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# DPRK: Current Status of the Development of Nuclear Weapons

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## Summary

*North Korea has conducted five nuclear tests and more than 20 missile tests to date. Nuclear weapon systems are considered by North Korea to be critical assets that provide it with asymmetric strategic advantages. Its nuclear weapon program is supported by extensive infrastructure networks of facilities, experts, technologies and materials at the Yongbyon Atomic Energy Research Center and by illegal international trafficking networks. To solve the impasse of its nuclear and missile programs, it is important to understand the full capacity of the North Korea's nuclear infrastructure and adopt integrated strategies to manage the threats in a timely manner. The lessons from the historic US-led Cooperative Threat Reduction programs applied to the former Soviet Union and to Iraq can be used to design custom-made solutions for North Korea. In addition, financial packages should be developed in advance to support future programs of international cooperation.*

## Brief History

1. The Democratic People's Republic of Korea (DPRK or North Korea) officially started its nuclear program in 1959 by signing a bilateral cooperation agreement with the former Soviet Union, followed by the start of construction of the IRT-2000 research reactor in Yongbyon in 1962. The IRT-2000 first reached criticality in 1965 and was subsequently upgraded to become the IRT-8000. The progress of the DPRK's early phase nuclear program is quite relevant to the parallel developments in the Republic of Korea (ROK or South Korea). South Korea signed a bilateral agreement with the United States a couple of years earlier. The "123 Agreement"[1] of 1956 between the two countries supported the start in 1959 of the construction of South Korea's first research reactor, a TRIGA Mark-II, and its inauguration in 1962. The ROK proclaimed its intention to develop a commercial nuclear power plant program in 1971, the final year of its second five-year economic development plan.

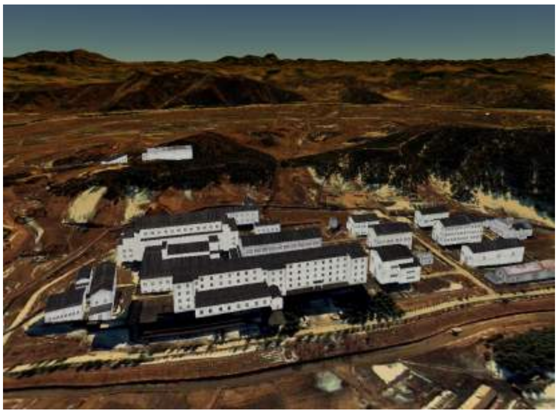
2. The DPRK started to construct the notorious 5MWe MAGNOX reactor in Yongbyon in 1980 and it reached criticality in 1986. But it did not complete the construction of the large-scale commercial facilities such as 50 and 200 MWe reactors. The 5 MWe reactor has become the cornerstone facility for the production of plutonium (Pu-239) for nuclear weapons through the PUREX (Plutonium-URanium EXtraction) reprocessing process. Unlike commercial pressurized water reactors (PWR) whose annual burn-up is at the level of 45,000 megawatt days per metric ton of uranium (MWD/MTU), the average burn-up of this MAGNOX reactor is just

[1] The reference is to agreements pursuant to s.123 of the US Atomic Energy Act that are commonly referred to as "123 agreements." They incorporate IAEA guidelines in US bilateral agreements as a condition of peaceful nuclear cooperation.

around 300-1,000 MWD/MTU, quite adequate to produce high quality weapon grade plutonium with a higher Pu-239 content

3. The IRT-2000 reactor started with 10 per cent enriched uranium fuel, but began to use HEU fuels through upgrades in 1974 and 1984. The DPRK temporarily halted the operation of the reactor after full consumption of the original Soviet Union-supplied fuels. But recently, the DPRK is assumed to manufacture fuels for the IRT-2000 locally, based on domestic research and possibly foreign assistance. At this moment, it is not clear whether the IRT-2000 is using 80 per cent or 36 per cent enriched uranium. In both cases, it is still higher than the 20 per cent enrichment criteria, extensively discussed throughout the Iranian deal, as the danger threshold between peaceful and weapon-relevant programs.

Figure 1: 3D Model View of the Radiochemistry Lab in the Yongbyon AERC



Source: Korea Institute of Nuclear Nonproliferation and Control

4. The introduction of the Radiochemistry Lab, illustrated in Figure 1, with an annual capacity of 200 MTU was the critical pathway for the DPRK to develop nuclear weapons. With a number of small-scale experiments, the DPRK began to master the technologies needed to use the PUREX process for reprocessing the spent nuclear fuel discharged from the 5MWe reactor. Through a series of upgrades, the DPRK is now capable of operating the PUREX processes comprising mechanical de-cladding and the pulsed column extraction. Prior to the adoption of the PUREX process , the DPRK had relied on the old chemical de-cladding technologies that Eurochemic in Belgium used in the 1970s, and outdated mixer-settler extraction methods.

5. While developing reprocessing to acquire plutonium, the DPRK also pursued development of centrifuge technology to produce HEU, through international illicit trafficking for technologies, designs and materials. The DPRK succeeded in establishing generation II type centrifuge enrichment facilities at the Yongbyon Atomic Energy Research Center (AERC), as witnessed by Professor Siegfried Hecker in 2010 (Hecker and two colleagues visited the enrichment facility in October 2010).[2] Now, the capacity of the enrichment facilities at Yongbyon is believed to have doubled to 4,000 centrifuges compared with the initial situation when Prof Hecker visited as illustrated in Figure 2. Considering the construction times for the initial facility and also of the subsequent additional facility in Yongbyon AERC, there is a possibility that one or two covert enrichment facilities could have been constructed elsewhere in the time between the two construction projects at Yongbyon. Also, one can assume that the DPRK installed its first enrichment facility at a secret site before constructing the one at Yongbyon AERC.

Figure 2: Extension of Enrichment Facility at Yongbyon AERC


Source: Korea Institute of Nuclear Nonproliferation and Control

6. While the throughput of each centrifuge of the original IR-1 type used by Iran is limited to

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[2] Siegfried S. Hecker, "What I Found in North Korea," *Foreign Affairs*, 9 December 2010; http://www.foreignaffairs.com/articles/67023/siegfried-s-hecker/what-i-found-in-north-korea

1 SWU/year,[3] the P-2 type centrifuge in the DPRK has the capacity of 4 SWU/year. The enrichment effort required to produce enough HEU to make a single nuclear weapon in a year, starting with natural uranium, is 5,000 SWU. Figure 3 illustrates the expansion of enrichment facilities at the AERC.

7. Under pressure from the Soviet Union, the DPRK joined the Nuclear Non-proliferation Treaty (NPT) in 1985 and signed an NPT Safeguards Agreement in January 1992 (supplanting the original facility-specific INFCIRC/66 agreement which had hitherto applied to the IRT-2000). The DPRK submitted the initial inventory report under this agreement to the IAEA in May 1992. The IAEA conducted safeguards inspections in 1992 and 1993, which led to suspicions over the DPRK's nuclear activities. The inspection results indicated that the DPRK had undertaken three reprocessing campaigns, compared with the one that it had declared to the IAEA. The DPRK decided to withdraw from the NPT in 1993.

Figure 3: Locations of the Five Nuclear Weapon Test Sites


Source: US Geological Survey

8. That led to an 18 month crisis during which the intense efforts of the international community, involving the IAEA and the UN Security Council, plus dialogue between the DPRK and the US, resulted in the Agreed Framework signed in Geneva in October 1994 under which the relentless reprocessing effort by the DPRK was temporarily halted. But in the 2000s, the final withdrawal from the NPT followed by the breakdown of the DPRK–US dialogues, the Agreed Framework was completely demolished. It triggered the first nuclear weapon test in 2006. Since then, the five tests in 2006, 2009, 2013 and 6 January and 9 September 2016, were conducted at conducted at Mt. Mantap, near Punggye-ri, in the northeastern North Hamgyong Province.

## Management of Expertise

9. The future of the DPRK nuclear program is uncertain. There might be a chance of a peace agreement ultimately ensuring the denuclearization of the DPRK. The first phase of the denuclearization might involve freezing of current nuclear programs. Or there could be military conflict or the sudden collapse of the DPRK. In any case, the proper management of the critical infrastructure at the AERC and the other places in the DPRK is the key to securely stabilize the DPRK nuclear issues. In this respect, the importance of the proper management of the human resources in the field of nuclear energy in the DPRK cannot be over-emphasized.

10. The DPRK invested significant effort to educate talented young students in nuclear physics from the Kim-il Sung University after the end of the Korean War. Since then the educational program has been extended to cultivate excellent engineers from the Kim Chaek Engineering University. These human resources became the cornerstone to establish the DPRK's nuclear programs. In addition, the Yongbyon University near the AERC has provided a regular supply of field engineers.

11. The number of highly experienced experts in the nuclear weapon program is estimated to be around a couple of hundred. And the total size of the personnel now working on the nuclear weapon area is in the several thousands. This estimate is based on counting the number of students who have graduated from the relevant departments of these universities. The scope of the engineering work covers all major areas of the front and the back end of the nuclear fuel cycle. From the beginning of the program, the DPRK has cultivated uranium ore-

[3] Separative work units (SWU) is a measure of the amount of separation done by an enrichment process.

mining experts to produce uranium domestically.

12. Effective management of these nuclear experts and engineers will be the key to preventing the potential diffusion of sensitive information, personnel and nuclear materials from the DPRK to other countries or non-state entities. As illustrated in the former Soviet Union and the Middle East, highly sensitive information could be diffused not just by key experts but by the mid-level field workers if they cannot be properly supported within their own countries or through international programs. To prevent any potential problem from releasing key nuclear technologies and special materials to the hands of sub-national terrorist groups and rogue states, it will be critical to set up a purpose-made approach to manage these technical and human resources in the DPRK for a long period.

## Understanding North Korea's Nuclear Weapons Production Capacity

13. As stated, the DPRK has relied on two processes for making nuclear weapons: reprocessing and uranium enrichment to produce plutonium and HEU respectively. It is not clear how many times the DPRK conducted large scale reprocessing. The best guess at this moment is that the DPRK has conducted five reprocessing campaigns including the last attempt in 2016. In each campaign, around fifty tons of spent nuclear fuel from the 5MWe reactor has been reprocessed.

14. The cumulative amount of plutonium is not fully known due to many factors. First, it is not clear how many of the DPRK's five nuclear tests were based on plutonium devices. Second, it is not known how many kilograms of plutonium the DPRK consumed for each test. Even though for assessment purposes eight kilograms is the notional figure for the amount of plutonium required to make a nuclear weapon, the actual amount required very much depends on the level of the technology available. Therefore, even though many news media claim that the DPRK might possess around 50kg of plutonium right now, still, it is not clear exactly how much plutonium was produced and how much has been used, and therefore, how much remains.

15. The uncertainty in the amount of HEU available to the DPRK is much greater. The operational history of the Yongbyon facility has not been released to the outside world. In addition, many analysts believe there are clandestine enrichment facilities in the DPRK. However, one can roughly predict the general capacity based on a series of assumptions. Thermal imaging data for the Yongbyon facility available in the public domain illustrates that the enrichment facility is under good operational temperature range at all times. Since it uses uranium hexafluoride (UF6) in gaseous phases, it requires an operating temperature of around 60 degrees centigrade inside the cascades. The ambient temperature for the enrichment facility can be checked through the thermal image data analysis.

16. The time span to finish the construction of the enrichment facilities is another important factor to estimate the maximum capacity of the DPRK enrichment program. Based on analyses of the date from satellite imagery, it took around 24 months to completely construct the first phase enrichment facility at the AERC. As noted in paragraph 5 above, there was a two year gap between the first and second phases of construction at AERC, in which some experts claim , the DPRK was able to construct an additional clandestine facility somewhere else. This is difficult to verify. As stated in many studies, such as the one by the Washington–based Institute for Science and International Security, one can roughly estimate that North Korea could possess around 100 nuclear bombs by 2020.[4] This is the level of the number of nuclear bombs possessed by both Pakistan and India, which might be good enough to assure a second strike capability during any engagement with other nuclear weapon states.

## Legacy Waste Management

17. The PUREX reprocessing sometimes creates by-products that are hard to manage properly. As already happened at the early pe-

[4] Joel S. Wit and Sun Young Ahn, "North Korea's Nuclear Futures: Technology and Strategy," (Washington DC: US–Korea Institute at SAIS, 2015), http://38north.org/wp-content/uploads/2015/02/NKNF-NK-Nuclear-FuturesWit-0215.pdf

riod of the defence nuclear reprocessing in the US Hanford site and the UK Sellafield site, it created the liquid wastes hard to be solidified. The mixing and co-storage, of the high and intermediate level waste liquid effluents from the PUREX processes with wastes from the previous chemical de-cladding processes, creates two key issues: first, difficulties for IAEA safeguards inspectors to track down the exact amount of extracted plutonium; and second, proper solidification of the liquid wastes. The US has spent billions of dollars from its 'Superfund' (a federal government program established in 1980 for the clean-up of sites contaminated with hazardous substances and pollutants) for solidification of the controversial liquid waste from the Hanford Site which once operated nine reactors to produce spent nuclear fuel for defence reprocessing.

18. The current prediction is the completion of all vitrification of the wastes by the end of 2020s. In this sense, how to properly manage solid and liquid waste stored in Yongbyon Building 500 and the other facilities will be a big issue technically and financially. It will require the full support by the international community. In addition, the Radiochemistry Lab is known to be radioactively contaminated. Its timely and proper decommissioning will also require another international endeavour for comprehensive clean up in the future.

## Blocking Illicit Trafficking while Promoting Future Cooperation

19. The so-called "Steel Will" of the DPRK top leaders has been the key factor to developing the DPRK's nuclear weapon programs. Even during periods of economic depression, the DPRK upgraded the research reactor and maximally prioritized the A. Q. Kahn illicit procurement network to install the P2 type centrifuge cascades at the AERC. Consistent effort at all times also has supported the domestic research programs such as the tritium production and extraction programs in the 2000s. As a first step , it is critical to further strengthen the NSG (Nuclear Suppliers Group) mechanisms to demolish the tie of the DPRK with the black markets. The continuous supply of key components and materials for the enrichment facility upgrade and operation depending on the black market supply should be terminated. Also, the potential illegal supply of tritium for the boosted weapon development should be halted at once. Constant pressure is needed to stop illicit trafficking.

20. As experienced already, the Nunn–Lugar Initiative including the strong Cooperative Threat Reduction (CTR) package was the key to smoothly overcoming critical problems after the collapse of the Soviet Union.[5] To actively support this initiative, background cooperation between the US and the Russian Academies of Sciences, along with other Track 2 approaches, contributed significantly. It is important to initiate cooperative efforts as soon as possible among prominent think tanks and individuals in the US, the ROK, Japan, China and other concerned parties, to set up comprehensive programs to identify the roadmap from today's impasse to the ultimate denuclearization of the DPRK. Similarly, they should put in place financial arrangements to support the roadmap and the subsequent technical solutions to manage and dismantle the nuclear facilities in Yongbyon, Poonggyeri and other locations, to supply the energy and electricity in return for the ultimate denuclearization if requested, and to manage the human resources in the DPRK.

## Implications of DPRK Nuclear Weapon Tests

21. After the announcement of its intention to conduct a nuclear weapon test, the DPRK conducted its first nuclear weapon test in the West Portal at Poonggyeri in Giljoo-Gun, Hamgyoungbook-Do in October 2006. There are a number of excavated tunnel networks at the mountain in Poonggyeri ready to conduct additional tests. Three portals, the West, North and South are located on that site. The West Portal was used for the first, second and third tests. The North Portal was used for the fourth and fifth tests. Figure 3 illustrates the locations for the five test sites.

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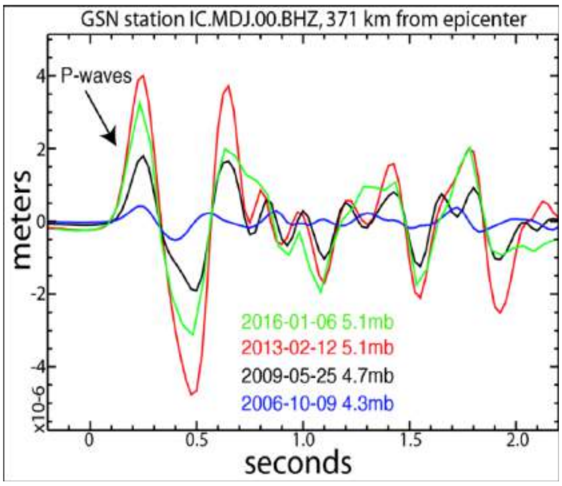
[5] See Gareth Evans, Tanya Ogilvie-White and Ramesh Thakur, *Nuclear Weapons: The State of Play 2015* (Canberra: Centre for Nuclear Non-Proliferation and Disarmament, 2015), p. 176. Available for free download at: https://cnnd.crawford.anu.edu.au/publication/cnnd/5328/nuclear-weapons-state-play-2015

22. The site is located in the high mountainous area, Mt. Mantap, whose altitude is around 2,200 metres. The granite body in that mountain assures good mechanical stability against blasts from nuclear explosions. It is estimated to bear the damage from the blast up to the level of 300kt so that it is good enough to withstand the current bomb blast at the level of a couple of tens of kilotons. In this sense, the DPRK can conduct the new tests, including of boosted weapons, at any time in the nearby tunnel even though it will be difficult to conduct a "traditional" hydrogen bomb test whose yield could be in the range of megatons.

23. The seismic analyses for the last five tests illustrate the clear progress in the bomb development in the DPRK. As illustrated in Figure 4, the earthquake magnitude of the first bomb was not so high at all. But the magnitudes from the second and third tests show significant advances. Throughout these three tests the DPRK demonstrated its capacity to manufacture the fission bombs successfully.

Figure 4: Seismic Wave Analysis for Tests 1–4

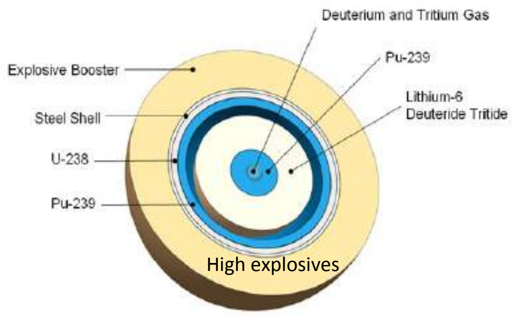



Source: Private Communication with J. Town, US–Korea Institute at the Johns Hopkins School of Advanced International Studies.

24. Even though sometimes the DPRK announces the possibility of testing HEU weapons, it is not easy to verify it by scientific evidence for the outside world. The practical measures to identify the successful blast of the HEU bombs are through the detailed identifications of four gaseous Xenon isotopes immediately after the test due to their short lives. This gas collecting effort becomes impractical when certain blocking systems are installed in the test tunnel to minimize the immediate release of the gaseous species. Figure 4 indicates the significant changes in the earthquake waves in the January 2016 test. The peak of the fourth test is smaller than the third one. In addition, unlike the third test sign function curve shape, there are irregularities in the fourth test wave.

25. This suggests some interesting points. Even though there is no direct evidence, it illustrates that the DPRK might have exploded a different type of bomb for the fourth test. Probably, it aimed at the test of a boosted bomb. The proper function of a boosted bomb is composed of two-step processes. The first one is the compression of fissile materials such as Pu-239 and U-235 with the initial fusion reactions by heavy hydrogen and tritium along with a lithium target. This fusion process can create a significant amount of neutrons promptly triggering the fissionable chain reactions. The efficiency of a boosted bomb, illustrated in Figure 5, depends primarily on the economy of neutrons.

Figure 5: Schematic View of a Plutonium Based Boosted Weapon




26. If this chain reaction works well, the magnitude of the bomb explosion is increased even though a smaller amount of fissile materials is used. The earthquake wave shape in Figure 4 shows that if the boosted bomb is used, the detonation was successful but the exact timing in the following reactions might not be fully achieved. If this assumption is true, then there is a strong motivation for the DPRK to conduct another test using a similar design later on.

27. After the fourth test, the DPRK leader showed the mock-up of the tested bomb in the

DPRK news media. Figure 6 illustrated that mock-up bomb. This mock-up shows two important features, the size of the bomb and the lid to exchange the decaying tritium with fresh material. If the density of the bomb is in the range of the average density of nuclear bombs this figure illustrates that the weight of the fourth tested bomb might be below 1,000 kg. However, if the density is around that of the Iraq design, the payload might be heavier than 1,000 kg.

28. The DPKR claimed that in the fifth test conducted in September 2016, the bomb manufacturing standardization was successfully verified. If this is true, then the next tasks will be to improve the efficiency of the booster and to minimize the payload weight again for the re-entry capability of intercontinental ballistic missiles (ICBMs). Then the ultimate goal with the success of the delivery systems is to develop multiple warhead systems.

Figure 6. The Mock-up Nuclear Bomb for the 4th Test in January 2016

Source: Screen capture of the DPRK's KCNA News

## The Tritium Program

29. As proclaimed from 2010, the DPRK has worked on the development of hydrogen (thermonuclear) bombs including boosted weapons. As stated, a boosted weapon requires tritium. Even though there is strong possibility that the DPRK might have relied on the black market to acquire tritium for the 2016 test, the DPRK has developed its national program to produce tritium from irradiated lithium-6 targets at reactors. Among the four well-known mechanisms to produce the tritium, the approach of bombarding a significantly slowed down neutron to a lithium target is the practical way to produce the few moles of tritium needed to produce a boosted weapon. This approach is well proven in the US by the successful production of tritium at the Watts Bar Nuclear Power Plant Unit 1. The IRT-2000 research reactor and the 5MWe reactor can similarly be used for this mission.

30. To extract the tritium from the irradiated targets, the existing radio-isotope separation facility near the IRT-2000 can be used. However, to produce one mole of tritium, it requires almost a yearlong endeavour along with difficulty in extraction processes. In practice, it is not easy to produce significant amounts of tritium to make multiple boosted weapons. Recently, the DPRK completed the construction of suspicious hot cell facilities at the southeastern corner of the AERC's enrichment complex area. The new building, easily accessible to the railway to transport irradiated spent fuels from the IRT-2000 and the 5MWe reactors, could be used for relatively easy extraction of tritium from the target materials. Tritium has a short half-life of 12.4 years, so that it decays at an annual rate of 5.5 per cent. Therefore, the DPRK would need to produce tritium not only for new weapons but to replenish existing weapons. Once this building with five newly installed hot cells is in operation it is assumed to provide a better opportunity to acquire enough tritium for the weapon supply.

## Conclusions

31. Since the mid-1950s, the DPRK has worked hard to enhance its capacity for producing nuclear weapons. Through step-by-step approaches, the DPRK began to produce plutonium weapons, HEU weapons, and so-called boosted weapons based on both plutonium and uranium fission bombs. The infrastructures and human expert networks along with the strong tie to the international black market act as the cornerstones for the DPRK. To solve the nuclear impasse in the Korean Peninsula, a comprehensive "carrot and stick" approach including sanctions and meaningful dialogue is

essential. For the ultimate denuclearization of the Korean Peninsula, the following tasks are recommended.

32. ***First***, it is essential to fully understand the real capacity of the DPRK. To reach the final denuclearization goal, a temporary measure would be freezing the nuclear weapon systems and the relevant infrastructure in the DPRK. To achieve a practical freeze, it is essential to fully understand North Korea's capacity from the beginning.

33. ***Second***, comprehensive strategic measures should be created as soon as possible covering detailed plans for implementation of safeguards over the relevant facilities in the DPRK, and an overall plan to manage and eventually dismantle and decommission the nuclear installations in the DPRK.

34. ***Third***, a long-term plan to manage wastes and contaminated facilities is required.

35. ***Fourth***, a comprehensive long-term plan to manage several thousand workers in the DPRK is needed. Just retraining the workers to shift their jobs to the mechanical and chemical engineering fields might not be good enough. Instead, a new project for the decommissioning of the facilities and waste management is recommended The program to decommission the nuclear facility and to properly manage wastes will take significant time and effort and can offer decent and stable new job opportunities for DPRK nuclear personnel for a long period of time.

36. ***Finally***, it is urgent to set up a new international mechanism to secure proper funding to support the entire DPRK denuclearization processes. The DPRK might demand a significant international contribution to solve its perennial energy and electricity shortage problems. To support electricity supply is not an easy matter simply because it requires installation of new power generation along with a nation-wide grid network system. To fully support all the expenses, the previous Korean Energy Development Organization (KEDO) type foundation to secure enough fund from the international society is recommended.

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