast breeder reactors (FBRs) is also expected in the future. If political risks are disregarded, it would become possible to enhance nuclear warheads using plutonium extracted from these civilian production facilities—approximately 100 warheads per year during the 2020s, and approximately 200 warheads per year from the 2030s onward.
- The production capacity for other fissile materials necessary for constructing nuclear warheads, such as uranium and tritium, is also believed to exist to a sufficient degree to support the expansion of nuclear warheads.
- The above enables the strengthening of nuclear capabilities that would make a certain second strike (retaliation) against the U.S. and Russia possible. Considering its nuclear warhead production capacity, China could deploy 1000 operational nuclear warheads by around 2030, and increase this number to approximately 2000 by around 2035.
- Particularly over the next two years, the pace of China's nuclear warhead buildup will be crucial. If the number of nuclear warheads continues to increase, it strongly suggests the military conversion of civilian technologies, such as FBRs, or heavy water reactors.

Structure of the Report

Following the awareness of the issues described in the Preface, this report is divided into three chapters for analysis and discussion.

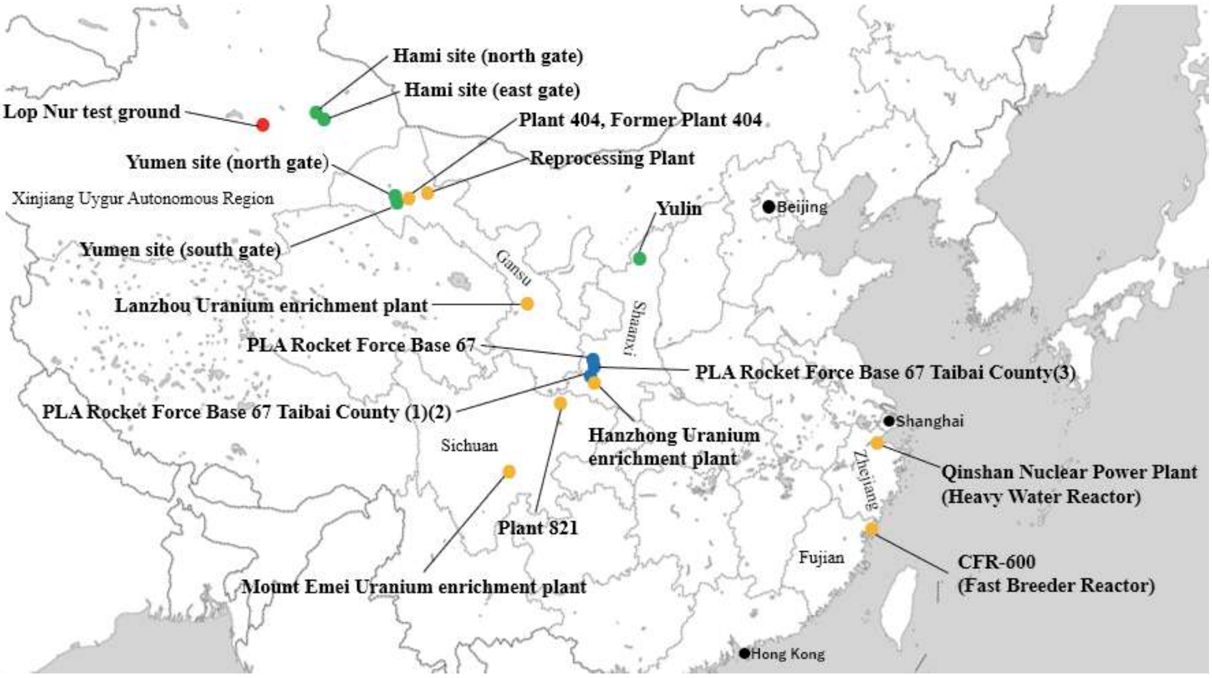
Chapter 1, *What Is the Nuclear Warhead Production Cycle?*, focuses primarily on understanding what materials and technologies are needed to produce a nuclear warhead in the first place, and what processes they undergo in the course of completing a nuclear warhead. Since the nuclear warhead production cycles of both the U.S. and Russia, two countries that pioneered nuclear weapons development, have been clarified to some extent after the Cold War, the cycles of these two countries are analyzed to prepare for elucidating the nuclear warhead production cycles of China in the next chapter.

Chapter 2, ***China's Nuclear Warhead Production Cycle: What We Know and What We Don't,*** provides an overview of China's nuclear development history and attempts to elucidate its nuclear material production and nuclear warhead assembly systems, including hypotheses. It also examines the recent status of nuclear test sites and the process of how China acquired nuclear-related technology.

Chapter 3, ***Future Prospects for Nuclear Warhead Production Cycle,*** examines how the nuclear warhead production cycle analyzed thus far relates to the formulation of China's nuclear strategy. It also forecasts trends in the nuclear warhead production cycle to provide insights for future verification activities.

The analysis and verification based on this structure yielded the key findings and future outlook listed at the beginning of this report. On the other hand, the full scope of the nuclear warhead production cycle in China has not yet been elucidated, and continued research will be essential in the coming years. We hope that this report will further deepen these efforts.

Figure 1: Major nuclear-related facilities in China analyzed in this report



Source: Prepared by our Study Group

Chapter 1

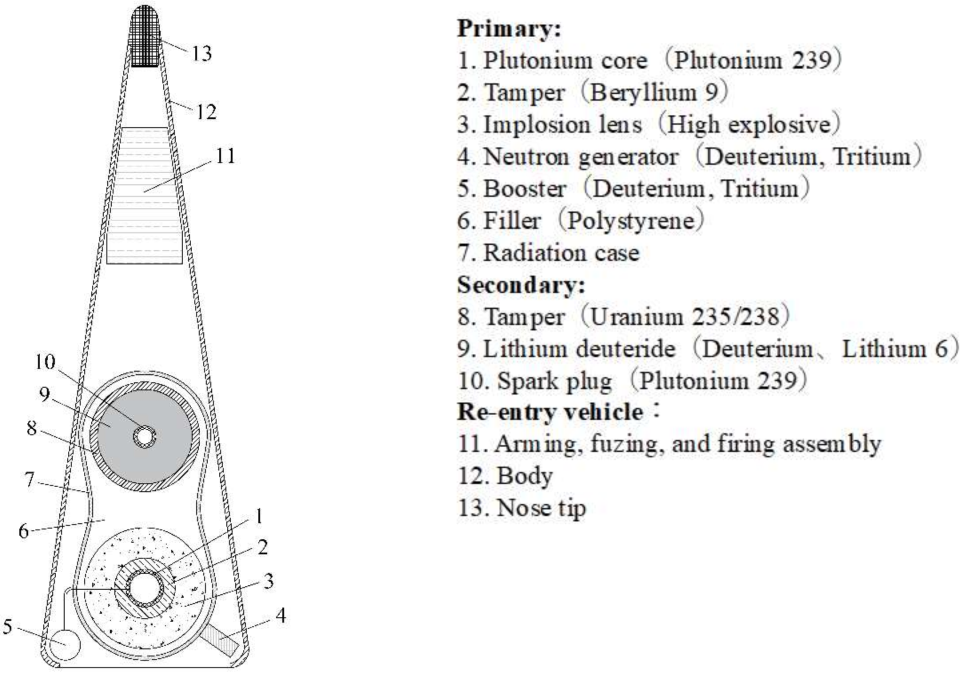
What Is the Nuclear Warhead Production Cycle?

1. Nuclear Warhead Configuration

Materials and Mechanism of Action for Nuclear Warheads

As a prerequisite for examining China's nuclear warhead production cycle, we will outline the components of a nuclear warhead. In other words, what exactly constitutes the nuclear warhead materials that should be the subject of examination in this study? First, the general components of a nuclear warhead are shown in Figure 2 (depicted housed within a reentry body, assuming it will be mounted on a ballistic missile).

Figure 2: Nuclear Warhead Configuration



Source: Prepared by our Study Group

Modern nuclear warheads are weapons utilizing nuclear fusion (so-called hydrogen bombs), and the part that causes nuclear fission serves to generate X-rays for heating the fusion material. The parts that cause nuclear fission and nuclear fusion are called the primary and secondary, respectively. The following describes the operational sequence of the nuclear weapon and explains the function of each component.

First, the primary is detonated. When the optimal detonation position is reached, based on conditions such as altitude, the detonation control device (11), installed inside the reentry body, energizes the detonator of the implosion lens (3), detonating it. The implosion lens burns from the outer to the inner side, forming a spherically symmetric shock wave surface at the point where it contacts the innermost tamper (2) and compressing the tamper. The compressed tamper further compresses the plutonium core (1) located inside it. At the instant the compressed plutonium core reaches critical conditions, neutrons are irradiated from the neutron generator (4) toward the core, initiating a nuclear fission reaction. Simultaneously, a mixture of deuterium and tritium gas is injected into the core from the booster (5). The injected mixed gas undergoes nuclear fusion within the high-temperature, high-pressure environment at the core's center, producing a large number of neutrons. These cause the primary to undergo a nuclear explosion, producing even larger quantities of neutrons and X-rays.

X-rays generated in the primary are reflected within the radiation case (7) and absorbed by its internal components, raising their temperatures (i.e., heating them). The filler (6) vaporizes into plasma, increasing the pressure inside the case and compressing the secondary tamper (8). Meanwhile, the tamper is also rapidly heated, causing its surface to vaporize and scatter (abrasion). At this point, the scattered surface reaction forces compress the non-vaporized portion of the tamper inward, thereby compressing the nuclear fusion material, lithium deuteride (9). (This is the main pressure.) The spark plug (10) located innermost of the secondary is also compressed. Since the spark plug is made of plutonium, it reaches criticality conditions and undergoes a nuclear explosion, triggered by neutrons arriving from the primary, along with X-rays. As a result of this reaction, the lithium deuteride is compressed from within as well. On the other hand, the lithium in the lithium deuteride reacts with neutrons released from the primary and spark plug to form tritium. The fusion material, now a mixture of deuterium (heavy hydrogen) and tritium, is heated to high temperatures by X-rays and compressed to high densities through the aforementioned process. This satisfies the Lawson criterion for sustaining nuclear fusion reactions, triggering a nuclear explosion (nuclear fusion reaction).

Components of the Primary

● Plutonium core

Next, we will examine each component of the nuclear warhead in greater detail. First is the primary, whose plutonium core is not the main player in terms of nuclear yield, but only serves to produce X-rays and neutrons. However, among the components listed above, procuring plutonium is the most difficult, making it a particular focus in nuclear material management. This is because plutonium does not exist as a natural resource in the first place and must be produced through nuclear reactions. The capacity to produce nuclear weapons is often described in terms of this plutonium production capacity.

Natural uranium consists mostly of uranium-238. When uranium-238 absorbs a neutron, it becomes uranium-239, which decays into neptunium-239 with a half-life of 23 minutes. Furthermore, neptunium-239 decays into plutonium-239 with a half-life of 2.4 days. Since a nuclear reactor is a facility that can produce large quantities of neutrons, plutonium-239 is produced by loading uranium-238 into a nuclear reactor and irradiating it with neutrons.

This statement makes it sound as if plutonium-239 could be produced even in light water reactors, which represent commercial nuclear reactors, but there are two problems in this case. Both are attributable to the fact that the fuel rod assemblies are immersed in a large tank containing water, which serves as both coolant and moderator. First, water has a large neutron capture cross section, resulting in poor neutron utilization efficiency. Therefore, natural uranium cannot be used in fuel rods that produce neutrons through nuclear fission reactions; instead, enriched uranium, with an increased concentration of uranium-235, must be used. The process of obtaining this enriched uranium is also complex, and requires a large-scale plant. Another problem is that replacing the fuel rods is a major operation that requires shutting down the reactor. Therefore, frequent replacement is difficult; for example, in Japanese commercial reactors, fuel rods are replaced once a year.

In the fuel, uranium-238 absorbs neutrons to produce plutonium-239, which further absorbs neutrons to become plutonium-240. Plutonium-240 has a frequency of spontaneous fission 70,000 times greater than that of plutonium-239, making it prone to uncontrollable fission and harmful as material for the primary core. Therefore, plutonium used in nuclear weapons must be kept below a few percent of plutonium-240. Then, the fuel rods in the reactor would need to be replaced early and often, in essence, at a stage when they are producing plutonium-239, but not much plutonium-240. Light water reactors are not suited for that purpose.

For these two reasons, plutonium production reactors separate the coolant and moderator, using water for the former and graphite for the latter. Furthermore, the fuel rods are installed individually in the pressure tubes through which the cooling water flows. Each fuel rod can be discharged without stopping the reactor. In more advanced production reactors, heavy water is used instead of graphite due to its smaller neutron absorption cross section, but it is more expensive. For reference, past operational results from graphite-type plutonium production reactors indicate that the plutonium production rate is approximately 0.8 grams per day per 1 megawatt (MW) of thermal power.[3] Therefore, by multiplying this value, 0.8 g/MWd, by the thermal power and the number of operating days, we can estimate the amount of plutonium produced by that graphite reactor.

A completely different idea is to produce plutonium using fast breeder reactors (FBRs). In FBRs, neutrons travel at high speeds without moderators; however, this means the fission cross section of uranium-235 is significantly small, and a chain reaction cannot be sustained. Therefore, a method is employed to increase the reaction probability by covering the core with uranium-238 to reflect neutrons escaping from the core and allowing them to pass through the core many times. This part covering the core is called the blanket, but the uranium-238 that makes up the blanket not only reflects (scatters) neutrons but also absorbs some of them. In other words, the plutonium generation process will occur unintentionally in the blanket.

The same is true for the plutonium-239 produced, which further absorbs neutrons to become plutonium-240. However, the capture cross section for atomic nuclei capturing neutrons differs significantly between plutonium-239 and plutonium-240 depending on the neutron velocity. Figure 3 shows its velocity dependence. In short, for fast neutrons, the ratio of the probability of producing plutonium-239 to the probability of producing plutonium-240 is 200 times greater than for neutrons of the speed used in light water reactors. In other words, it is 200 times easier to produce weapons-grade plutonium. According to a paper estimating plutonium production in the Russian fast breeder reactor BN-800,[4] after 420 days of operation, the isotopic abundance of plutonium-239 and plutonium-240 in the produced plutonium is estimated to be 96.5% and 3.36% for the axial blanket (above and below the core), and 97.5 % and 2.49% for the radial blanket (around the core), respectively. Assuming a reactor availability of 80%, it is estimated that both blankets together can produce 162 kg of plutonium per year.

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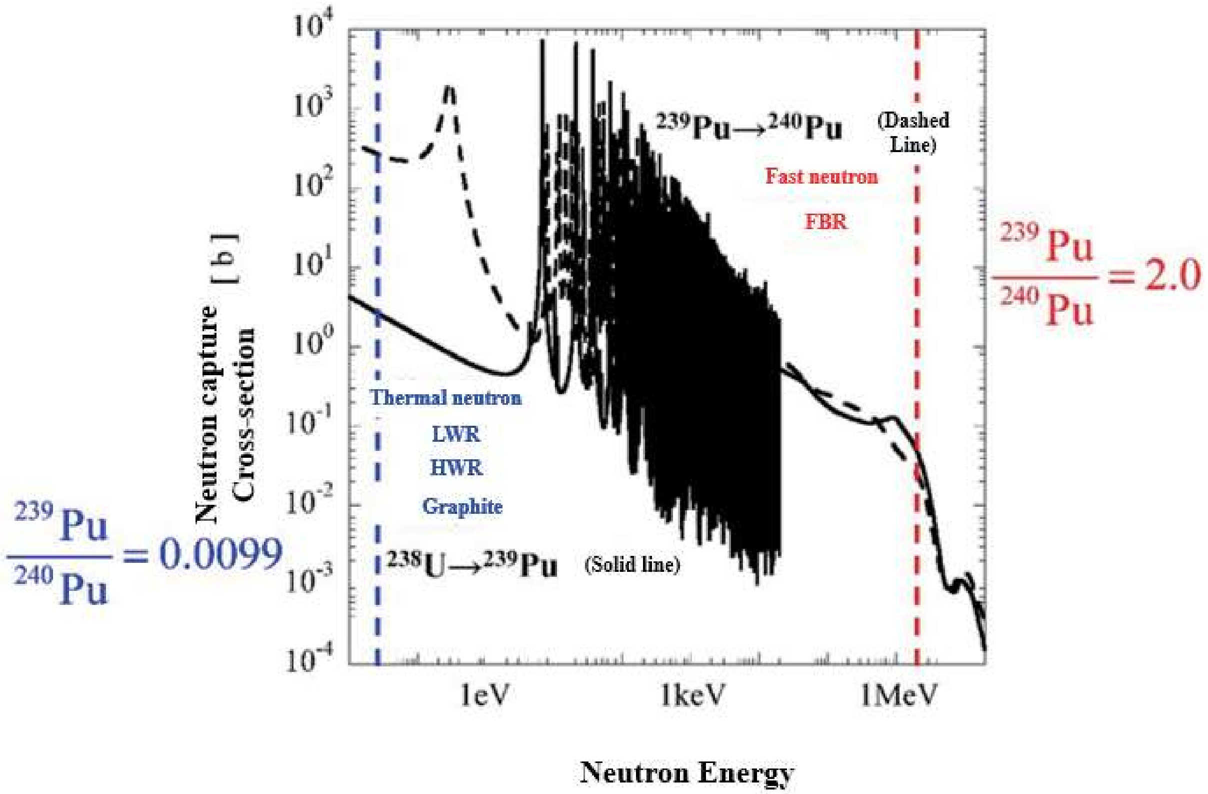
[3] Calculated based on the production record for the Hanford B reactor as described in "*Technological Issues Related to the Proliferation of Nuclear Weapons,*" Strategic Weapons Proliferation Teaching Seminar, 1998.

[4] Moritz Kütt, Friederike Frieß, and Matthias Englert, "*Plutonium Disposition in the BN-800 Fast Reactor: An Assessment of Plutonium Isotopics and Breeding,*" *Science & Global Security* **22**, 2014, 188–208.

Figure 3: Neutron capture cross section of plutonium

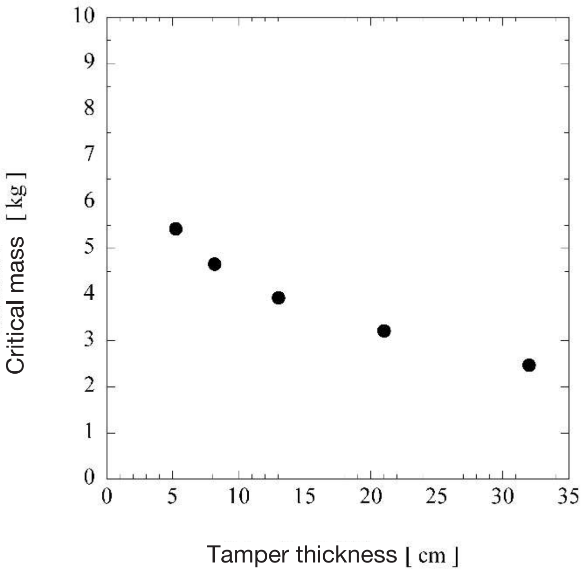


Source: prepared by our Study Group based on JENDL-4.0 data published by JAEA Nuclear Data Center

● Tamper

The tamper in the primary not only compresses the plutonium core but also serves as a reflector, reflecting neutrons leaking from the core back into it. Therefore, it is standard practice to use beryllium-9, whose neutron scattering cross section is many orders of magnitude larger than its capture cross section. Furthermore, some reactions involving beryllium-9 and neutrons involve absorbing one neutron and emitting two neutrons, making beryllium-9 even more advantageous. Increasing the thickness of the er reduces the critical mass of the plutonium core, but the primary itself also becomes larger. Therefore, the standard modern nuclear warhead design is to keep the tamper to a certain thickness and to improve the critical conditions using the boosters described below. Figure 4 shows the results of an experiment demonstrating how the critical mass of a spherical plutonium changes with the thickness of the tamper.

Figure 4: Relationship between tamper thickness and critical mass of plutonium



Source: Prepared by our Study Group

Implosion lens

The implosion lens is an element consisting of explosives to compress the plutonium core via tamper and create critical conditions. The implosion lens of the Mk 3 nuclear bomb, which was used in the first nuclear test (Trinity test) and also dropped on Nagasaki, had a diameter of 1.4 meters and had 32 detonators. Subsequently, implosion lenses were miniaturized. For example, the implosion lens in the U.S. W80 nuclear warhead, which was deployed starting in 1981, is small enough to fit inside a 30-cm-diameter radiation case. There are only two detonators. Because the number of detonators is finite, the explosives do not initiate combustion in a spherically symmetric manner. When the explosive burns in the diameter direction and comes to the tamper position, its shock wave surface must be spherically symmetrical. Thus, the diameter of the implosion lens provides the necessary distance for the shock wave to gradually become spherically symmetric. In the era of the Mk 3 bomb, which had to be designed by hand calculations, a distance of 1.4 meters was required. However, by the W80 era, computer simulations had become available, and with the accumulated results of numerous experiments, it became possible to create a spherically symmetric shock wave at a shorter distance, even with a two-point ignition system.

Note that W80's implosion lens is not spherically symmetric but has the shape of an ellipsoidal rotor, like a football. It is only through advanced technology and extensive experience that such an implosion lens can be implemented. As can be seen in Figure 2, the implosion lens is the largest component, and it determines the diameter of the nuclear warhead (or reentry body). To develop multiple independently targetable reentry vehicles for ballistic missiles, the reentry body must be made slimmer, making the miniaturization of implosion lenses an essential requirement. This aspect may be one of the reasons why the use of multiple warheads has not progressed in countries other than the U.S. and Russia.

Neutron generator

The neutron generator (more precisely, initiator) sends the first neutron of the chain reaction into the plutonium core. The neutron generator itself is used in nondestructive testing, so consumer products are commercially available and are not special devices today. Since deuterium and tritium are used internally, the neutron generator has an “expiration date” like the booster described below. Therefore, it is attached to the outside of the radiation case for easy replacement. Because neutrons have great penetration capability, they can reach the core from there.

Components of the Booster and Other Elements

The booster was not present in early nuclear fission weapons, but has become essential today. Classic nuclear fission weapons react with only a portion of the prepared nuclear fuel material (15% in the case of Mk 3) due to the insufficient amount of neutrons. The meaning of boost is to accelerate the reaction by supplying more neutrons. Originally conceived to increase nuclear yield by reacting more unreacted nuclear fuel material, the booster in modern nuclear warheads is not designed for this purpose. Instead, the design philosophy now focuses on achieving nuclear yield by the secondary.

The role of the booster in modern nuclear warhead design, then, is to replenish the core with neutrons to bring it to criticality in a condition that is not originally critical under those conditions. This reduces the amount of core and the thickness of the tamper, allowing for a more economical primary to be fabricated. Consequently, the mass of the plutonium core in modern nuclear warheads is kept to approximately 4 kg.

The DT reaction is used for a booster, and thus requires deuterium and tritium. Deuterium is a stable isotope and can remain in the radiation case, but tritium decays with a half-life of 12 years and must be replaced periodically. Therefore, tritium is placed outside the radiation case for easy replacement, and is piped into the inside of the core. The container for the U.S. booster is spherical, and the mass of the filled tritium is approximately 4 g.[5]

The filler is used to secure the primary and secondary in their designated positions within the radiation case. Since it must not significantly obstruct X-ray transmission, polystyrene is used as a material with high X-ray transmittance (i.e., low specific gravity).

The radiation case reflects X-rays to efficiently irradiate the secondary, and is made of materials with high specific gravity, such as tungsten alloys.

Components of the Secondary

● Tamper

Next, we discuss the secondary. For the tamper of the secondary, a material with a high specific gravity is still preferred in order to react well with X-rays. Moreover, the high specific gravity has another meaning. The tamper, as its name suggests, must confine the nuclear fusion material inside, but mechanical strength is meaningless in an ultra-high temperature environment where any material can become plasma. Everything scatters in all directions. However, the heavier the nucleus, the longer it takes to scatter. Therefore, the contents remain confined for that period of time. In that sense, materials with greater specific gravity are selected.

Tungsten alloys are acceptable, but uranium-238 is often used to achieve another effect. It is often thought that uranium-238 does not undergo nuclear fission, but in reality, it depends on the neutron velocity. Although the fission reaction does not occur at the speed of neutrons slowed down by light water reactors, etc., uranium-238 has a fission cross section about half that of uranium-235 for the fast neutrons produced by the DT reaction. Therefore, if this tamper is made of uranium-238, this part also contributes to the increase in nuclear yield, and greater destructive power can be expected. Furthermore, if this is made with uranium-235, an even larger nuclear yield can be obtained. Both the U.S. and Russia have ample stocks of highly-enriched uranium-235 from mass production during the Cold War, which can be used to enhance the power of nuclear warheads (indeed, nuclear warheads manufactured by the US during the late Cold War period were designed this way). However, uranium-235 can undergo nuclear fission even with low-energy neutrons, so accumulating large quantities can reach a critical state. Therefore, for the tamper as well, mass and geometry controls are essential for preventing criticality before detonation. Design and manufacturing must take these factors into account, requiring advanced technology.

● Lithium Deuteride

Lithium deuteride is one of the factors that maximizes nuclear yield. To trigger the DT reaction, deuterium and tritium are required. However, tritium cannot be produced in large quantities because it uses a nuclear reactor in its production. Furthermore, it decays with a half-life of 12 years, making it extremely difficult to handle for

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[5] J. Carson Mark, Thomas D. Davies, Milton M. Hoenig, and Paul L. Leventhal, "*The Tritium Factor as a Forcing Function in Nuclear Arms Reduction Talks,*" *Science* **241**, 1988, 1166-1168.

weapons like nuclear weapons, for which long-term storage is essential. Furthermore, since tritium is a gas at room temperature, it cannot be loaded into a nuclear warhead in large quantities.

Therefore, as mentioned above, the method of producing tritium from lithium during a nuclear explosion is employed. In fact, when tritium is produced within nuclear reactors, lithium is also irradiated with neutrons to produce tritium. The lithium used in this case must be lithium-6, which constitutes only 7.6% of natural lithium. In other words, the enrichment process of lithium is necessary, but it is considerably easier compared to uranium enrichment (see Section 2 of this chapter).

However, the reaction cross section for lithium-7, which accounts for the remaining 92.4%, also varies significantly depending on the neutron velocity. At the neutron velocity (2 MeV) produced by nuclear fission reactions, tritium production reactions occur at a rate high enough to be counted in nuclear yield calculations. Furthermore, at the neutron velocity (14 MeV) produced by nuclear fusion reactions, the reaction cross section of lithium-7 becomes rather larger than that of lithium-6. However, to produce tritium from lithium deuteride, the neutrons produced from the fission reaction in the primary are used first, so it is still more efficient to use enriched lithium-6.

● Spark Plug

The spark plug consists of plutonium used to heat and compress nuclear fusion material from the inside while supplying neutrons. However, if it is acceptable for the nuclear fusion reaction rate to decrease, it can be omitted. This would reduce nuclear yield, but save valuable plutonium. Furthermore, design optimization may compensate for that reduction.

● Detonation Control Device

The detonation control device is unexpectedly important. For nuclear warheads, accuracy is more important than nuclear yield. Halving the circular error probable (CEP) produces an effect equivalent to increasing nuclear yield eightfold. The two-dimensional accuracy of a nuclear warhead is determined by the ballistic missile side, but the vertical accuracy—specifically, the altitude at which detonation occurs—is determined by this detonation control device. The ballistic missile's reentry velocity, even when slowed by the atmosphere, is several km/s at impact, so a 0.1-second shift in the timing of detonation would result in a shift in altitude of several hundred meters. All of the U.S. nuclear warheads were manufactured in the 20th century, but this particular part has been continuously upgraded by replacing it with the latest model. For example, the W88 nuclear warhead for UGM-133, a submarine-launched ballistic missile (SLBM) of the U.S., replaced the detonation control device in its entirety between 2021 and 2026 under the Alteration 370 modernization program, launched in 2012.[6]

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[6] https://www.energy.gov/sites/default/files/2022-01/W88-ALT370%20012422.pdf.; https://www.twz.com/41531/first-improved-w88-nuclear-warhead-for-navys-trident-missiles-rolls-off-the-assembly-line

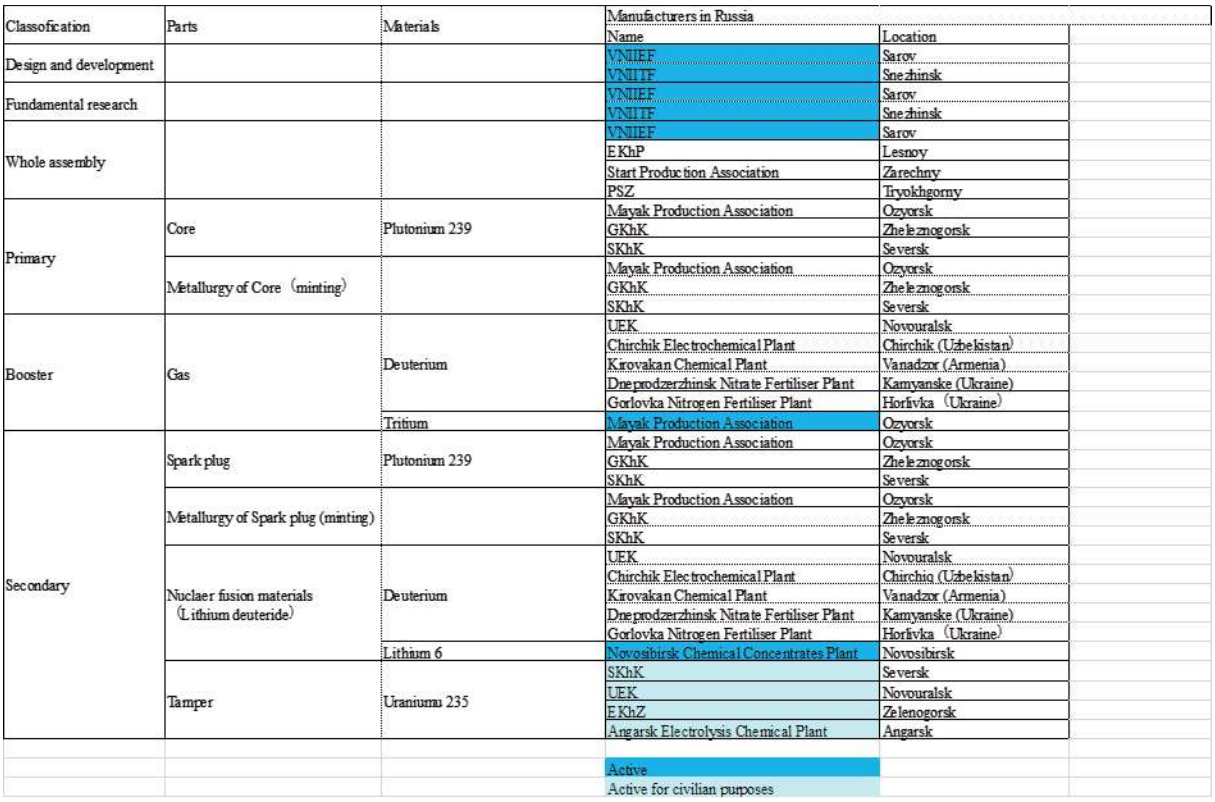
2. Nuclear Warhead Production Cycles by the U.S. and Russia

Nuclear Weapons Facilities by the U.S. and Russia

Building on the nuclear warhead components discussed in the previous section, this section examines how these elements are produced and integrated into nuclear warheads as the ultimate products, using the examples of the U.S. and Russia. Tables 1 and 2 summarize the production sites for each nuclear weapon component in the U.S. and Russia. Additionally, Figures 5 and 6 illustrate the locations of these facilities on maps of Russia and the U.S., respectively.

Currently, both the U.S. and Russia have terminated the production of fissile materials, although tritium production remains an exception. This is because both countries maintain stockpiles of nuclear materials that, even if limited to those accumulated during the Cold War era, are sufficient to produce tens of thousands of nuclear warheads. Figures 7 and 8 respectively show the global stockpiles of weapons-grade plutonium and highly enriched uranium, indicating that the two countries together hold 90% of the world's inventory of both materials. This also means that for Beijing to build a nuclear force capable of rivaling that on the part of Washington, China must produce vast quantities of plutonium.

Table 1: Production sites for each nuclear weapon component in Russia



Classofication	Parts	Materials	Manufacturers in Russia	
			Name	Location
Design and development			VNIIEF	Sarov
			VNIITF	Snezhinsk
Fundamental research			VNIIEF	Sarov
			VNIITF	Snezhinsk
Whole assembly			VNIIEF	Sarov
			EKhP	Lesnoy
			Start Production Association	Zarechny
			PSZ	Tryokhgorny
Primary	Core	Plutonium 239	Mayak Production Association	Ozyorsk
			GKhK	Zheleznogorsk
			SKhK	Seversk
	Metallurgy of Core（minting）		Mayak Production Association	Ozyorsk
			GKhK	Zheleznogorsk
			SKhK	Seversk
Booster	Gas	Deuterium	UEK	Novouralsk
			Chirchik Electrochemical Plant	Chirchik (Uzbekistan）
			Kirovakan Chemical Plant	Vanadzor (Armenia)
			Dneprodzerzhinsk Nitrate Fertiliser Plant	Kamyanske (Ukraine)
			Gorlovka Nitrogen Fertiliser Plant	Horlivka（Ukraine）
		Tritium	Mayak Production Association	Ozyorsk
Secondary	Spark plug	Plutonium 239	Mayak Production Association	Ozyorsk
			GKhK	Zheleznogorsk
			SKhK	Seversk
	Metallurgy of Spark plug (minting)		Mayak Production Association	Ozyorsk
			GKhK	Zheleznogorsk
			SKhK	Seversk
	Nuclaer fusion materials（Lithium deuteride）	Deuterium	UEK	Novouralsk
			Chirchik Electrochemical Plant	Chirchiq (Uzbekistan）
			Kirovakan Chemical Plant	Vanadzor (Armenia)
			Dneprodzerzhinsk Nitrate Fertiliser Plant	Kamyanske (Ukraine)
			Gorlovka Nitrogen Fertiliser Plant	Horlivka（Ukraine）
		Lithium 6	Novosibirsk Chemical Concentrates Plant	Novosibirsk
	Tamper	Uraniumu 235	SKhK	Seversk
			UEK	Novouralsk
			EKhZ	Zelenogorsk
			Angarsk Electrolysis Chemical Plant	Angarsk

Active

Active for civilian purposes

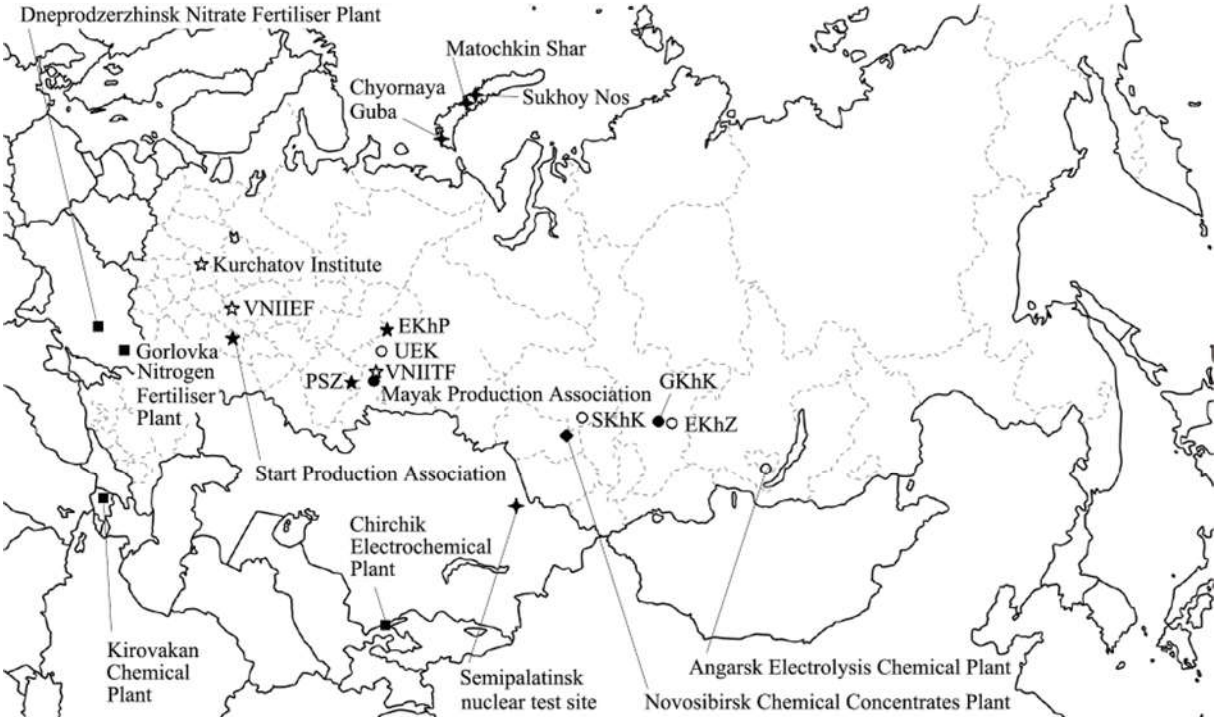
Source: Prepared by our Study Group

Table 2: Production sites for each nuclear weapon component in the U.S.

Classofication	Parts	Materials	Manufacturers in U.S.A	
			Name	Location
Design and development			LANL	Los Alamos County, New Mexico
			LLNL	Alameda County, California
Fundamental research			LANL	Los Alamos County, New Mexico
			LLNL	Alameda County, California
			SNL	Bernalillo County, New Mexico
Whole assembly			LANL	Los Alamos County, New Mexico
			LLNL	Alameda County, California
			Pantex Plant	Carson County, Texas
Primary	Core	Plutonium 239	Hanford Site	Benton County, Washington
			Savannah River Site	Barnwell County, South Carolina
	Metallurgy of Core（minting）		Rocky Flats	Jefferson County, Colorado
			LANL	Los Alamos County, New Mexico
			Hanford Site	Benton County, Washington
	Tamper	Beryllium	Rocky Flats	Jefferson County, Colorado
	Implosion lens		Pantex Plant	Carson County, Texas
	Detonator for implosion lens		Mound Laboratory	Montgomery County, Ohio
	Neutron generator		Pinellas Factory	Pinellas County, Florida
Booster	Gas	Deuterium	Savannah River Site	Barnwell County, South Carolina
			Morgantown	Monongalia County, West Virginia
			Wabash River Site	Vermillion County, Indiana
			Redstone Arsenal	Talladega County, Alabama
		Tritium	Savannah River Site	Barnwell County, South Carolina
	Bottle		Rocky Flats	Jefferson County, Colorado
Secondary	Spark plug	Plutonium 239	Hanford Site	Benton County, Washington
			Savannah River Site	Barnwell County, South Carolina
	Metallurgy of Spark plug (minting)		Rocky Flats	Jefferson County, Colorado
			LANL	Los Alamos County, New Mexico
			Hanford Site	Benton County, Washington
	Nuclaer fusion materials（Lithium deuteride）	Deuterium	Savannah River Site	Barnwell County, South Carolina
			Morgantown	Monongalia County, West Virginia
			Wabash River Site	Vermillion County, Indiana
			Redstone Arsenal	Talladega County, Alabama
		Lithium 6	Clinton Engineer Works	Anderson County, Tennessee
	Tamper	Uranium 235	Clinton Engineer Works	Anderson County, Tennessee
			Paducah Gaseous Diffusion Plant	McCracken County, Kentucky
			Portsmouth Gaseous Diffusion Plantポー	Pike County, Ohio
Structural materials	Radiation case		Kansas City National Security Campus	Jackson County, Missouri
	Filler	Polystyrene	Kansas City National Security Campus	Jackson County, Missouri
Electronic components	Detonator		Kansas City National Security Campus	Jackson County, Missouri
			Active	
			Active for civilian purposes	

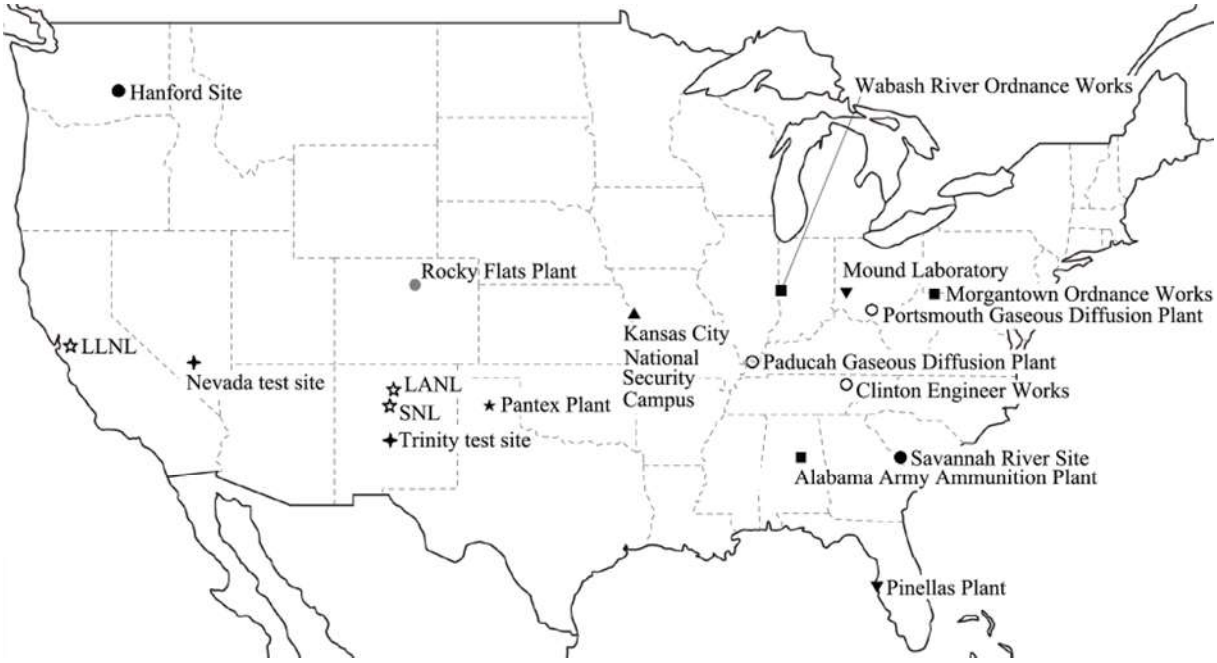
Source: Prepared by our Study Group

Figure 5: Nuclear Weapons Facilities in Russia



Source: Prepared by our Study Group

Figure 6: Nuclear Weapons Facilities in the U.S.



Source: Prepared by our Study Group

Figure 7: Global stockpiles of weapons-grade plutonium (Unit: metric tons)

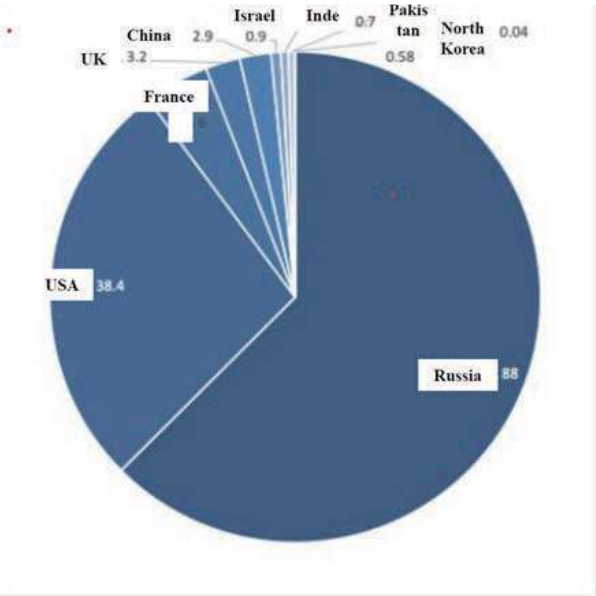
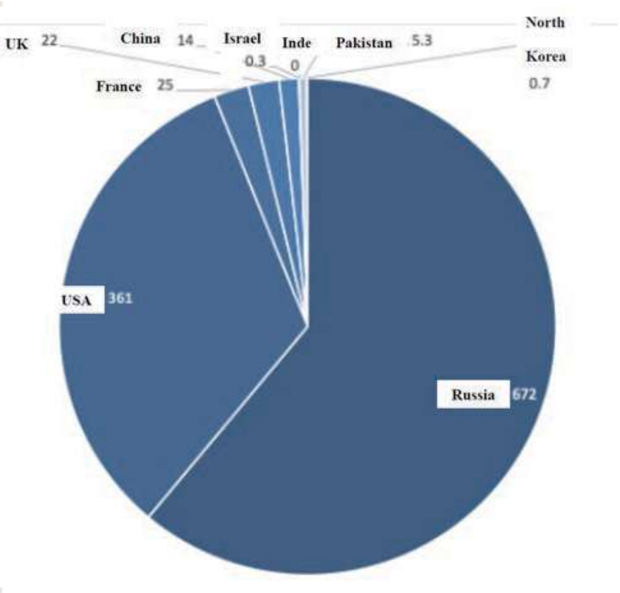


Figure 8: Global stockpiles of weapons-grade highly enriched uranium (Unit: metric tons)



Source: Compiled by the Study Group based on data from “Fissile material stocks, 2024,” International Panel on Fissile Materials, 2024.

Design, Development, and Final Assembly

First, we will detail the manufacturing facilities for each component shown in Table 1. We start by examining the design and development of nuclear weapons. In Russia, all nuclear weapons have been designed and developed at two sites since the Soviet era: the All-Russian Research Institute of Experimental Physics (VNIIEF) in Sarov, Nizhny Novgorod Oblast, and the Zababakhin All-Russia Research Institute of technical Physics (VNIITF) in Snezhinsk, Chelyabinsk Oblast. VNIIEF has been active since 1947 and VNIITF since 1955; both continue their operations to this day. Basic research is also conducted at these two institutes.

In the U.S., all nuclear weapons have been designed and developed at two sites: Los Alamos National Laboratory (LANL) in Los Alamos County, New Mexico, and Lawrence Livermore National Laboratory (LLNL) in Alameda County, California. LANL has been active since 1943 while playing the central role in the Manhattan Project, and LLNL has been active since 1952; both continue their operations to this day. In addition, Sandia National Laboratories (SNL) in Bernalillo County, New Mexico, has shared the responsibility for basic research and the development of each component since 1949.

Final assembly, which involves bringing together all nuclear weapon components, has been conducted in Russia at VNIIEF (since 1951) and three other plants: the Elektrokhimpribor Combine (EKhP) in Lesnoy, Sverdlovsk Oblast (since 1951), the Start Production Association in Zarechny, Penza Oblast (from 1963 to 2002), and the Instrumentation Factory (PSZ) in Trekhgorny, Chelyabinsk Oblast (since 1955). While VNIITF assembles nuclear warheads for nuclear tests, it does not do so for combat use. Additionally, Start has produced nuclear weapon components since 1954—possibly detonation control devices, given its stated operations include "microelectronics manufacturing." Similarly, PSZ may be producing detonation control devices as well, given that its stated operations also include the manufacturing of “specialized microelectronics.”

The final assembly process in the U.S. has been conducted by LANL (since 1945) and LLNL (since 1958), along with the Pantex Plant in Carson County, Texas. Operated by private companies from 1951, when it started to assemble nuclear weapons, the Pantex Plant has been under the management of SNL since 2014. The replacement of detonation control devices for the above-mentioned W88 nuclear warheads is also carried out at the Pantex Plant.

In both the U.S. and Russia, final assembly facilities feature high-ceilinged buildings with vast interior spaces, as they are designed to integrate re-entry vehicles onto the Post-Boost Vehicle (PBV) of ballistic missiles. As an example, Satellite Image 1 depicts the final assembly building at LANL. The presence of multiple assembly plants in the U.S. and Russia respectively reflected their intention to facilitate the production of thousands of nuclear warheads annually. However, China's current production pace—estimated at around 100 warheads per year—could be sufficiently handled by a single plant or research institute. Therefore, while its production pace may alone suggest that China’s nuclear warhead assembly is centralized at a single location, it cannot be ruled out that there are two or more such sites in the country so that risks can be diversified.

Satellite Image 1: Satellite image of the nuclear weapons assembly building at Los Alamos National Laboratory (the gray building in the center)

Source: Google Earth

Primary Production

The heart of the primary is the plutonium core, consisting of fissile material. Figure 9 illustrates the production process. Uranium, the source material for plutonium, is described below.

As graphite-moderated and heavy-water reactors use natural uranium in fuel rods, its enrichment is not a prerequisite. Furthermore, the dimensions and configurations of the fuel rods differ significantly from those used in light-water power reactors. In the U.S., fuel rod optimization was also pursued. For instance, the Hanford N Reactor (described below), which was operational until the last phase, utilized a combination of two types of fuel rods: Mark I-A and Mark IV. The Mark I-A was 533 mm in length, containing 16.6 kg of uranium. It featured a double-cylindrical structure with an inner enrichment of 0.947% uranium-235 and an outer enrichment of 1.25%, resulting in an average enrichment of 1.15%. The Mark IV was 660 mm in length with a uranium weight of 23.5 kg, featuring an enrichment of 0.947% for both its inner and outer cylinders. Sixteen of these fuel rods were housed for loading in what is known as a single cylindrical process tube (890 mm in length, with an inner diameter of 69 mm and a thickness of 6 mm). The loading ratio consisted of 20% Mark I-A and 80% Mark IV, with these fuel rods coated with Zircaloy (a zirconium alloy containing tin) . If such optimization is to be achieved, the uranium enrichment process must also be integrated into the plutonium production cycle.

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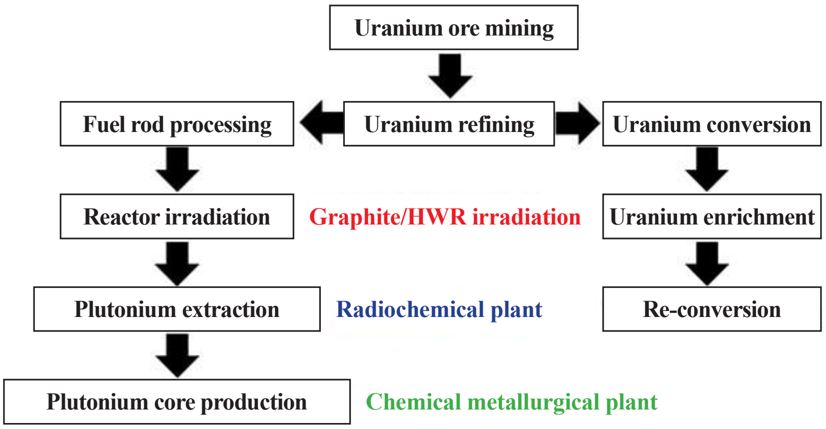
[7] Natural Resources Defense Council, Inc, “*Nuclear Weapons Databook Volume III U.S. Nuclear Warhead Facility Profiles,*” 1987.

Figure 9: Production process for fissile materials



Source: Prepared by our Study Group

Once irradiated with neutrons inside the nuclear reactor, these fuel rods are removed and processed to separate plutonium from other elements. Based on chemical methods, isotopic separation cannot be achieved. Therefore, achieving a higher concentration of the desired plutonium-239 requires careful consideration at the irradiation stage (refer to the previous section).

Chemical separation is performed at a radiochemical plant (reprocessing plant). Having been used in the reactor operation, fuel rods are highly radioactive due to the presence of fission products and minor actinides other than plutonium generated by neutron irradiation of uranium, requiring facilities dedicated to preventing worker exposure, contamination, and environmental leakage. Given the various restrictions on transporting highly radioactive materials via public roads, both the U.S. and Russia respectively locate their radiochemical plants within the same site as the production reactors. At these radiochemical plants, which also manage exhaust emissions, the exhaust stacks serve as prominent landmarks (Satellite Image 2).

Plutonium extracted from the fuel rods is converted into a pure metal or alloy before being cast into the shape of plutonium cores. This process is carried out at a chemical-metallurgical plant. As plutonium itself is not so highly radioactive, its risk of external exposure is not significant. However, strict contamination control is required, alongside mass and geometry management to prevent criticality. In Russia, chemical-metallurgical plants are similarly located on the same site as the production reactors, where plutonium is cast into cores before shipment. In contrast, the U.S. primarily performs these processes at separate facilities off-site.

As mentioned earlier, the U.S. and Russia respectively possess vast stockpiles of weapons-grade plutonium, and all of their production reactors listed below have already ceased plutonium production. However, some of the related buildings remain, providing valuable references for understanding the nature of these facilities. In Russia, plutonium production was conducted at the Mayak Production Association in Ozyorsk, Chelyabinsk Oblast, which operated four graphite reactors and one heavy-water reactor between 1948 and 1990; the Mining and Chemical Combine (GKhK) in Zheleznogorsk, Krasnoyarsk Krai, where three graphite reactors were active from 1958 to 2010; and the Siberian Chemical Combine (SKhK) in Seversk, Tomsk Oblast, which utilized five graphite reactors from 1955 until 2008. Table 3 shows the specifications for each production reactor, along with their cumulative production volumes. As examples of a radiochemical plant and a chemical-metallurgical plant, the buildings located within the Mayak complex are shown in Satellite Images 2 and 3, respectively.

Figure 10 shows the historical trend of Russia's annual plutonium production since the Soviet era. At its peak, with 13 production reactors reaching a combined annual output of nearly 4,000 kg, the average per reactor was approximately 300 kg. Assuming that Chinese production reactors maintain a similar level, the number of its reactors in operation can be estimated by back-calculating from the annual production rate of nuclear warheads.

Table 3: Plutonium production reactors in Russia

Site	Reactoe	Moderator	Heat output [MW]		Come online	Cease operation	Output
			Initial	Final			[kg]
MPA	A	Graphite	100	900	1948.6.10	1987.6.16	6,138
	AV-1	Graphite	300	1,200	1950.4.5	1989.8.12	8,508
	AV-2	Graphite	300	1,200	1951.4.6	1990.7.14	8,407
	AV-3	Graphite	300	1,200	1952.9.15	1990.11.1	7,822
	OK-180	Heavy water	40	100	1952.12.22	1987.5.25	53
GKhK	AD	Graphite	1,450	2,000	1958.8.25	1992.6.30	15,433
	ADE-1	Graphite	1,450	2,000	1961.7.20	1992.9.20	14,184
	ADE-2	Graphite	1,450	2,000	1961.1	2010.4.15	16,317
SKhK	I-1	Graphite	400	1,200	1955.11.20	1990.9.21	8,237
	EI-2	Graphite	400	1,200	1958.9.24	1990.12.31	7,452
	ADE-3	Graphite	1,450	1,900	1961.7.14	1990.8.14	14,020
	ADE-4	Graphite	1,450	1,900	1964.2.26	2008.4.20	19,460
	ADE-5	Graphite	1,450	1,900	1966.6.26	2008.6.5	19,144

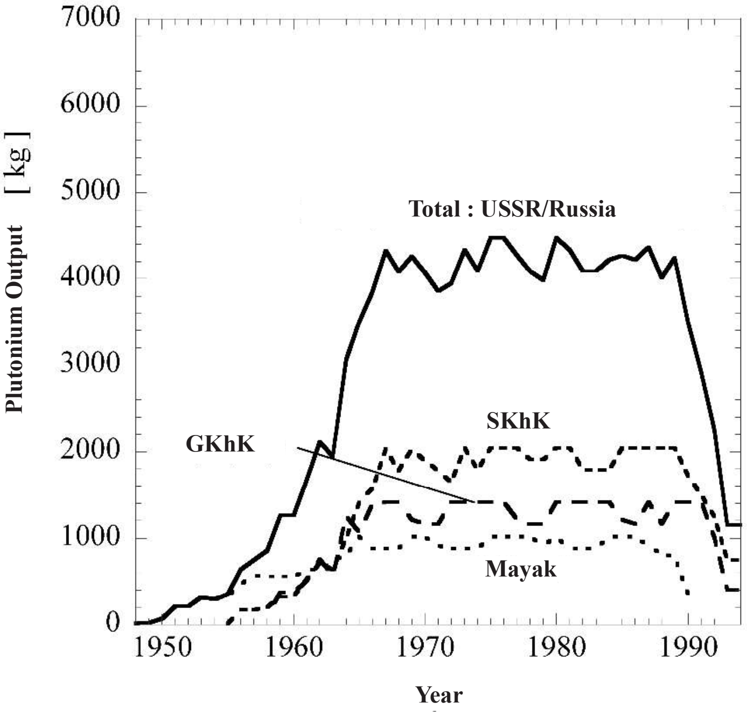
Source: Created by the research group based on data from Анатолий Дьяков, "История Производства Плутония в России," Science and Global Security 19, 2011: 28–45.

Satellite Image 2: Radiochemical Plant at the Mayak Production Association

Satellite Image 3: Chemical-Metallurgical Plant at the Mayak Production Association

Source: Google Earth

Figure 10: Historical trend of annual plutonium production in Russia (Soviet Union)



Source: Compiled by the Research Group based on data from the United States Department of Energy, "Plutonium: The First 50 Years," DOE/DP-0137, 1996.

In the U.S., plutonium was produced at the Hanford Engineer Works (Hanford Site) in Benton County, Washington, which operated nine graphite reactors between 1944 and 1987, and at the Savannah River Plant (Savannah River Site) in Barnwell County, South Carolina, which utilized five heavy-water reactors from 1953 to 1992. As an example, Satellite Image 4 shows the C Reactor at the Savannah River Site, where the reactor building still stands today. Also, Table 4 shows the specifications for each production reactor, along with their cumulative production volumes. Meanwhile, Figure 11 shows the historical trend of annual plutonium production in the U.S. As is evident from these facts, the U.S. often adopts a strategy of manufacturing the required quantity in a short period before closing the facilities concerned. This approach is unique to a country endowed with such immense industrial capacity and financial resources.

Chemical-metallurgical plants at the Hanford Site were in operation from 1949 to 1965. The Rocky Flats Plant, a dedicated facility in Jefferson County, Colorado, was in operation from 1953 to 1992, along with those at LANL. The metallurgical plant at LANL, known as the Chemistry and Metallurgical Research Facility, was responsible for core casting from 1949 to 2013. However, when deemed too aged for continued use, the original building was replaced by a new facility called the Chemistry and Metallurgical Research Replacement Facility, constructed adjacent to the nuclear weapons assembly plant and completed in 2021.[8] As of 2006, the U.S. possessed approximately 23,000 plutonium cores; 10,000 of them were deployed within nuclear warheads, while the remaining 13,000 were in storage at Pantex.[9]

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[8] Greg Mello, "*Build Warhead Factories Now, Worry about Weapons Policy Later Will Congress Take Back the Reins,*" Los Alamos Study Group Feb. 12, 2008.; "*Chemistry and Metallurgy Facility Replacement Subproject at LANL Completed Ahead of Schedule, Under Budget,*" *Los Alamos Reporter*, Jan 22, 2021.

[9] "Plutonium Pit Production — LANL's Pivotal New Mission," *Los Alamos Study Group*, Jul., 2006.

Other primary components besides plutonium cores included beryllium tampers manufactured at the Rocky Flats Plant, implosion lenses at Pantex, detonators for these lenses at the Mound Laboratory in Montgomery County, Ohio, and neutron generators at the Pinellas Plant in Pinellas County, Florida.

Satellite Image 4: Plutonium at the Savannah River Site Production-C Reactor

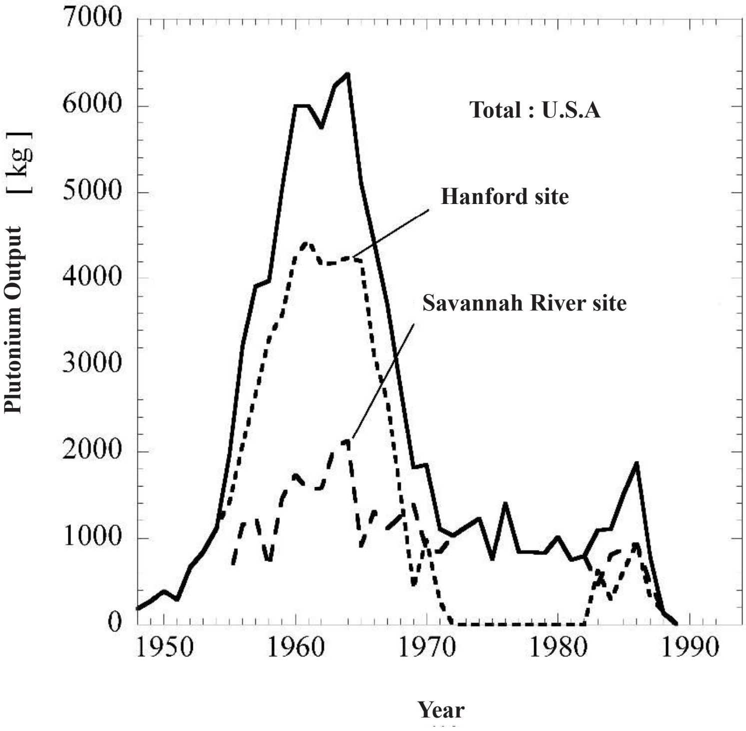
Source: Google Earth

Table 4: Plutonium production reactors in the U.S.

Site	Reactor	Moderator	Heat output [MW]		Come online	Cease operation	Output [kg]
			Initial	Final			
Hanford	B	Graphite	250	2,210	1944.9	1968.2	54,463
	D	Graphite	250	2,165	1944.12	1967.6	
	F	Graphite	250	2,040	1945.2	1965.6	
	H	Graphite	400	2,140	1949.10	1965.4	
	DR	Graphite	250	2,015	1950.10	1964.12	
	C	Graphite	650	2,500	1952.11	1969.4	
	KW	Graphite	1,800	4,400	1955.1	1970.2	
	KE	Graphite	1,800	4,400	1955.4	1971.2	
	N	Graphite	4,000	4,000	1963.12	1987.1	
Savannah River	R	Heavy water	500	2,500	1953.12	1964.6	36,079
	P	Heavy water	500	2,500	1954.2	1988.8	
	K	Heavy water	500	2,500	1954.10	1992.7	
	L	Heavy water	500	2,500	1954.7	1988.6	
	C	Heavy water	500	2,500	1955.3	1985.6	

Source: Compiled by the group based on data from “Plutonium: The First 50 Years,” United States Department of Energy, DOE/DP-0137, 1996.

Figure 11: Historical trend of annual plutonium production in the U.S.



Source: Prepared by our Study Group

● Production of Boosters

A booster consists of deuterium and tritium. Produced through the electrolysis of water, deuterium is not as specialized an industry as other nuclear materials. Heavy water is commercially available.

Tritium, on the other hand, is produced by irradiating lithium-6 with neutrons in a nuclear reactor. Consequently, tritium production requires highly specialized processes comparable to those of plutonium, ranging from lithium-6 enrichment and fuel rod fabrication to nuclear reactor irradiation and chemical separation. Unlike the stable isotope deuterium, tritium must be periodically replaced or replenished, requiring its continued production as long as a nuclear force is maintained. This distinguishes tritium from other components: plutonium-239, uranium-235, deuterium, and lithium-6. The same applies to China, where understanding its nuclear warhead production cycle requires attention to not only plutonium production reactors but also those for tritium.

In Russia, deuterium is produced at the Urals Electrochemical Combine (UEK) in Novouralsk, Sverdlovsk Oblast. During the Soviet era, deuterium was produced at the Chirchiq Electrochemical Combine in Uzbekistan, the Kirovakan Chemical Combine in Vanadzor, Armenia, and the Dniprodzerzhynsk Nitrogen Fertilizer Plant in Kamianske and the Gorlovka Nitrogen Fertilizer Plant in Horlivka, both in Ukraine.

Tritium has been produced at Mayak since 1951. In operation were: one heavy water reactor also used as a reactor for plutonium production, three dedicated heavy water reactors, one dedicated graphite reactor, and one dedicated light water reactor (Table 5). Still in operation today among them are one dedicated heavy water reactor and one dedicated light water reactor. As an example, Satellite Image 5 shows Ludmila, a dedicated heavy water reactor for tritium production.

Table 5: Tritium production reactors in Russia

Site	Reactor	Noderator	Heat output [MW]		Come online	Cease operation
			Initial	Final		
MPA	AI-IR	Graphite	40	100	1952.12.22	1987.5.25
	OK-180	Heavy water	100	233	1951.10.17	1966.3.3
	OK-190	Heavy water	300	300	1955.12.27	1965.11.8
	OK-190M	Heavy water	300	300	1966.4.16	1986.4.16
	Lyudmila	Heavy water	800	800	1988.5	Active
	Ruslan	Light water	800	1,100	1979.6.12	Active

Source: Created by the Study Group based on “История Производства Плутония в России” Science and Global Security, 19 28-45 (2011)

Satellite Image 5: Lyudmila Tritium Production Reactor at Mayak

Source: Google Earth

Deuterium production in the U.S. was conducted at the Savannah River Site from 1952 to 1982 to support its own plutonium production reactors (all of which were heavy-water reactors). Additional production took place at the Morgantown Ordnance Works in Monongalia County, West Virginia (1943–1945), the Wabash River Ordnance Works in Vermillion County, Indiana (1943–1945 and 1952–1957), and the Alabama Army Ammunition Plant in Talladega County, Alabama (1943–1945). Tritium has been produced at the Savannah River Site, with the production methods evolving over time.

From 1955 to 1988, when plutonium production reactors were in operation, tritium was produced using the same reactors on a dual basis; however, from 1988 to 2003, tritium was instead extracted and recovered from dismantled nuclear weapons. This was only possible timed with the massive decommissioning of warheads under the Strategic Arms Reduction Treaty (START). On the other hand, since 2003 in the post-Cold War era, tritium has been produced by loading Lithium-6 rods into commercial reactors and subsequently recovering them for extraction. The reservoirs for storing deuterium and tritium within nuclear warheads are manufactured at the Rocky Flats Plant.

- ## Secondary Production

Next, we will examine the components of the secondary.

Since the secondary's spark plug is made of plutonium, its production method is identical to that of the above-mentioned plutonium production reactors and chemical metallurgical plants. As for the “deuterium” in lithium deuteride, the process to make it can be understood in the same context as the deuterium production plants mentioned earlier.

On the other hand, as for the “lithium” component, as mentioned in the previous section, what is required for nuclear weapons manufacturing is lithium-6. Accounting for only 7.6% of natural lithium, lithium-6 must be concentrated through an enrichment process. For this process, there are two primary methods: the COLEX process and the mercury electrode method; the former was adopted mainly by the U.S., while the latter by Russia (the Soviet Union).

In Russia, the Novosibirsk Chemical Concentrates Plant in Novosibirsk, Novosibirsk Oblast, has been conducting lithium enrichment since 1958. The plant also manufactures nuclear fuel rods and related assemblies for commercial reactors.

In the U.S., the Clinton Engineer Works in Anderson County, Tennessee, conducted lithium enrichment from 1950 to 1963, rapidly producing the required amount in a short period, consistent with their established practice. Production through the COLEX process and the mercury electrode method has ceased since 1963, as both methods require the use of massive quantities of mercury and cause severe environmental pollution. The building used for lithium enrichment was converted from what was called the Y-12 plant, originally used for uranium enrichment through the electromagnetic enrichment method during World War II.

As mentioned in the previous section, uranium-235 is sometimes used for the tamper of the secondary. In this section, we will discuss the enrichment plants for uranium-235. As earlier mentioned, like the case of lithium, both the U.S. and Russia possess vast stockpiles of uranium-235 produced during the Cold War, so far putting an end to uranium enrichment for nuclear weapons in the two countries. However, uranium enrichment remains necessary even today for commercial nuclear reactors and naval nuclear reactors.

In Russia, its four uranium enrichment plants all remain in operation to this day. First, the above-mentioned SKhK, which previously produced plutonium, conducted uranium enrichment using the gaseous diffusion method from 1953 to 1973, switching to the gas centrifuge method in 1976, with a maximum separation capacity of 3,400 t SWU per year.[10] Also, UECP, which performs the above-mentioned deuterium enrichment, conducted uranium enrichment using the gaseous diffusion method from 1949 to 1987, and using the gas centrifuge method since 1964, with a maximum separation capacity of 11,900 t SWU per year. ECP (Electrochemical Plant) in Zelenogorsk, Krasnoyarsk Krai, conducted uranium enrichment using the gaseous diffusion method from 1962 to 1990, while also additionally using the gas centrifuge method since 1964, with a maximum separation capacity of 7,000 t SWU per year. Finally, Angarsk Electrolysis Chemical Complex in Angarsk, Irkutsk Oblast, conducted uranium enrichment using the gaseous diffusion method from 1957 to 1990, and then using the gas centrifuge method since 1990. Its maximum separation capacity is 2,000 t SWU per year.[11] As an example, Satellite Image

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[10] SWU stands for Separative Work Unit, a unit of required work to separate isotopes of uranium. It is used as an index to represent the amount of work required to produce enriched uranium from natural uranium. The Nuclear Encyclopedia ATOMICA.

[11] Pavel Podvig, “*History of Highly Enriched Uranium Production in Russia,*” *Science and Global Security*, 19, 2011, 46-67.

6 shows the uranium enrichment building of EKhZ. Uranium enrichment plants typically feature long, narrow buildings placed in a straight line, as they house cascades interconnecting a large number of devices. At EKhP, mentioned as one of the final assembly plants for nuclear weapons, uranium enrichment via the electromagnetic enrichment method was conducted for a brief period from 1947 to 1951.

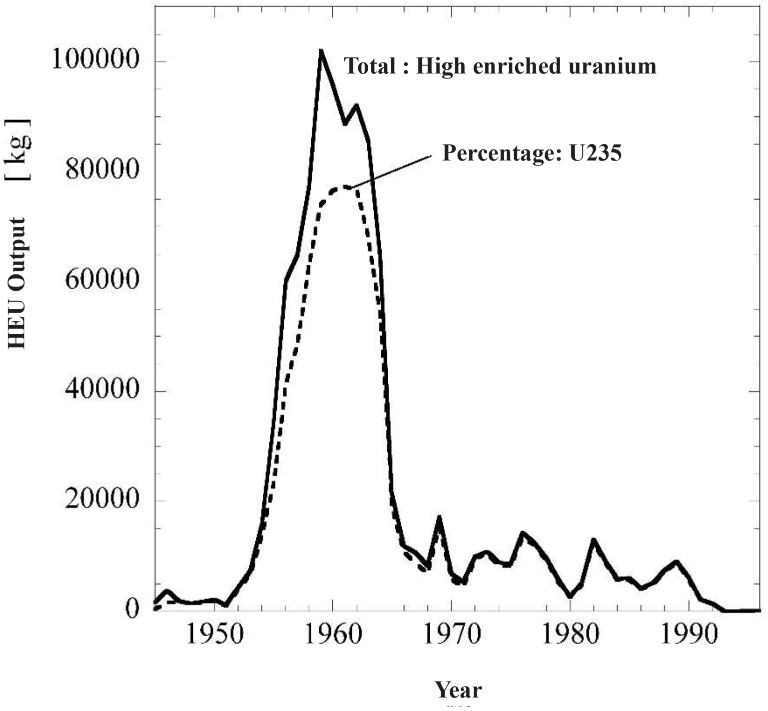
Satellite Image 6: Uranium enrichment building of EKhZ

Satellite Image 7: Lithium enrichment building of Novosibirsk Chemical Concentrates Plant

Source: Google Earth

The U.S. was home to three uranium enrichment plants, only one of which, the Paducah Site, to be described later, currently remains in operation. First, the above-mentioned Clinton Engineer Works, established under the Manhattan Project, conducted uranium enrichment using the gaseous diffusion process at its K-25 facility from 1945 to 1985 (with a maximum capacity of 7,700 t SWU/yr). During the Manhattan Project, both the thermal diffusion method at the S-50 plant and the electromagnetic enrichment method at the Y-12 plant were utilized, while the X-10 plant served as a pilot plant for the plutonium production reactor before mass production began at the Hanford Site. Next, the Paducah Gaseous Diffusion Plant, located in McCracken County, Kentucky, has been conducting uranium enrichment using the gaseous diffusion process since 1952. The plant currently remains in operation, with a maximum capacity of 11,300 t SWU per year. Finally, the Portsmouth Gaseous Diffusion Plant, located in Pike County, Ohio, conducted uranium enrichment using the gaseous diffusion process from 1954 to 2001. Its maximum separation capacity is 8,300 t SWU per year. Multiple plans to construct a separate plant using the centrifuge process within the same site have all ultimately failed to materialize. This is because the production of sufficient stockpiles of highly enriched uranium had completed before the technology to apply the centrifuge process for weapons-grade enrichment was fully established. Figure 12 shows the historical trend of annual highly enriched uranium production in the U.S.

Figure 12: Historical trend of annual weapons-grade highly enriched uranium production in the U.S.



Source: Created by the Study Group based on “Highly Enriched Uranium: Striking a Balance,” U.S. Department of Energy, National Nuclear Security Administration, Office of the Deputy Administrator for Defense Programs (2001).

Other components, including the radiation cases, fillers, and detonation control devices, are all manufactured at the Kansas City National Security Campus, located in Jackson County, Missouri.

Chapter 2

China’s Nuclear Warhead Production Cycle: What We Know and What We Don't

1. History of Nuclear Warhead Development

Evolution of the Nuclear Weapons Development Systems

China's nuclear development was initiated against the backdrop of Great Power competition during the Cold War—an environment defined by the threat from the U.S. and the provision of nuclear technology from the Soviet Union. The outbreak of the First Taiwan Strait Crisis in 1954, followed immediately by the signing of the Sino-American Mutual Defense Treaty, forced the People's Republic of China to confront the prospect of a direct military conflict with the U.S. in its pursuit of liberating Taiwan by force. Mao Zedong's declaration of the intention to develop nuclear weapons at the enlarged meeting of the Secretariat of the CPC Central Committee in January 1955 was clearly linked to these preceding events. Against this backdrop, on October 15, 1957, China signed the "New Defense Technical Accord" with the Soviet Union, which stipulated the provision of atomic bomb technology from the Soviet side.[12]

Subsequently, in July 1958, the Chinese government established the Ninth Bureau of the Second Ministry of Machine Building as the central organization for nuclear weapons development, thereby putting in place the structure for its nuclear weapons program. The Soviet Union provided not only technical materials on nuclear weapons but also assistance in the recruitment and training of technicians.[13] The technical materials also included text-based models and design diagrams related to nuclear weapons. However, with the tensions in Sino-Soviet relations escalating, these technical provisions from the Soviet Union were delayed, eventually leading the Soviet Union to formally notify China in June 1959 of its refusal to provide technical materials for nuclear warheads.

Even with no further technical support coming from the Soviet Union, China went on to pursue its nuclear weapons development on its own. In early 1960, the Ninth Bureau of the Second Ministry of Machine Building was reorganized into the Nuclear Weapons Research Institute. It was given jurisdiction over four departments (comprising 13 laboratories) for theory, experimentation, design, and production at the Beijing Nuclear Weapons Institute, as well as the Northwest Nuclear Weapons Development Base established in Haiyan County, Qinghai Province.[14]

China successfully conducted its first nuclear test on October 15 1964, followed in May of the following year by a successful air-drop test from a bomber, leading to the successful testing of a hydrogen bomb in June 1967. In addition, China began planning the development of nuclear warheads for ballistic missiles in March 1964, this time facing the need to possess advanced technology to reduce both volume and weight compared to standard nuclear bombs.[15] Nevertheless, efforts to challenge this culminated in a successful test in October 1966.

In this process, China saw a series of industrial clusters for the nuclear industry being formed across the country. While research and development was initially conducted in the capital city of Beijing, the key functions, including the development, manufacture, and deployment of nuclear weapons, were shifted to the inland regions thanks to the "Third Line Construction" (Sanxian jianshe) that entered its earnest phase in the mid-1960s. Most notable

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[12] Editorial Committee of the "Contemporary China" Series, Contemporary China. Nuclear Industry (China Social Sciences Press, 1987), pp. 13–14.

[13] Editorial Committee of the "Contemporary China" Series, op. cit., p. 258.

[14] "*China Breaks the European Cartel,*" *The Nuclear Express,*Zenith Press, 2010, p.96.

[15] Editorial Committee of the "Contemporary China" Series, op. cit., p. 287.

among these was the city of Mianyang in Sichuan Province, which emerged as a "Nuclear City," becoming the hub for a vast network of nuclear weapons development. Mark Stokes of the Project 2049 Institute points out that Base 67 of the Second Artillery Force (now the Rocket Force), where nuclear warheads are stored, was constructed in 1965 in Taibai, Baoji City, Shaanxi Province, adjacent to Sichuan, further noting that during the 1960s, the construction of a railway network connecting Baoji, Chengdu, and nuclear material production facilities near Mianyang was led by the People's Liberation Army Railway Corps.[16] Currently, Base 67 of the Rocket Force is believed to comprise multiple units primarily responsible for the operation of nuclear warheads: a missile technical service brigade tasked with managing nuclear warheads and conducting various tests; Unit 96038, which conducts the inspection and protection of warheads; and a special equipment transport regiment, which is responsible for the transportation of nuclear warheads.[17]

Satellite Image 8: Base 67 of the Rocket Force, deemed as a nuclear warhead storage facility

Source: Created by the Study Group based on Google Earth

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[16] Mark Stokes, "*China's Nuclear Warhead Storage and Handling System,*" Project 2049 Institute, March 2010, p.4.

[17] China Aerospace Studies Institute, "*PLA Rocket Force Organization*" October 24, 2022, pp.179-193.

Research and Development Organizations for Nuclear Weapon Development

When reviewing the development history of nuclear weapons in China, it is important to note that its nuclear governance underwent significant changes during the reform and opening-up process, which likely extended to the nuclear defense industry as well. Following the decision to adopt reform and opening up, the focus of the Party and the state shifted, and the defense science and technology industry was strategically adjusted “to military-civilian integration, with the military as the main focus.”[18]

To be specific, in April 1979, the Second Ministry of Machine Building, a then administrative organization, became responsible for the active development of nuclear power generation, the promotion of the application of radioisotopes and other nuclear technologies, the production of civilian and export products, and the design and construction of civilian engineering. Through these adjustments, the nuclear industry reportedly shifted its focus to building the national economy while maintaining national security.[19] In addition, the Second Ministry of Machine Building was renamed the Ministry of Nuclear Industry in May 1982 and reorganized into the China National Nuclear Corporation in September 1988. Although the China National Nuclear Corporation was positioned as a corporation, it was evident that it actually retained administrative organizational functions and concurrently performed governmental duties.[20]

The current China National Nuclear Corporation (CNNC) and the China Nuclear Engineering & Construction Corp. were separated into two distinct entities in 1999 in the process of reorganizing the previous China National Nuclear Corporation. CNNC is essentially a state-owned company, but it maintains close ties with the government and performs some administrative functions. One of the most emblematic examples of the privatization trend is the 404 Company Ltd., China National Nuclear Corporation. The company was originally the state-owned 404 Plant located in Jiuquan, Jiayuguan City, Gansu Province, and is said to have served as a key industrial production base for nuclear weapons development.[21] However, as a result of CNNC's establishment in 1999, the 404 Company became a subsidiary of CNNC in 2003. Amidst the ongoing shift toward a market economy, it appears to have reduced its military equipment manufacturing business and focused on civilian nuclear power development projects, such as the treatment of radioactive waste.[22]

However, CNNC is believed to still be involved in military force development. In this regard, of the nine directly-controlled companies under CNNC (Figure 14), the Nuclear Power Institute of China (NPIC), located in Chengdu City, is important. The website of an equipment manufacturing plant owned by NPIC partially discloses that it manufactures “military equipment”.[23] Furthermore, Zhang Hui of Harvard University's Belfer Center pointed out that NPIC developed a second-generation nuclear reactor for naval vessels in 2006, suggesting that CNNC remains involved in the production of nuclear-related military equipment.[24]

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[18] 「中国核工业：在改革中新生，在开放中崛起」, China Atomic Energy Authority, December 20, 2018

[19] 「改革开放40年大事记 我们一路走来」、中国核网, December 19, 2018

[20] 「中国核工业：在改革中新生，在开放中崛起」, China Atomic Energy Authority, December 20, 2018

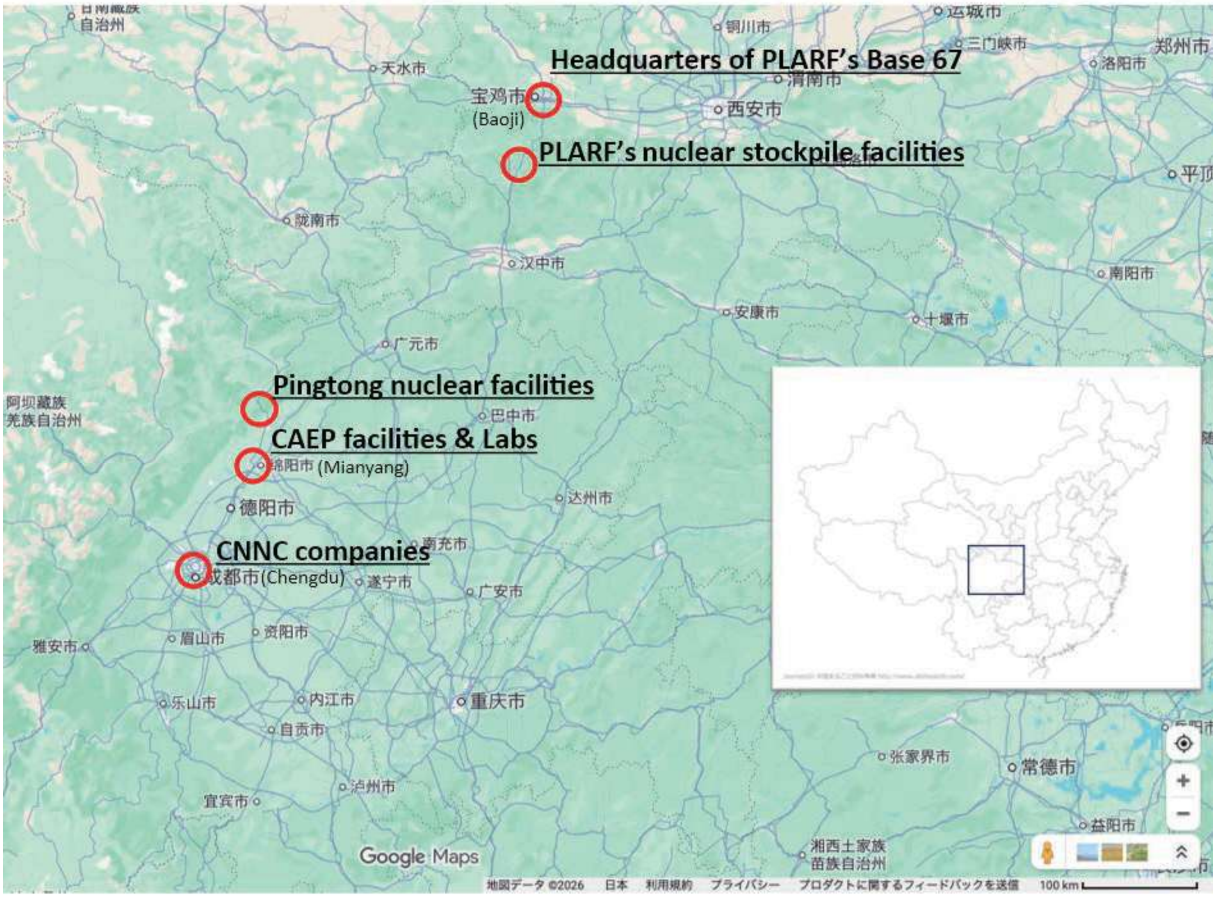
[21] 「穿越时空追忆红色历史 央视走进中国核城“404”」, The Paper, February 22, 2021

[22] 「核城之旅」, National Nuclear Safety Administration, April 21, 2025

[23] 「设备制造厂 关于我们」, Nuclear Power Institute of China, accessed November 5, 2025

[24] Hui Zhang, “*China’s Fissile Material Production and Stockpile,*” Research Report No. 17 International Panel on Fissile Materials, p.17.

Figure 13: Nuclear Industry Sites Centered on Sichuan Province



Source: Prepared by our Study Group

On the other hand, regarding the development of nuclear weapons themselves, the China Academy of Engineering Physics (CAEP) is believed to play a significant role. CAEP is said to be equivalent in scale to an organization that integrates the Los Alamos, Lawrence Livermore, and Sandia national laboratories in the U.S.[25] CAEP was originally called the Ninth Bureau (Institute) because it was an institute under the jurisdiction of the Ninth Bureau of the Second Ministry of Machine Building. The institute took over the operations of the Northwest Nuclear Weapons Research and Design Academy (now closed), which was located in Haiyan County, Qinghai Province, during several reorganizations in the course of the Third Front Construction in the 1960s, and separated from China National Nuclear Corporation in 1990 to become the current CAEP.[26] According to CAEP's webpage for researcher recruitment, the following 15 research institutes exist under its umbrella.[27] Many of these institutes are believed to be located within Mianyang City.[28]

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[25] Thomas C. Reed & Danny B. Stillman, “*China’s Decade of Nuclear Transparency,*” *The Nuclear Express: A Political History of the Bomb and its Proliferation*, Zenith Press, 2000, p.220.

[26] For a history of the CAEP's reorganization, refer to 中国核工业「九院，旧居还是九所?这次终于厘清了」, Chinese Nuclear Society, dated August 18, 2020.

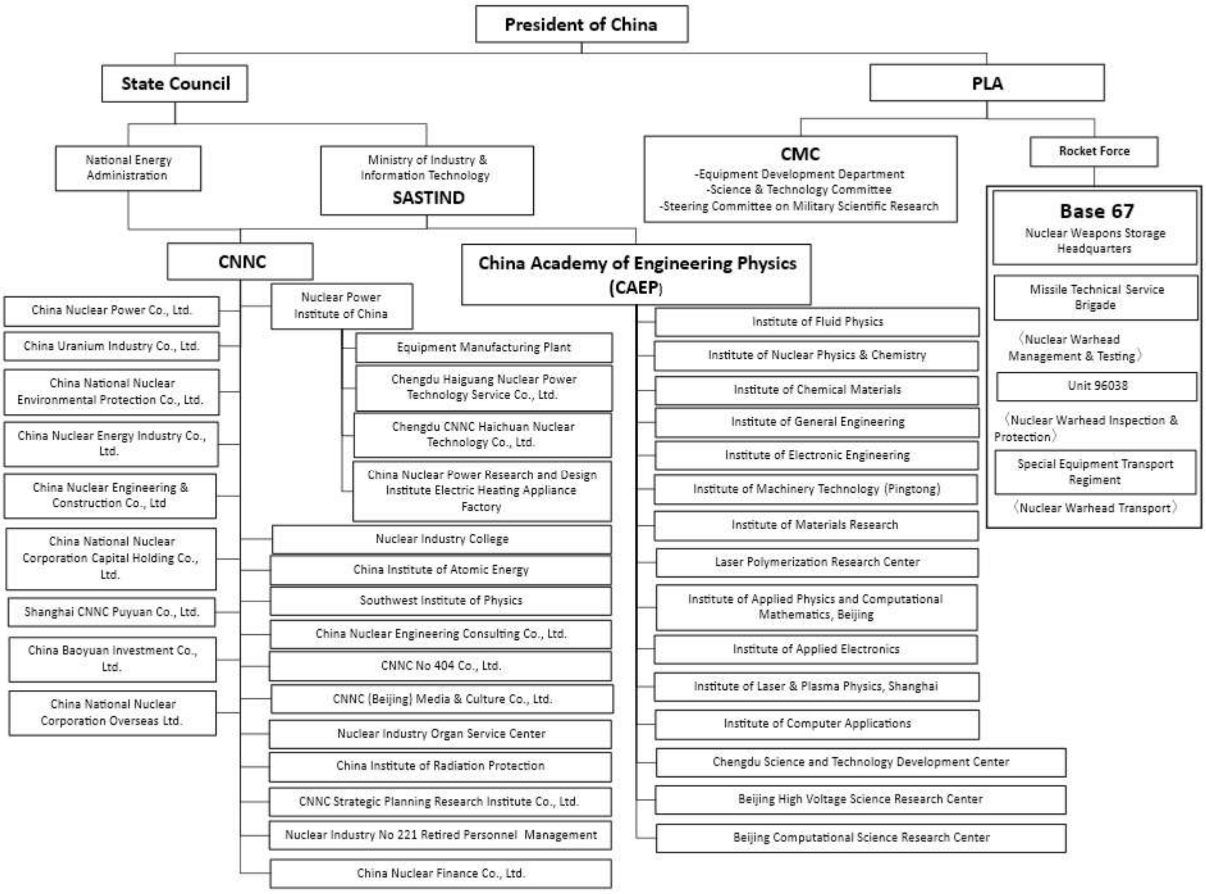
[27] 「培养单位」, CAEP's graduate school - admissions information website, accessed November 5, 2025

[28] NTI, “*Chinese Academy of Engineering Physics (CAEP),*” last updated: September 29, 2011.

Note that various information within China suggests that scientific research institutions associated with CAEP in Mianyang City and organizations associated with CNNC in Chengdu City suffered significant damage during the 2008 Sichuan earthquake.[29]

1. Institute of Fluid Physics
2. Institute of Nuclear Physics and Chemistry
3. Institute of Chemical Materials
4. Institute of Systems Engineering
5. Institute of Electronic Engineering
6. Institute of Mechanical Manufacturing Technology
7. Institute of Materials
8. Laser Fusion Research Center
9. Beijing Institute of Applied Physics and Computational Mathematics
10. Institute of Applied Electronics
11. Shanghai Institute of Laser Plasma
12. Institute of Computer Application
13. Chengdu Science and Technology Development Center
14. Beijing High Pressure Science Research Center
15. Beijing Computational Science Research Center

Figure 14: Organizational Chart of Nuclear Development in China



Source: Prepared by our Study Group based on each document

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[29] For example, 马娜，高炳焱，宋生「攀积极传承 勇于实践 探索创新 中国核动力研究设计院军工核安全文化建设纪实」『中国军转民』pp. 20–25

2. Activities for Acquiring Nuclear-related Technology

History of Technology Acquisition

On the other hand, China's development of nuclear weapons has not been entirely self-reliant. As previously mentioned, the development of nuclear weapons in the Cold War era began with technical cooperation from Soviet Union. However, it is known that, after Cold War, active technology acquisition from the U.S. was pursued. From a methodological perspective, this type of technological acquisition appears to have evolved through parallel and complementary pathways: from cyber attacks and human pathways.

The turning point that revealed the true extent of China's technology acquisition was 2014. In the same year, the U.S. Department of Justice indicted 5 officers of the People's Liberation Army Unit 61398 for theft of trade secrets from nuclear-related and other companies in the U.S., and other offenses.[30] In the following year, 2018, two members of the so-called APT10,[31] Zhu Hua and Zhang Shilong, were indicted, revealing that the attack is not limited to individual companies, but has a structure that can spread simultaneously to diverse industries and multiple countries through chain intrusion, using the legitimate authority of an MSP (Managed Service Provider: external IT operations provider) as a springboard.[32]

In 2023-2024, a joint recommendation by U.S. agencies, including CISA, NSA, and FBI, confirmed that a China-backed group Volt Typhoon had infiltrated the IT networks of important infrastructure operators and remained in hiding for a long period of time. It also pointed out that Volt Typhoon had been "pre-positioning" in various sectors, including communications, energy, transportation, and water utilities, in order to establish inconspicuous footholds during peacetime to potentially disrupt Operational Technology (OT) in the future.[33] This suggests that concrete intrusion pathways and procedures to gain access to core data, such as design, processes, materials, and procurement, from nuclear-related peripheral fields, including power, communications, and logistics, were already operational.

In Europe, too, while a report appeared on December 4, 2023 concerning Sellafield in the U.K., pointing to "infiltration by Russia/China-affiliated groups," on the same day the U.K. government officially stated that it had no evidence of a successful attack. However, the weakness of information security management at nuclear-related facilities was officially recognized judicially as well, with a guilty plea and fine of £332,500 in 2024 for deficiencies in the cyber management system at the facility in 2019–2023.[34] Opinions were mixed as to whether the intrusion was actually successful. However, the independent fact of these control deficiencies means that, from the attacker's perspective, realistic opportunities and pathways existed to access internal information.

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[30] U.S. Department of Justice, "*U.S. Charges Five Chinese Military Hackers for Cyber Espionage Against U.S. Corporations and a Labor Organization,*" May 19, 2014; Federal Bureau of Investigation (FBI), "*Five Chinese Military Hackers Charged with Cyber Espionage Against U.S.,*" May 19, 2014.

[31] A subgroup of an Advanced Persistent Threat, APT: A group receiving support from a state or similar entity to conduct long-term covert operations and sustained campaigns

[32] U.S. Department of Justice, "*Two Chinese Hackers Associated With the Ministry of State Security Charged with Global Computer Intrusion Campaigns,*" Dec 20, 2018.; CISA / NSA / FBI et al, "*PRC State-Sponsored Actors Compromise and Maintain Persistent Access to U.S. Critical Infrastructure (AA24-038A),*" Feb 7, 2024 (PDF).; NCSC, APT10 advisory, Dec 20, 2018 (PDF)

[33] CISA / NSA / FBI et al, "*PRC State-Sponsored Actors Compromise and Maintain Persistent Access to U.S. Critical Infrastructure (AA24-038A),*".

[34] UK Government, "*Response to a news report on cyber security at Sellafield,*" Dec 4, 2023 ; *The Guardian* Dec 4, 2023 ; *Reuters* Dec 4, 2023 ; Office for Nuclear Regulation (ONR) "*Sellafield Ltd fined £332,500 for cyber security shortfalls,*" Oct 2, 2024 ; *Financial Times* Oct 2, 2024.

There were also many cases involving human pathways. Allen Ho (Szuhsiung Ho/He Zhixiong) was sentenced to 24 months' imprisonment in 2017 for his involvement in supporting the overseas development of special nuclear materials for the China General Nuclear Power Group (CGN) without a permit under the U.S. Atomic Energy Act.[35] Turab Lookman was sentenced to probation for 5 years and fined $75,000 (in 2020) for false declaration of involvement in China's national human resources program.[36] Even within formally legitimate frameworks, such as recruitment, joint research, and part-time work, it has been demonstrated that knowledge can leak out through lax data governance and lack of transparency in conflicts of interest.

Methods

A typical cyber operation targeting nuclear-related areas follows the chain: (1) initial access (spear phishing email, exploitation of edge device vulnerabilities, and MSP as a stepping stone), (2) persistence (abuse of schedulers, VPN configurations, and cloud trust relationships, etc.), (3) credential theft (compromise of domain credentials and administrator accounts), (4) lateral movement, and (5) collection and exfiltration. The key here is LOTL (Living Off The Land: a method that keeps traces inconspicuous by using only legitimate tools and official accounts), and since it uses legitimate management tools, such as RDP and WMI, detection becomes difficult. Analysis of Volt Typhoon identified risks where vulnerabilities, such as Fortinet, Ivanti, Citrix, and Cisco, could ultimately lead to access of NTDS.dit (Windows domain account databases) or the log infrastructure.[37]

Another important point highlighted by APT10 is that by abusing the legitimate authority of an MSP, one could indirectly access design blueprints, test and quality records, material specifications, purchase ledgers, and even analysis data such as HPC/EDA—all without directly infiltrating individual nuclear-related companies. This is achievable by leveraging the legitimate administrative privileges and connection paths held by an MSP (an external IT operator). The joint technical report by an international audit and consulting firm, PricewaterhouseCoopers (PwC) and a U.K. defense and cybersecurity firm, BAE Systems, stated that this method "could affect thousands of companies," specifically indicating a structure in which effects could spread to many organizations simultaneously.[38] In other words, infiltrating the backup log and configuration management areas of the MSP path can serve as a concrete pathway for actually accessing critical data, such as nuclear-related design drawings, process records, material specifications, and purchasing records.

Nuclear facilities and their supply chains are closely linked to critical infrastructure, including power, telecommunications, logistics, water supply, and MSP. In the case of Cloud Hopper (common name for a widespread infiltration operation targeting MSP, carried out by a cyber group, APT10, with the support of China), the following step-by-step method was identified: first, enter the customer's network using MSP's management

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[35] U.S. Department of Justice "*U.S. Nuclear Engineer, China General Nuclear Power Company and Energy Technology International Indicted in Nuclear Power Conspiracy against the United States,*" Apr 14, 2016 ; U.S. Department of Justice (USAO-EDTN "*U.S. Nuclear Engineer Sentenced to Serve Twenty-Four Months in Federal Prison for Violating The Atomic Energy Act,*" Aug 31, 2017

[36] U.S. Department of Justice "F*ormer employee at Los Alamos National Laboratory sentenced to probation for making false statements about being employed by China,*" Sep 15, 2020.

[37] CISA / NSA / FBI et al, "*PRC State-Sponsored Actors Compromise and Maintain Persistent Access to U.S. Critical Infrastructure (AA24-038A),*" Feb 7, 2024 (PDF).

[38] PwC UK / BAE Systems, Operation Cloud Hopper: Exposing a systematic hacking operation with an unprecedented web of global victims, Apr 2017 (PDF).

path; then, consolidate and store the collected data on the MSP side; finally, transmit it externally.[39] As a result, it became clear that confidential information entrusted to the MSP by customers could potentially leak externally, mixed in with the MSP's normal business data exchanges.

Applying this mechanism to nuclear-related fields creates a realistic path to gain undetected access to facilities themselves and the main vendor’s information technology (IT) and operational technology (OT) systems, thereby enabling broad access to critical data, such as design drawings, process records, quality records, material specifications, and procurement records. Rather than immediately committing sabotage, Volt Typhoon is said to have first lurked inconspicuously for a long time, gathering information that could be useful for future sabotage, such as network configuration diagrams and operational procedures, as well as which routes the manager usually operates on. While this information does not directly relate to the design of nuclear weapons on its own, when combined with information from various processes, such as the procurement and processing of nuclear fuel, the manufacturing, quality assurance, and operation and maintenance of machinery, it can be reorganized into detailed, practical knowledge.

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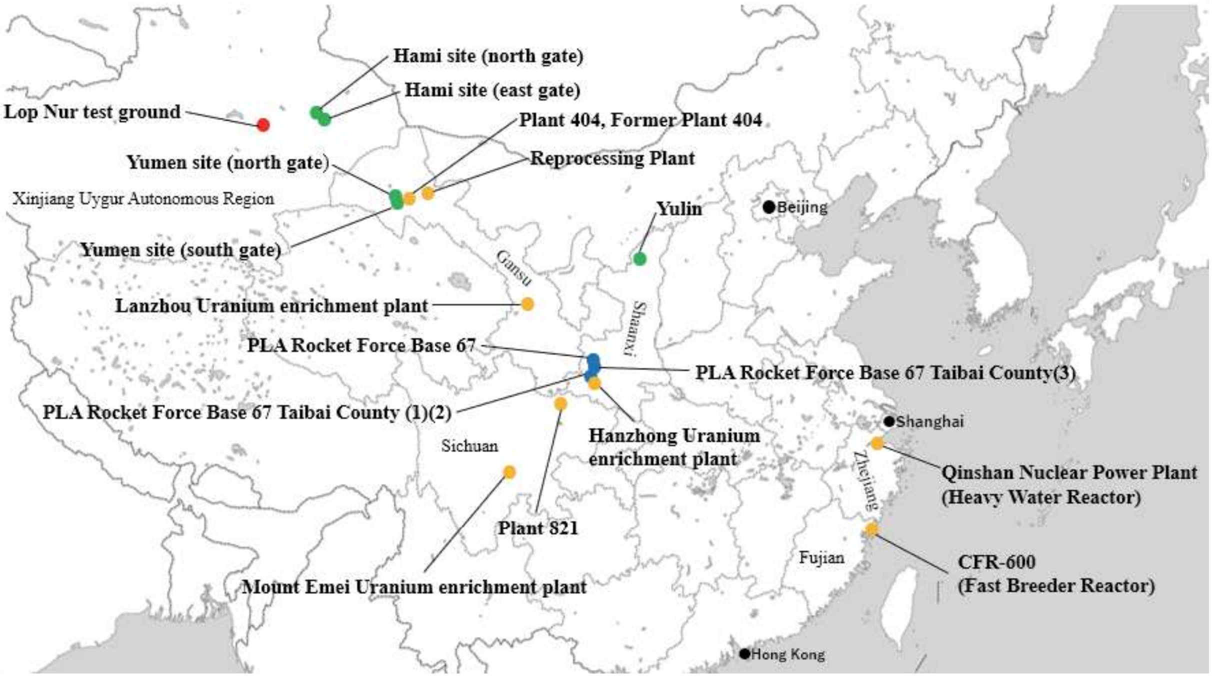
[39] Ibid.

3. Current Framework for Nuclear Material Production and Nuclear Warhead Assembly

Overview

China is a country specifically authorized under the Nuclear Non-Proliferation Treaty (NPT) to possess nuclear weapons, and it is not required to comply with safeguards (inspections of nuclear facilities and nuclear material) imposed by the International Atomic Energy Agency (IAEA). Consequently, while there are still many unknowns regarding the nuclear warheads production cycle, some details have come to light. Therefore, this section summarizes "what we know" and "what we don't know" about China’s nuclear warheads production cycle, while also taking into account the contents of Chapter 1 and Section 1 of this chapter. Of these, “what we know” is plotted on the map in Figure 15 below, and in this section below we will describe the current status of the main facilities.

Figure 15: China’s Major Nuclear-related Facilities (reprinted)



Source: Prepared by our Study Group

Plutonium Production

Plutonium production in China during the Cold War period was carried out at the 404 plant in Gansu Province (see Section 1) and the 821 plant in Sichuan Province, but plutonium production at both plants is believed to have ceased once by 1989.[40] In addition, since 1998, based on the IAEA’s Guidelines for the Management of Plutonium (INFCIRC/549), China has been reporting its civilian plutonium holdings to the IAEA. The latest report from

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[40] Hajime Matsukubo, “*Yuryo Sareru Chugoku no Kakunenryo Risaikuru Shisetsu* (China’s Nuclear Fuel Cycle Facilities Raising Concerns),” *Genshiryoku Shiryo Johoshitsu Tsushin* (CNIC Newsletter) No. 614, August 2025, pp. 12–13; International Panel on Fissile Materials (IPFM) “*Plutonium: China,*”

China, based on this, stated that it had 40.9 kg of civilian plutonium at the end of 2016.[41] Including the above, the International Panel on Fissile Materials (IPFM) estimated China's plutonium holdings as of January 2024 to be 2.9 ± 0.6 tons (Table 6).

Table 6: Plutonium Holdings of Each Country

Country	Plutonium Holdings (Unit: t)	Amount of Military-convertible Plutonium (Unit: t)
Russia	193	88±8
US	87.6	38.4
UK	120	3.2
France	102	6±1
China	3	2.9±0.6
Pakistan	0.58	0.58±0.2
India	11	0.7±0.16
Israel	0.9	0.9±0.1
North Korea	0.04	0.04
Japan	44.4	0

Source: Prepared by our Study Group based on Data from the International Panel on Fissile Materials (IPFM)

However, since 2017, China has ceased reporting based on INFCIRC-549 without specifying the reason. As a result, China is the only one of the five nuclear powers (US, Russia, China, UK, and France) that does not report under INFCIRC-549. In response to the expansion of nuclear capabilities that began around this time (discussed later in Section 1 of Chapter 3), there is a possibility that China attempted to conceal the plutonium production capacity, which was a bottleneck in its nuclear warhead production cycle.

In fact, shortly before this, China had begun to increase its plutonium production capacity. As of 2025, China is operating 57 nuclear reactors, nearly 4 times as many as Japan, mainly pressurized light-water reactors (PWRs), the technology of which was transferred from France.[42] In addition, considering the possibility of a future shortage of uranium fuel, China has been trying to establish a nuclear fuel cycle technology in which plutonium is separated from PWR spent fuel and mixed with uranium into mixed oxide fuel (MOX fuel) to be used in fast breeder reactors (FBRs) with high power generation efficiency.[43] Therefore, it is believed that two FBRs, called CFRs, were constructed in Fujian Province, and a civilian reprocessing facility was constructed at the 404 plant, which started operation around 2010. However, due to ongoing troubles, it is estimated that the plant did not resume normal operations until around 2019.[44]

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[41] IAEA "*Communication Received from China Concerning its Policies Regarding the Management of Plutonium,*" October 18, 2017. IAEA "*Power Reactor Information System: China,*"

[42] IAEA "*Power Reactor Information System: China,*"

[43] Mark Hibbs, "*The Future of Nuclear Power in China,*", 2018, p.77.

[44] Hui Zhang, "*Chugoku no purutonium risaikuru keikaku—genjou to mondaiten*", (China's Plutonium Recycling Plan: Current Status and Issues), New Diplomacy Initiative, Vol. 15, April 2022, p. 1

Satellite image 9: 404 plant

Source: Google Earth

Since 2015, construction of two new reprocessing plants has started in the desert area of Gansu Province, not far from the above-mentioned pilot reprocessing plant. Although the Chinese government and China National Nuclear Corporation (CNNC), the designated operating entity, have not disclosed details, the first plant had completed the civil construction phase by February 2020, and moved on to the equipment installation phase. Although there has been no official announcement, it appears that construction of the second plant began around 2020. According to the investment plan for Gansu Province released in 2021, the total investment in the development of reprocessing plants, including the first and second plants, is stated as 300 billion yuan (approximately 6 trillion yen).[45] Comparing satellite images 10 and 11 (as of 2021 and 2024), the progress of the construction is obvious, and the first plant is expected to start operation sometime in 2026. On the other hand, some facilities of the second plant have not yet had their roofs laid, so operation is not expected to begin until 2030 or later.

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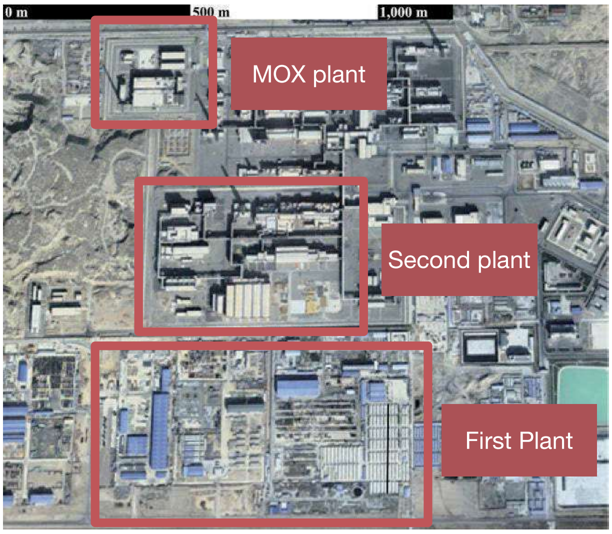
[45] Hajime Matsukubo, “*Yuryo Sareru Chugoku no Kakunenryo Risaikuru Shisetsu* (China’s Nuclear Fuel Cycle Facilities Raising Concerns),” pp. 12–13

Satellite image 10: Reprocessing plant in Gansu Province (November 8, 2021)

Satellite image 11: Reprocessing plant in Gansu Province (November 12, 2024)



Source: Prepared by our Study Group based on Google Earth

FBR, which constitutes another pillar of the nuclear fuel cycle, has been called the “dream reactor” because the reaction of nuclear fuel during operation produces new plutonium, allowing for the recovery of more plutonium than the amount of fuel loaded. The U.S., Russia, France, the UK, and Japan were leading the way in the development of FBR technologies for practical use, and Japan operated a prototype reactor called “Monju” from 1994 to 1995. However, due to difficulties in controlling the sodium used to cool the FBR, the U.S. stopped development in the 1980s, the UK and France in the 1990s, and Japan also decided to decommission Monju in 2018.

Meanwhile, China signed an agreement on nuclear energy cooperation with Russia in 2018 and has continued to develop the FBR. In the case of FBR, reprocessing its spent fuel can extract ultra-pure plutonium-239 that is optimum for nuclear weapons. Consequently, concerns about military diversion persist. The U.S. Department of Defense points out that China, which aims to achieve a military balance with the U.S., may use these FBRs as sources of weapons-grade plutonium.[46]

Satellite image 12 shows a clearly visible white whirlpool in the drain located above Unit 1, indicating that a large amount of discharge is taking place. To operate the FBR safely, it is necessary to draw in approximately 50 tons of seawater per second to cool the reactor’s auxiliary equipment; therefore, a large volume of discharge indicates that the reactor has entered the test operation phase. The roof has also been installed on the reactor building at Unit 2, indicating that completion is nearing. It was confirmed that Unit 1 began discharging large volumes of water into the sea in the summer of 2023, but since the discharge has been known to stop intermittently, it should be considered that the unit has not yet reached full-scale operation.[47] The spent fuel loaded

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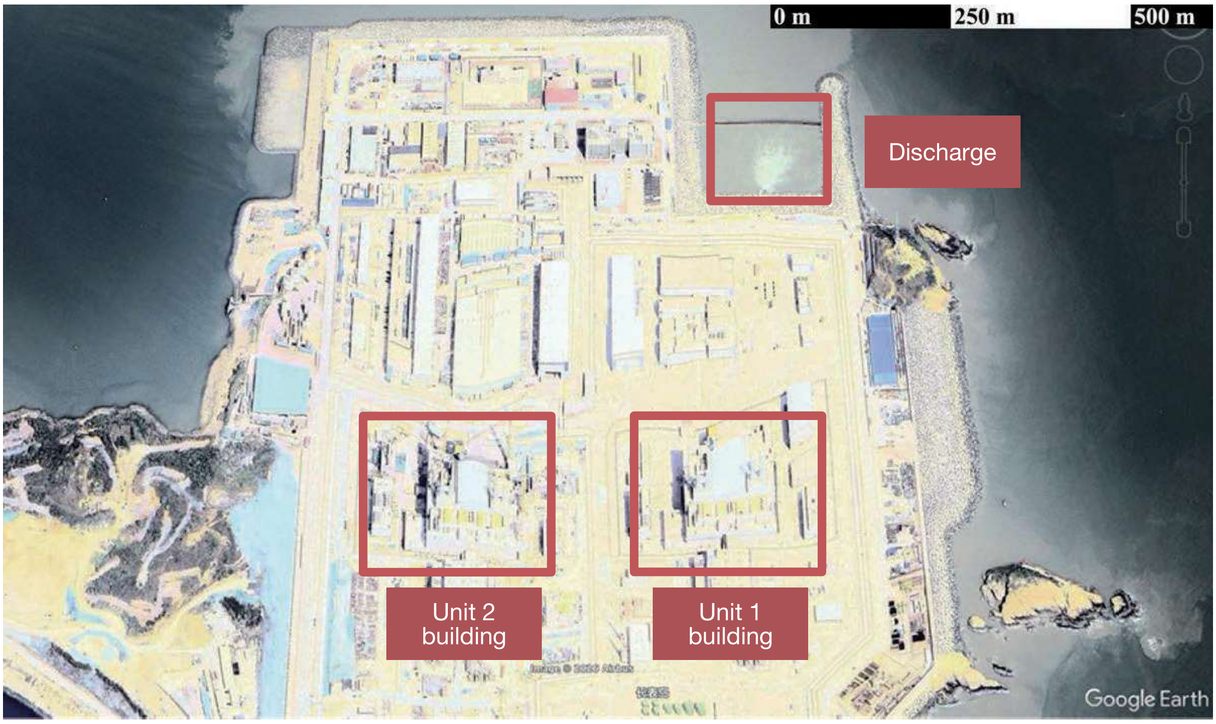
[46] U.S Department of Defense “*MILITARY AND SECURITY DEVELOPMENTS INVOLVING THE PEOPLE’S REPUBLIC OF CHINA 2024,*” Dec 2024, p. 101.

[47] Satellite imagery reviewed by our Study Group showed that discharge from the FBR stopped for a relatively long period of time from March 8 to 20, 2024.

in Unit 1 will not be removed and reprocessed to obtain plutonium until after 2026 at the earliest. In any case, it should be noted here that China has been systematically increasing its plutonium production capacity since the 2010s, and it is believed that this is based at the 404 plant and the surrounding facilities in Gansu Province, and FBRs in Fujian Province.

Satellite image 12: FBR in Fujian Province



Source: Prepared by our Study Group based on Google Earth

Uranium Production and Enrichment

Uranium enrichment in China began in 1964. It is reported that the uranium enrichment facility at Lanzhou, in Gansu Province, which began operations that same year, was producing 200 t SWU/y; however, due to insufficient power supply capacity, the decision was made to abandon the facility in 1996. Meanwhile, in 1992, China signed an agreement with Russia on the provision of uranium enrichment technology by centrifugal separation, and began operating enrichment facilities in Lanzhou and Hanzhong in Shaanxi Province in 1996. The total enrichment capacity of both facilities is estimated to reach 1500 t SWU/y.[48]

However, both facilities are subject to safeguards imposed by IAEA, making it difficult to divert the enriched uranium produced there to nuclear weapons. In addition, China's uranium enrichment technology was originally introduced from Russia, but since military diversion is prohibited by the agreement when receiving technical cooperation, it is difficult to assume that nuclear weapons will be manufactured using enriched uranium produced at both plants from this point of view.

On the other hand, the highly enriched uranium used in nuclear fusion weapons produces sufficient power through the action of neutrons, even with enrichment below 80%, and does not require the very laborious process

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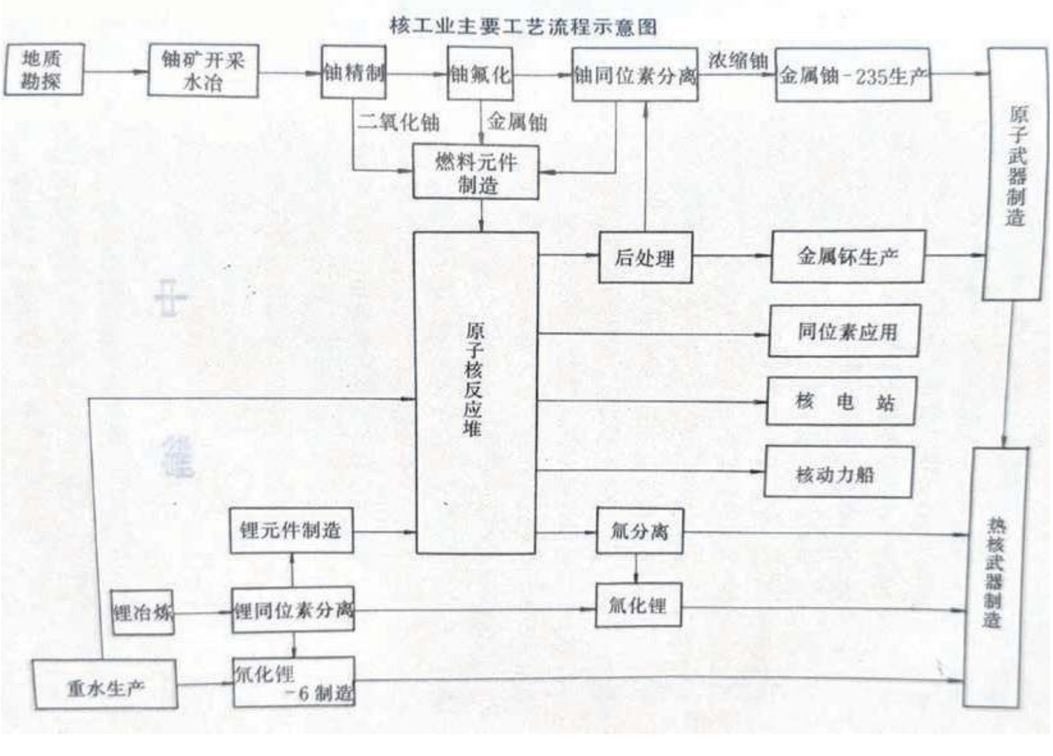
[48] Japan Atomic Energy Agency (JAEA), "*Chugoku no kakunenryo saikuru* (China's Nuclear Fuel Cycle)"

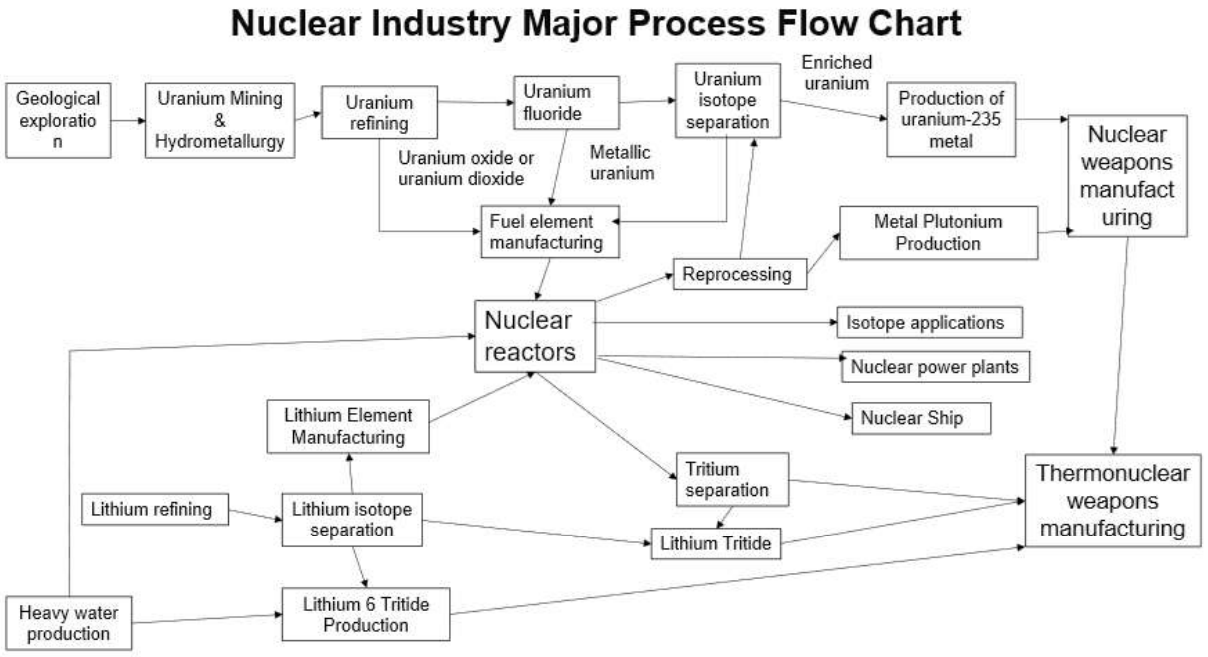
of enrichment above 90%. China successfully domesticated uranium enrichment technology using the centrifugal separation method in 2013, and it should be considered fully feasible to mass-produce enriched uranium at approximately 80%. Furthermore, since 80% enriched uranium can also be used as fuel for naval nuclear reactors, it appears that China has the capability to supply fuel independently for nuclear-powered naval vessels as well.

Specifically, China has a third uranium enrichment plant at Emei Shan, Sichuan Province, which is likely the production site for enriched uranium for nuclear weapons and nuclear-powered vessels. If this plant had an enrichment capacity of approximately 1000 t SWU/y and 800 t of natural uranium (uranium hexafluoride) could be supplied to it, this would be sufficient to produce approximately 100 shots' worth of 80% highly enriched uranium for hydrogen bombs every year.

According to "Nuclear Industry Flowchart" of "Contemporary China. Nuclear industry" (China Social Sciences Press, 1987) published in China in the 1980s, it appears that China's nuclear weapons also use plutonium and uranium-235 to produce the primary (Figure 16). Of these, uranium-235 is likely being used as the tamper (see Chapter 1, Section 1).

Figure 16: Nuclear Industry Flowchart (Original text and English translation)





Source: "*Contemporary China. Nuclear industry*" (China Social Sciences Press, 1987), p. 100 The Japanese translation was prepared by our Study Group.

Tritium Production

The actual state of the production system for tritium required for the neutron generator and booster remains even more unclear. Tritium has the property of transforming into helium-3 in a short period of time through beta decay. Therefore, the tritium pit that constitutes the neutron generator and booster within a nuclear warhead requires the removal of helium-3 and addition of new tritium (refreshment) at approximately four-year intervals. (Note that the tritium required for a single nuclear warhead is said to be 4–8 g.) This is why the U.S. and Russia continued to operate their tritium production reactors even after halting fission material production, and the same situation should apply to China as well. Since the aforementioned "Nuclear Industry Flowchart" indicates that tritium is used for China's nuclear weapons, we should assume that the primary portion uses tritium as a booster.

According to recent research, China produced tritium for the booster until the 1980s at the plutonium production reactor in Jiuquan, Gansu Province, which is fueled by natural uranium. In addition, a project to build a heavy water reactor for tritium production (827 project) was brought up in the 1970s to enhance tritium production, but the plan was apparently abandoned in the early 1980s. Thus, the full picture is not yet clear as to where China has been producing tritium to maintain its existing nuclear warheads,[49] but some believe that the nuclear fuel production facility (812 plant) in Yibin, Sichuan Province, is producing tritium along with lithium-6.[50]

A report by the U.S. Department of Defense points out that part of the tritium production process may be taking place at the heavy water reactors located in Haiyan, Zhejiang Province.[51] There are two heavy water reactors, as detailed in the next chapter, and according to the IAEA, both have an output of 728 MW Since "nuclear-weapons-

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[49] Hui Zhang, *China's Fissile Material Production and Stockpile*, Research Report No. 17, International Panel on Fissile Materials, 2017, p. 18.

[50] "*PRC's Nuclear Facilities,*" atomicarchive.com.

[51] US. Department of Defense "*MILITARY AND SECURITY DEVELOPMENTS INVOLVING THE PEOPLES REPUBLIC OF CHINA 2024,*" p. 108

grade plutonium" can be extracted by reprocessing the spent fuel of heavy water reactors, the U.S. Department of Defense's observation implies that these heavy water reactors could serve as supply hubs for the nuclear material required for nuclear weapons in China.

Nuclear Warhead Assembly

As described in Section 1, China's nuclear weapons development was originally conducted at the Northwestern Nuclear Weapons Development Base in Haiyan County, Qinghai Province. It is believed that the facility was involved in the production of explosives for implosion lenses, fission components, and other related components, as well as final assembly.

However, production and assembly of the nuclear warheads at that facility continued only until the 1970s; since then, Sichuan Province has played a central role. Of particular importance is the testimony of an American researcher who visited the FBR and the high-speed explosive testing facility located in the mountains away from Chengdu in 1990.[52] This is believed to have been a nuclear warhead manufacturing facility near Pingtong Town, Pingwu County in Mianyang City, Sichuan Province.[53] According to Renny Babiarz, a classified underground facility has been established in this area, and it appears to be responsible for processing, manufacturing, and assembling plutonium metals and other hazardous substances into components for nuclear weapons.[54] Babiarz also points out that its production capacity may have increased significantly over the past 20 years. In fact, from satellite image 13, it can be seen that there was significant building expansion in this area from the 2000s to the 2020s, followed by forest clearing and the construction of new facilities. According to a February 2026 report in the New York Times, expansion of the facility has been prominent since 2019 and is speculated to be used for plutonium core production.[55]

On the other hand, while there is information suggesting that the final assembly of nuclear warheads is carried out at Harbin, we were unable to identify any suspicious facilities within the scope of the present study.

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[52] Thomas C. Reed & Danny B. Stillman "*China's Decade of Nuclear Transparency,*" *The Nuclear Express: A Political History of the Bomb and its Proliferation*, Zenith Press, 2000, pp.226-227.

[53] Hailey Wingo "*Complex near Mianyang likely associated with China's nuclear weapons program,*" *Vertic*, May 6, 2025.

[54] Renny Babiarz "*Expansion at China's Pingtong Nuclear Facility, 2002-2020, AllSourc Analysis,*" 13 November 2020, p.2.

[55] *The New York Times*, February 15, 2025.

Satellite image 13: Progress on the development of the nuclear-related facility areas in Pingtong Town

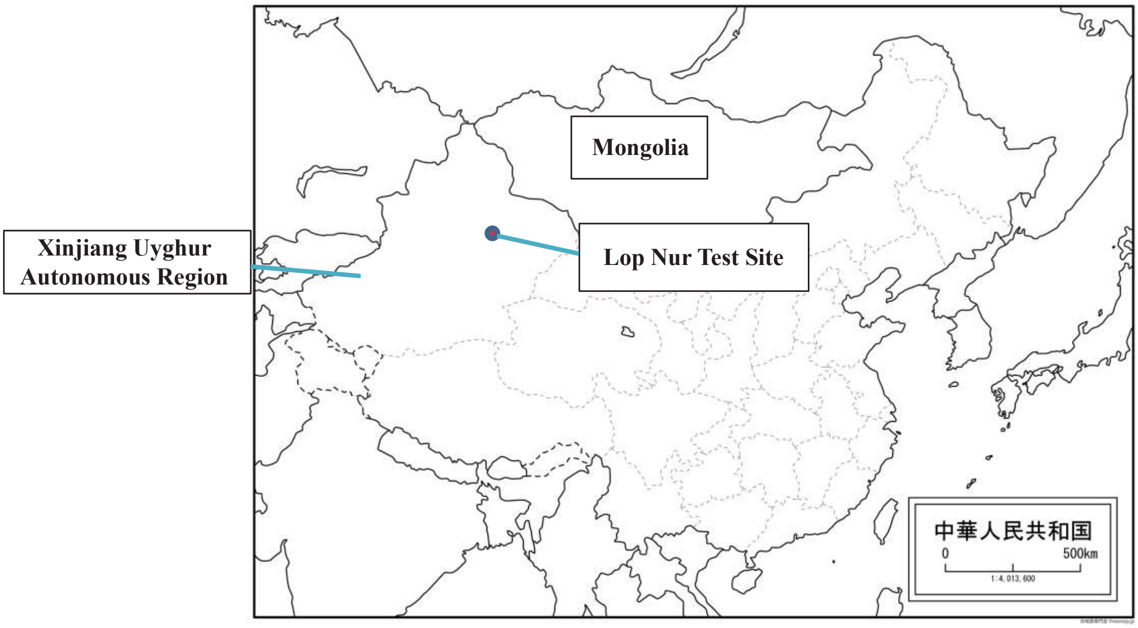
Source: Created by the Study Group based on Google Earth

4. Nuclear Test Facilities

Overview of the Lop Nur Nuclear Test Site

Nuclear explosion tests are necessary for deploying nuclear warheads in order to verify the behavior of nuclear materials and the effectiveness of implosion technology. Nuclear tests are also necessary to improve the performance of nuclear weapons. This prompted the United States and the Soviet Union to conduct numerous nuclear tests during the Cold War. China has also conducted atmospheric and underground nuclear tests at the Lop Nur Test Site in the Xinjiang Uyghur Autonomous Region (Figure 17).

Figure 17: The Lop Nur Test Site



Source: Prepared by our Study Group

A total of 46 nuclear tests are said to have been conducted at this test site, beginning with the atmospheric nuclear test carried out in early October 1964. In August 1963, the United States, the United Kingdom, and the Soviet Union signed the Partial Test Ban Treaty (PTBT), which banned atmospheric nuclear testing. China, however, which had fallen behind in nuclear development, did not join the treaty and continued to conduct atmospheric nuclear tests until the 1980s.

Since the 1980s, China has shifted from atmospheric to underground nuclear testing and has developed a total of five tunnels to date at the site. The last nuclear test at the Lop Nur Nuclear Test Site was conducted in July 1996. This move is believed to have been made in anticipation of the United Nations General Assembly's adoption of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in September 1996, which would ban all nuclear tests involving nuclear explosions. Despite not having ratified the CTBT, China has signed the treaty and has repeatedly declared its commitment to abide by it.

Table 7: History of nuclear tests by nuclear-armed states

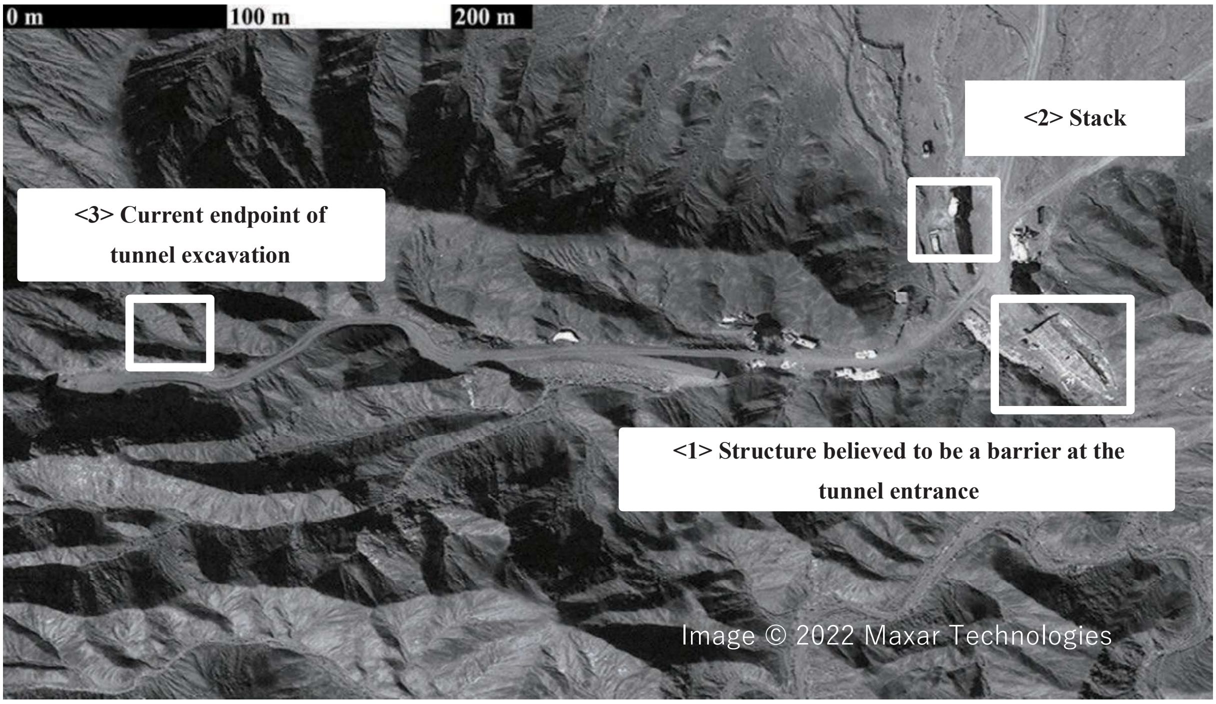
Country (primary test sites)	No. of tests	No. of tests by type (atmospheric/underground)
United States (Nevada Test Site)	1030	215/815
U.S.-U.K. joint testing	24	
Soviet Union (Semipalatinsk Test Site and Novaya Zemlya Nuclear Test Site)	715	219/496
France (Mururoa Atoll in the South Pacific)	210	50/160
China (Lop Nur Test Site)	46	22/24
United Kingdom (Maralinga Test Site in Australia)	45	21/24
North Korea (Punggye-ri Nuclear Test Site)	6	0/6
India (Pokhran in the Thar Desert)	3	0/3
Pakistan (Rasko hills)	2	0/2

Source: Prepared by our Study Group with reference to United States Nuclear Tests, July 1945 through September 1992, etc.

Recent Trends

However, new tunnel construction activity has recently been observed at the Lop Nur Test Site, raising speculation that China may conduct a new nuclear test. The primary purpose is likely to miniaturize nuclear warheads with the intent of developing multiple independently-targetable reentry vehicle (MIRV) ballistic missiles.

Satellite Image 14: Line believed to represent a new tunnel at the Lop Nur Test Site (August 2022)



Satellite Image 14, captured in August 2022, reveals a large artificial covering in the area <1>. Underground nuclear test sites are often constructed by digging tunnels deep into mountains. To prevent the release of large amounts of radioactive material, the tunnel entrances are shielded by thick steel walls and covered with earth and sand. Additionally, to prepare for situations in which the explosive force exceeds expectations, the tunnel is bent in the middle and dug deeper to accommodate the nuclear bomb. Looking again at Satellite Image 14, we see that a line extends along the ridges and valleys from near the covered area to the current endpoint indicated by <3>. This suggests the possibility of a sixth tunnel being excavated, in addition to the five already known. It remains unclear whether the current endpoint of the tunnel excavation will be used to place a nuclear bomb. However, the tunnel is considerably long and bends in the middle to conform to the mountainous terrain, indicating that preparations to use this site as a testing ground are almost finished.

Meanwhile, it is worth noting that a tall stack <2> can clearly be seen near the tunnel entrance, with its shadow distinct enough to be discernible. One possible reason is to ensure efficient ventilation and worker safety during tunnel construction, but it is questionable whether such a tall stack is truly necessary solely for the ventilation of the tunnel. Another possibility is that it is a stack designed to release radioactive noble gases to enable the continuous conduct of subcritical nuclear tests. Since there is an undeniable risk of criticality control failure leading to detonation in subcritical nuclear tests, these tests have been conducted underground. Therefore, regarding the tunnel excavation work in question, it is necessary to consider not only the possibility of resuming nuclear explosion tests, but also the possibility of preparing for subcritical nuclear tests.

Meanwhile, the Trump administration in the United States has claimed that China secretly conducted nuclear tests. According to U.S. Assistant Secretary of State Christopher Yeaw in 2026, China conducted a nuclear test at Lop Nur on June 22, 2020, which was detected by a seismic monitoring facility in Kazakhstan 720 km away, registering a magnitude of 2.75.[56] While the veracity of the U.S. claim is unknown, if true, we must also consider the possibility that nuclear testing has already resumed at the Lop Nur Nuclear Test Site.

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[56] *Reuters*, February 18, 2026.

Chapter 3

Future Prospects for Nuclear Warhead Production Cycle

1. Future Development of Nuclear Capabilities

Nuclear capability development aimed at achieving the “nuclear deterrence of moderate intensity”

Following its first successful nuclear test in 1964, China operationalized the DF-3 intermediate-range ballistic missile (IRBM) and the DF-4 intercontinental ballistic missile (ICBM) in the 1970s, both capable of reaching the entirety of the Soviet Union. In the 1980s, China began deploying the DF-5 ICBM, which can reach the U.S. mainland. By this time, China had acquired the capability to carry out limited-scale retaliatory nuclear strikes (second strikes) against the United States and the Soviet Union. In other words, “the mating of nuclear warheads and missiles.”[57]

However, the number of deployed nuclear-tipped ballistic missiles was very limited, and they had a large circular error probable (CEP). Consequently, China's nuclear strategy during the Cold War was based on “key point counterstrikes,” or minimum deterrence targeting several cities in the United States and the Soviet Union.[58] Therefore, China developed its nuclear capability based on the principle of having a “small but effective nuclear counterstrike capability.”[59] However, it was highly uncertain whether China could actually deter the United States and the Soviet Union, which had vastly superior nuclear capabilities in terms of both quality and quantity.

Therefore, China adopted several strategies to strengthen the credibility of its minimal deterrence strategy, which was based on limited nuclear capabilities. Specifically, this involved concealing nuclear doctrine and the actual state of nuclear capabilities as much as possible to complicate the calculations of potential adversaries; adopting a no-first-use (NFU) strategy, whereby China would refrain from using nuclear weapons unless an adversary used them first; and prioritizing the survivability of nuclear delivery systems.

The shift away from the minimum deterrence strategy in this manner began to be discussed in China by the mid-1980s. This is due to U.S. advancements in intelligence, surveillance, and reconnaissance (ISR) capabilities; improvements in the CEP of ICBMs; strengthened long-range conventional strike capabilities using precision-guided munitions (PGMs); and emerging missile defense (MD) capabilities. These developments have raised significant doubts about the survivability of nuclear weapons against a first strike.[60]

Changes in China's nuclear strategy have also become apparent in official documents. For example, Michael Chase pointed out that the concept of “nuclear deterrence of moderate intensity” first appeared in the 2001 edition of the People's Liberation Army's doctrinal document, Science of Strategy. This represents a middle ground between the U.S.-Soviet (Russian) model of maximum deterrence—supported by a broad spectrum of nuclear capabilities extending from tactical to strategic levels—and the Chinese model of minimum deterrence. It was defined as a strategy of achieving deterrence by “threatening to inflict intolerable damage on the adversary.”[61]

Entering the 2010s, China began active deployment of the DF-31A, an upgraded version of the DF-31 with an

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[57] 「毛泽东与两弹一星」『中国共产党新闻网』, May 27, 2013.

[58] Ken Jinbo, “China–The Transition from “Minimal Deterrence” to “Assured Retaliation”” in *The End of Nuclear Forgetting: Revival of Nuclear Weapons*, edited by Nobumasa Akiyama and Sugio Takahashi, Keiso Shobo, 2019, pp. 76-78.

[59] M. Taylor Fravel, *Active Defense: China’s Military Strategy since 1949* (Princeton University Press, 2019), p. 241, 261.

[60] Narang, “*China's Strategic Deterrence,*” p. 131.

[61] Michael S. Chase, “*PLA Rocket Force: Executors of China’s Nuclear Strategy and Policy,*” Joe McReynolds, ed, *China’s Evolving Military Strategy* (The Jamestown Foundation, 2017), pp. 143-144.

extended range; the DF-31AG, having enhanced off-road mobility; the DF-41, a road-mobile ICBM equipped with MIRVs; and the Type 094 SSBN, armed with JL-2 SLBMs. Of these, the development and deployment of the DF-41 is especially notable. As Sugio Takahashi states, the DF-41's ability to carry small-CEP MIRVs clearly contradicts the minimum deterrence strategy, suggesting that a nuclear strategy involving counterforce strikes is highly likely to be intended.[62]

On the other hand, China has not comprehensively developed the tactical nuclear capabilities, early warning (EW) capabilities, and command, control, and communications (C3) capabilities, which are required for the nuclear deterrence of moderate intensity. Therefore, much prior research concludes that China's objective is not a scaled-down version (limited deterrence) of the nuclear capabilities possessed by superpowers such as the United States and Soviet Union (or Russia), but rather the capability of assured retaliation (not assured destruction) sufficient to reliably deter an enemy's first strike. This objective is considered an extension of the minimum deterrence strategy.[63]

Understanding of China's Broad Nuclear Strategy

As Fravel points out, China's nuclear doctrine has been largely consistent: defining the sole mission of its nuclear capabilities as deterrence for self-defense, maintaining small-scale, survivable nuclear capabilities to ensure retaliation, and committing to a no-first-use (NFU) policy.[64]

However, given that China's nuclear capabilities have undergone significant changes, there should have been corresponding changes to actual operational policy. In other words, there has always been significant flexibility in interpreting the declaratory policies announced by leaders. Therefore, it has long been acknowledged that the actual situation regarding the “small-scale yet effective nuclear counterstrike capabilities to ensure retaliation” can change significantly depending on the external security environment, the nuclear capabilities of other nations, technological advancements, and shifts in the structure, procedures, and policies of the bureaucratic apparatus.[65]

For example, the white paper on arms control, disarmament, and non-proliferation titled China's Efforts in Arms Control, Disarmament, and Non-Proliferation issued on September 1, 2005 by the State Council Information Office of China stated, “As the two largest nuclear weapon states, the United States and Russia bear a special and primary responsibility for nuclear disarmament [...] and should further reduce their nuclear weapons in accordance with the principles of verifiability and irreversibility,” thereby expressing the view that the United States and Russia should take the lead in advancing nuclear disarmament. It further stated, “China will always maintain the minimum necessary size and scale of its armed forces to safeguard national security and interests.”[66] This stance

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[62] Sugio Takahashi, “*Strategic Stability and the Impact of China's Modernizing Strategic Strike Forces,*” James M. Smith and Paul J. Bolt, eds, *China's Strategic Arsenal: World View, Doctrine, and Systems* (Georgetown University Press, 2021), p. 69.

[63] M. Taylor Fravel, Henrik Stålhane Hiim, and Magnus Langset Trøan, “*China's Misunderstood Nuclear Expansion: How U.S. Strategy Is Fueling Beijing's Growing Arsenal,*” *Foreign Affairs*, 10 November 2023.; Tong Zhao, *What's Driving China's Nuclear Buildup?* (Carnegie Endowment for International Peace, 5 August 2021).; M. Taylor Fravel, *Active Defense: China's Military Strategy since 1949* (Princeton University Press, 2019), p. 241, 261.; Narang, *op. cit.,* 2019, pp. 121-138.; David Logan, “Hard Constraints on China's Nuclear Forces,” *War on the Rocks*, 8 November 2017.

[64] Fravel, “*Active Defense: China's Military Strategy since 1949,*” pp. 236-247.

[65] Eric Heginbotham, Michael S. Chase, Jacob L. Heim, Bonny Lin, Mark R. Cozad, Lyle J. Morris, Christopher P. Twomey, Forrest E. Morgan, Michael Nixon, Cristina L. Garafola, Samuel K. Berkowitz, “*China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States,*” (RAND Corporation, 2017), pp. 34-35.

[66] “China's Arms Control, Disarmament, and Non-Proliferation Efforts,” State Council Information Office of China, September 1, 2005, http://www.gov.cn/zwgk/2005-09/01/content_28157.htm.

was essentially carried forward in the 2025 white paper, reaffirming China's position that it should only pursue nuclear disarmament once its security is guaranteed. After China decided to develop a hydrogen bomb, Mao Zedong, who was then Chairman of China, aptly expressed the country's mindset as follows: “What the enemy possesses, we must possess; what the enemy does not possess, we must also possess.”[67]

Given this context, China's “minimum necessary” refers to the subjective amount it deems necessary to safeguard its own security and interests, and the nature and extent of this minimum will likely change in response to the nuclear strategy and capabilities of the United States and Russia. In a recent example, Ambassador Li Song, China’s Permanent Representative to the Conference on Disarmament at the United Nations, delivered a speech on nuclear disarmament at the UN General Assembly, solemnly pledging that China would never use nuclear weapons first under any circumstances or conditions, and would unconditionally refrain from using or threatening to use nuclear weapons against non-nuclear-weapon states or nuclear-weapon-free zones. He also asserted that China has always maintained its nuclear capabilities at the minimum level necessary for national security and has not engaged in an arms race with other nuclear-armed states.[68]

Future Vision of Nuclear Capabilities

One interesting aspect of this research topic is that China began constructing a large number of ICBM silos in the 2010s. Analysis of satellite images indicates that there are at least 300 such silos. Currently, not all of these silos appear to house ICBMs, but it is possible that China aims to reach a quantitative level roughly equivalent to that of the United States and Russia when referring to the “minimum necessary” level.

Furthermore, these silo clusters are poorly concealed, making their locations easily identifiable in satellite imagery and vulnerable to a first strike. This clearly diverges from the conventional operational doctrine, which had long sought to achieve invulnerability through the covert construction of silos in mountainous regions and the installation of numerous dummy silos. This suggests that China's ICBM operational strategy has shifted to launch on warning (LoW), which means it will strike back before being hit if it senses a first strike from the United States. Supporting this, the U.S. Department of Defense's China military power report states, “China probably expanded its space-based early warning architecture in 2024 and early 2025 by launching two additional Tongxun Jishu Shiyan (TJS) satellites with likely infrared sensor payloads into geosynchronous orbit. China’s early warning infrared satellites can reportedly detect an incoming ICBM within 90 seconds of missile launch with an early warning alert sent to a command center within three to four minutes.”[69]

However, China's nuclear capabilities are still significantly behind those of the United States and Russia. The New Strategic Arms Reduction Treaty (New START), which was valid until February 2026, capped the number of operationally deployed nuclear warheads for the United States and Russia at 1,550. In contrast, the U.S. Department of Defense estimated in 2025 that China had between 600 and 650 operationally deployed nuclear warheads.[70] Previous assessments projected that China would have more than 1,000 operationally deployed

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[67] As aforementioned,「毛泽东与两弹一星」『中国共产党新闻网』.

[68] 「中国裁军大使李松在联大全面阐述中国核裁军立场」, Xinhua News Agency, October 19, 2022.

[69] US. Department of Defense “*MILITARY AND SECURITY DEVELOPMENTS INVOLVING THE PEOPLES REPUBLIC OF CHINA 2025,*” Dec 23, 2025.

[70] *Ibid.*

nuclear warheads by 2030 and reach 1,500 by 2035. However, such future estimates have not been mentioned in recent reports from the U.S. Department of Defense. This is likely an attempt to hide U.S. intelligence capabilities related to gathering and assessing information about China's nuclear warhead production capacity. However, it's clear that China will need more time to develop nuclear capabilities comparable to those of the United States and Russia.

Therefore, it is likely that China will continue to expand its production of nuclear warheads. Assuming that all silos constructed since the 2010s house an ICBM equipped with approximately three MIRVs each, that alone would require 900 nuclear warheads. Including existing road-mobile (and potentially rail-mobile) ICBMs, SLBMs, IRBMs, and other theater nuclear capabilities, fully equipping ground-launched ballistic missiles with nuclear warheads alone would require over 1,000 warheads. After the Intermediate-Range Nuclear Forces (INF) Treaty expired, Russia proceeded to redeploy theater nuclear capabilities. If the United States and Russia upload nuclear warheads onto delivery systems after the expiry of the New START Treaty in February 2026, the scope of China's stated “minimum necessary” amount will likely expand. In the future, China may aim to operationally deploy between 2,000 and 3,000 operational nuclear warheads.

Furthermore, if China were to adopt nuclear weapons and nuclear material management standards equivalent to those of the United States, it would need a large number of reserve warheads for its operationally deployed warheads. This is because tritium must be recharged every four to five years to maintain the explosive power of nuclear warheads, and it is necessary to compensate for the reduction of active warheads during their recharging period. Russia maintains 1,114 reserve warheads, approximately 65% of its 1,718 operationally deployed warheads. If we apply this ratio to China's supposed 2,000 to 3,000 nuclear warheads, maintaining them for operational deployment would require a total of 3,300 to 4,950 warheads, including those reserved.

2. Future of fissile material Production

Plutonium Production Capacity

That said, does China actually have the ability to produce nuclear warheads on the scale described above? As noted earlier in Chapter 2, China's plutonium inventory is much smaller than that of other major nuclear weapon states (Table 6). The IPFM's estimated plutonium inventory of 2.9 ± 0.6 tons is one-tenth to one-thirtieth the inventory of the United States and Russia. Clearly, increasing plutonium production is essential for strengthening China's nuclear capabilities.

The above inventory figure represents the total amount of military-grade plutonium produced by China, calculated based on the size and operational years of the two graphite reactors mentioned earlier. Since the amount of plutonium required for a nuclear weapon is calculated as 3.5 ± 0.5 kilograms, China's maximum nuclear warhead production capacity would be between 575 and 1,166 warheads. Given the current circumstances, it is impossible for China to catch up to the nuclear capabilities of the United States and Russia. Furthermore, as shown in Table 8, spent fuel from light water reactors—a type of civilian reactor operated in many countries, including Japan—has a low plutonium-239 ratio. Even if plutonium is extracted through reprocessing, this fuel is not necessarily suitable for military use. Although it is possible to extract plutonium suitable for nuclear weapons from FBRs, their stable operation is technically difficult. Analysis of satellite imagery has also revealed that China's FBR frequently halts operations.

Table 8: Composition of plutonium extracted from different reactor types

Pu grade / Reactor type	Pu238	Pu239	Pu240	Pu241	Pu242
Super-grade (FBR)	0	97-98	2-3	0	0
Nuclear weapons-grade (heavy water reactor, graphite reactor)	0	93-97	3-7	<0.5	0
Reactor-grade (light water reactor)	2.4	53.8	22	15.5	6.3

Source: Prepared by our Study Group

Nevertheless, the United States has voiced concerns that China could divert plutonium extracted from spent nuclear fuel from civilian reactors for military purposes. Of particular concern are heavy water reactors, which have been operated in various countries and are suitable for producing weapons-grade plutonium. Heavy water reactors use heavy water as both a reactor coolant and a moderator, which controls the rate of neutron emission and promotes nuclear fission reactions. In this context, heavy water refers to water with a high specific gravity, while ordinary water is referred to as light water for distinction. Heavy water reactors have the advantage of being able to directly use natural uranium as fuel. Additionally, since heavy water absorbs fewer neutrons than light water, the proportion of plutonium-239 produced in the fission reaction can be increased.

Since 2002, China has operated two heavy water reactors, each with an output of 728 MW, at the Qinshan Nuclear Power Plant in Zhejiang Province. A heavy water reactor can extract 0.8 grams of weapons-grade plutonium per day per megawatt. Assuming 300 days of operation per year, 174,720 grams (174.72 kilograms) of plutonium can be extracted, as derived from multiplying 0.8 grams by 728 megawatts by 300 days. Therefore, the two reactors combined can yield approximately 350 kilograms of weapons-grade plutonium per year through reprocessing. Using the aforementioned formula, which requires 3.5 ± 0.5 kilograms of plutonium per nuclear warhead, the production capacity of the two reactors would be 87 to 116 warheads per year. Additionally, if two FBRs become operational after 2030, an additional 350 kg of plutonium per year could be produced. Under this scenario, China's nuclear warhead production capacity would increase to between 175 and 232 warheads per year.

Although China has stopped reporting under INFCIRC-549, the military diversion of plutonium extracted and reprocessed from spent fuel in FBRs and heavy water reactors, which are publicly declared for civilian use, would be a matter of China's national credibility. As a nuclear-weapon state under the NPT, China is not required to accept IAEA safeguards. However, in 1988, it signed an agreement with the IAEA declaring that "nuclear material and equipment imported to China will only be used for peaceful purposes."[71] China imports FBR fuel from Russia, and its heavy water reactors are of Canadian origin. Therefore, using plutonium extracted from currently operating FBRs and heavy water reactors for military purposes would likely constitute a serious violation of international agreements.

On the other hand, we cannot rule out the possibility that China might, despite accepting such political risks, divert plutonium extracted from civilian facilities for military use. Therefore, as discussed above, we must assume that China's theoretical upper limit for producing nuclear warheads is approximately 175 to 232 per year.

Uranium and Tritium Production Capacity

As mentioned in the previous chapter, China already has uranium enrichment capabilities based on its own technology and is believed to be capable of consistently producing the 80% enriched uranium necessary for manufacturing nuclear weapons. Increasing the production of enriched uranium is at least easier than increasing that of plutonium, and its production capacity is unlikely to become a bottleneck in nuclear warhead production. Even if China were to acquire an annual plutonium production capacity of around 700 kilograms in the future, there is little basis for concluding that it would face significant problems in obtaining the necessary uranium enrichment capacity to weaponize this amount of plutonium.

This also applies to tritium production. As discussed in Chapters 1 and 2, the production of tritium does not require dedicated reactors. This is because replacing some of the fuel rods in a plutonium production reactor with lithium fuel rods allows for the production of tritium while still producing plutonium. Additionally, there have been instances in recent years in the United States where lithium fuel rods have been loaded into commercial reactors to produce tritium.

Therefore, with no dedicated tritium reactors, it is difficult to determine where production is occurring (i.e., which reactors are loaded with lithium fuel rods) unless the country in question discloses this information. However, since the extraction of tritium from lithium fuel rods after neutron irradiation requires reprocessing at a radiochemical plant, it may be possible to identify such reactors by tracking the transport of the fuel rods. Since the U.S. Department of Defense has identified the Qinshan Nuclear Power Plant as being involved in tritium

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[71] IAEA "*AGREEMENT OF 20 SEPTEMBER 1988 BETWEEN THE PEOPLE'S REPUBLIC OF CHINA AND THE INTERNATIONAL ATOMIC ENERGY AGENCY FOR THE APPLICATION OF SAFEGUARDS IN CHINA,*", p. 2.

production, our Study Group plans to monitor this plant using satellite imagery.

Estimating China's Nuclear Warhead Enhancement Capabilities

In summary, China is likely capable of producing about 100 nuclear warheads per year throughout the 2020s. This pace is projected to increase to between 175 and 232 warheads per year from the 2030s onward. Assuming China produces 100 nuclear warheads per year during the 2020s and 200 per year from the 2030s onward, it would possess around 1,000 warheads by 2030 and 2,000 by 2035. Applying Russia's ratio of operationally deployed warheads to reserve warheads, it is estimated that China will have just over 600 operationally deployed warheads by 2030 and just over 1,200 by 2035.

This estimate clearly contradicts the report from the U.S. Department of Defense. As mentioned earlier, the U.S. Department of Defense estimated that China would have “operationally deployed” over 600 nuclear warheads even by 2025. In other words, China's annual increase of 100 nuclear warheads refers only to “operationally deployed warheads.” However, it cannot be ruled out that the annual production figure including reserve warheads may be higher than previously stated (as estimated). Therefore, assuming China currently has a production capacity of approximately 150 nuclear warheads per year and this capacity increases with the full operation of its FBRs, China could deploy nuclear warheads comparable to those of the United States and Russia within the next decade.

Another possibility is that the number of reserve warheads needed for the operational deployment of 600 to 650 nuclear warheads is significantly lower. The reserve warheads held by the United States and Russia serve not only as backups during the maintenance of operationally deployed warheads, but also as a measure to ensure future upload potential. Therefore, if uploading is not a consideration, 20% or 30% of the number of operationally deployed warheads may be sufficient for the number of reserve warheads.

However, even if we accept this assessment, it would be difficult for China to keep pace with the nuclear capability buildup resulting from nuclear warhead uploads by the United States and Russia. Unless there is a significant change in its production capacity of fissile material (particularly plutonium), China's nuclear capabilities are expected to remain at a disadvantage compared to the future operational deployments of the United States and Russia (likely exceeding 2,000 warheads).

Conclusion

Continue Efforts to Understand China's Nuclear Warhead Production Cycle.

This report attempts to elucidate China's entire nuclear warhead production cycle. It treats the following aspects as a single cycle: production of plutonium and other nuclear materials; major components of nuclear weapons; components and technologies required for nuclear weaponization; transport and assembly of these components; nuclear explosive tests to verify the performance of assembled nuclear weapons; and storage and deployment of these weapons.

The cycle revealed by this study is as follows. First, the China Academy of Engineering Physics (CAEP) is responsible for developing and designing nuclear warheads as an institute equivalent to the Los Alamos, Lawrence Livermore, and Sandia National Laboratories in the United States, and the VNIIEF and VNIITF in Russia. As for fissile materials, the FBRs in Fujian Province are likely to be used to meet the large-scale demand for plutonium production, and it appears that the reprocessing plant in Gansu Province's desert region is being used for this purpose.

However, there are still many things that this study has not clarified. For example, regarding the production of tritium to maintain the explosive power of nuclear warheads, although it has been suggested that the China National Nuclear Corporation (CNNC)'s civilian reactors may be used for this purpose, we could not find clear evidence. Furthermore, the specifics of the cycle are unclear. For example, it is not known how spent nuclear fuel is transported from the FBR site in Fujian Province, which faces the East China Sea, to the nuclear fuel reprocessing facility in Gansu Province, which is located inland. Given that our Study Group has pointed out the potential military applications of civilian technology, we must continue our efforts to fully understand the nuclear warhead production cycle, which includes analyzing the railway network. Given that China does not currently appear to be interested in improving its “nuclear transparency,” it is crucial for Japan and the international community to decipher China's nuclear strategy based on its nuclear warhead production cycle.

However, we want to emphasize that this initiative is not intended to unnecessarily stoke wariness or provoke excessive responses toward China. This effort will be even more valuable if it encourages China to improve its nuclear transparency through clarification or leads to arms control negotiations with the United States or Russia. This progress report from the Study Group of the International Trends in the Nuclear Warhead Production Cycle is only the first installment. Moving forward, we plan to continue clarifying the relationship between China's nuclear warhead production cycle and its nuclear strategy, while gathering feedback from research institutions and experts, both domestic and international.

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