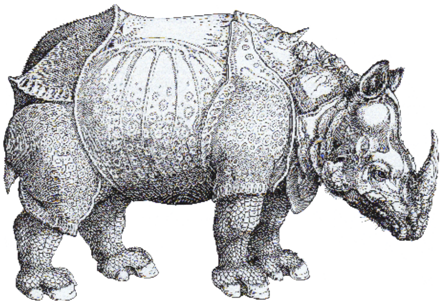

Non multa, sed multum

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Aleksandra Aladko

RUSSIA-CHINA COOPERATION IN NUCLEAR ENERGY: STATUS AND PROSPECTS

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Nuclear power stations offer long service life, steady electricity, low fuel costs, energy efficiency, weather independence, and zero carbon emissions. No wonder the Russian Federation and the People's Republic of China (PRC) prioritize the expansion and perfection of their nuclear energy industries. For advanced nuclear energy cooperation, the states have to identify mutual development interests, ensure a fair distribution of rights and obligations, and consider China's vulnerabilities in the nuclear fuel cycle. Therefore, this research paper examines promising models of Russia-China cooperation in the nuclear energy field based on a wide range of expert, industry, and technical literature, news releases, intergovernmental agreements, planning documents, and other official records.

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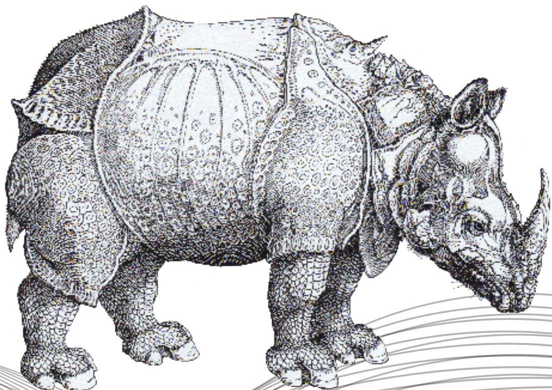

Contents

Highlights

- There are several promising directions for Russian-Chinese cooperation in the field of nuclear energy: the construction and maintenance of Russian-designed nuclear reactors at old and new sites in China; the supply of nuclear fuel, conversion of Chinese reactors to more efficient fuel cycles, organization of nuclear fuel production using Russian technology in China, and joint testing of new fuel types; the improvement of China's enrichment capacity and supply of enriched uranium products to China; a comprehensive development program for Generation IV nuclear reactors of various types, with a special regard to the design, equipment, commissioning, and fuel support of fast neutron reactors, etc.

- Russia leads in nuclear tech exports to China, but to remain competitive, long-term political support and cost-effective cooperation schemes, as well as proactive modernization at Russian production facilities, must be ensured.

- As China's capabilities improve, the dynamic will shift from predominant Russian assistance to joint global market offerings. Despite competing interests currently prevailing in some of the areas, the Sino-Russian strategic rapprochement offers a chance for any future interactions rooted in mutual respect instead of the West's style competitive confrontation.

- The Sino-Russian comprehensive and adaptable legal framework for nuclear energy partnership is generally formed, providing opportunities for standardized agreements and effectively addressing key sensitivities, such as its peaceful purpose, the state's nonproliferation obligations, and protection of intellectual property rights, for mutual benefit.

RUSSIA-CHINA COOPERATION IN NUCLEAR ENERGY: STATUS AND PROSPECTS[1]

Aleksandra Aladko

INTRODUCTION

Nuclear power stations offer long service life, steady electricity, low fuel costs, energy efficiency, weather independence, and zero carbon emissions. No wonder the Russian Federation and the People's Republic of China (PRC) prioritize the expansion and perfection of their nuclear energy industries.

China implements the world's most extensive nuclear power capacity build-up program and strengthens ties with foreign counterparts, primarily Russia, to fill gaps in relevant expertise. For Russia, aiding China's nuclear power growth offers commercial rewards and boosts its export potential, while collaborative research propels technological innovations in the sector. These pragmatic gains foster closer bilateral ties on highly sensitive nuclear issues, minimizing political competition and refining the bilateral legal framework while expanding spheres of coordinated international influence.

For advanced nuclear energy cooperation, the states have to identify mutual development interests, ensure a fair distribution of rights and obligations, and consider China's vulnerabilities in the nuclear fuel cycle. Therefore, this research examines promising models of Russia-China cooperation in the nuclear energy field based on a wide range of expert, industry, and technical literature, news releases, intergovernmental agreements, planning documents, and other official records.

GENERAL COORDINATION FRAMEWORK

Russian and Chinese national legislations are highly flexible, yet key parameters for major nuclear projects are set at the intergovernmental level. A framework Agreement between the states

[1] The author would like to thank Dr. Mikhail N. Lysenko, Ambassador Extraordinary and Plenipotentiary (retired), Deputy Head of the International Law Department at MGIMO University, member of PIR Center Advisory Board, Dr. Vladimir A. Orlov, Professor of the Department of Applied International Analysis at MGIMO University, Academic Advisor of the International Dual Degree M.A. Program *Global Security, Nuclear Policy and WMD Nonproliferation* (MGIMO-MIIS-PIR Center), Founding Director of PIR Center, and Dr. George Moore, Scientist-in-Residence at the James Martin Center for Nonproliferation Studies (CNS), USA, for their advice and valuable comments while working on this research note.

was reached by 1996[2], setting out an open list of research and work directions, pointing to the need for confidential data protection, and preventing commercial gains or interference in third-country dealings under its provisions (Articles 1 and 6). It also contains fundamental nonproliferation provisions for exclusively peaceful uses of nuclear export items, including their physical protection levels at least as recommended by the International Atomic Energy Agency (IAEA), restrictions on the use of any transferred dual-use technology in nuclear explosive devices, setting appropriate safeguards, and terms for re-export and reproduction of all transferred items or data (Article 4). Most of these provisions are tailored to specific projects.

Heads of state, government, competent ministries, or agencies achieve not legally binding but politically significant understandings through memoranda or joint statements. The 2006 inter-agency Memorandum of Understanding on the development of medium-term cooperation on the peaceful uses of nuclear energy and the 2016 Joint Statement of the Heads of Government of Russia and the PRC on the development of strategic cooperation in the peaceful use of nuclear power[3,4]. As to practical actions, the 1996 Agreement envisages various formats, including joint production, consultations, training, scientific exchanges, investor search, and equipment development (Article 2). Especially important is the Commission for preparing regular meetings between the heads of the Russian and Chinese Governments, formed in 1997[5]. Its regular sub-commission on nuclear issues, with thematic working groups, reveals joint work outcomes, promising areas, and the need to conclude or modify a specific intergovernmental agreement. Conditions and procedures are concretized in contracts between civil nuclear-related enterprises united by industry-specific exhibition forums (e.g., China International Import Expo and Russian Atomexpo).

27th meeting of the Russian-Chinese sub-commission on nuclear issues

Source: www.atomic-energy.ru

[2] Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the peaceful uses of nuclear energy of April 25, 1996 // The Bulletin of International Treaties. 2006. No. 2. P. 41-51.

[3] Memorandum of Understanding between the Federal Agency on Atomic Energy and the Commission of Science, Technology, and Industry for National Defense, there is the China Atomic Energy Authority of the PRC on the development of medium-term cooperation in the peaceful uses of atomic energy of November 09, 2006 // Electronic collection of legislative and normative documentation of the Kodeks Consortium. URL: https://docs.cntd.ru/document/902029770 (accessed: 18.08.2023).

[4] Joint Statement of the Heads of Government of the Russian Federation and the PRC on the development of strategic cooperation in the peaceful uses of atomic energy of November 07, 2016 // The Russian Government. URL: http://government.ru/info/25225/ (accessed: 18.08.2023).

[5] O mekhanizme regulyarnyh vstrech glav pravitel'stv Rossii i Kitaya [On the mechanism of regular meetings between the Heads of Government of Russia and China] // China Internet Information Center. URL: http://russian.china.org.cn/russian/85692.htm (accessed: 18.08.2023).

POWER UNITS AT THE TIANWAN NPP

Background

The nuclear power plant (NPP) project in Jiangsu Province originated in 1982[6], but Chinese elites awaited the major political obstacles for talks to be removed for substantial negotiations[7]. The shift in rhetoric was primarily because Soviet NPP technology was easier to master than Western one[8]. After inspecting Finnish facilities with Soviet equipment, the State Council of the PRC approved the initiative, while the Soviet side offered to supply units of 440 or 1,000 MW[9]. Political issues and the 1986 Chernobyl disaster delayed progress, and a Memorandum of Understanding was reached only in 1990, providing a critical base for bargaining and drafting after the collapse of the Soviet Union[10,11].

Phase I

Signing a General Contract for NPP construction in China

Source: www.elib.biblioatom.ru

An intergovernmental Agreement for cooperation in constructing an NPP in China, with a state loan provision, was signed on 18 December 1992, during President Boris Yeltsin's visit to Beijing[12]. It envisaged the joint construction and operation of an onshore NPP with two 1,000 MW units, each comprising a reactor of the VVER-1000 type, a turbine generator, and support facilities.

The Russian side undertook the fundamental design and engineering documentation development of both primary and auxiliary NPP facilities; special installation work; the *designer supervision* function; commissioning and startup of the NPP; general technical assistance in the NPP operation and fuel loading; supplies of Russian-made equipment, instruments, and materials; training of Chinese personnel (Article 3). The Chinese side mainly supported site selection; data provision; general oversight; staff recruitment; safety and regulatory compliance; specialist ac-

[6] Goncharov S. The early stage of coordination of Moscow and Beijing positions on the construction of the nuclear power plant // Orientalistica. 2022. Vol. 5. No. 4. P. 901.

[7] Specifically, the reduction of the Soviet troops on the PRC and Mongolian borders; the withdrawal of Soviet troops from Afghanistan; and the encouragement of the Vietnamese leadership to withdraw troops from the People's Republic of Kampuchea. See Deng Xiaoping nianpu [Chronological biography of Deng Xiaoping] // The Central Committee of the Communist Party of China. Beijing, 2004. P. 1381.

[8] Li P. Qi bu dao fazhan: Li Peng hedian riji [From first steps to development: diary of Li Peng about nuclear energetics] // Beijing: Xinhua Publishing House, 2004. P. 73.

[9] Ibid. P.170-176.

[10] Rossiya postroit AES v Kitae pod klyuch [Russia to build a turnkey NPP in China] // Kommersant. May 11, 1993. URL: https://www.kommersant.ru/doc/47445 (accessed: 18.08.2023).

[11] Kozlov V. Rossijskaya atomnaya energetika za rubezhom: razvitie, krizis, vozrozhdenie [Russian nuclear power abroad: development, crisis, revival]. Moscow: Vash Format, 2018. P.126.

[12] Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of a nuclear power plant in China and for the provision of state loan by Russia to the PRC of December 18, 1992 // The Bulletin of International Treaties. 2011. No. 11. P. 61–70.

commodations; sustainable financing; issuing permits and licenses; adapting regulations; and supplying its part of equipment and materials (Article 4). The PRC also oversaw equipment purchases from third countries and managed the personnel required to commission it. In practice, Chinese operations heavily relied on Russian engineering and consultation.

Regarding nuclear safety and security, three compliance levels have been laid out: Russian norms, additional PRC requirements, and the IAEA regulations (Article 2). Russian bodies also prepared a feasibility study, later additionally reviewed by the IAEA at the PRC's request. A General Contract for the Lianyungang NPP (later renamed the Tianwan NPP) was concluded between Russian and Chinese enterprises in 1997[13]. Within two years, the newly formed Atomstroyexport developed the final technical documentation package, and China's authorities granted a building permit.

Technically, Phase I consisted of two AES-91 type power units, each equipped with the VVER-1000/V-428 reactor and the K-1000-60/3000 turbine generator set[14]. It was an evolution from the AES-91 design proposed but not constructed for Finland, which reflected the operating experience of the Loviisa VVER-440 units. The goal was to optimize the well-established VVER-1000/V-320 using Western experience and IAEA recommendations. The facilities featured enhanced neutron-physical performance and emergency protection by introducing a four-channel safety system, new active and passive protection devices (including an innovative core melt catcher), digital monitoring and control, and a reactor building double containment[15]. By 2007, units 1 and 2 had been put into warranty operation, and in 2010, the final acts of acceptance were signed[16]. For today, they operate at their nominal contracted capacity of 1,060 MW.

The Tianwan NPP construction start ceremony

Source: www.ase-ec.ru

Phase II

While a preliminary agreement for units 3 and 4 at the Tianwan site was reached in 2006, a new General Contract was concluded only in 2010[17]. At the intergovernmental level, a new Protocol to the 1992 Agreement of 6 December 2012 was sufficient due to the existing

[13] Denisov V., Dragunov Y. Reaktornye ustanovki VVER dlya atomnyh elektrostancij [VVER reactors for NPPs] Moscow: IzdAT, 2002. P. 367-369.
[14] Ibid.
[15] Engineering Division of Rosatom and JNPC signed the acceptance statement confirming the transfer of the nuclear island of Tianwan-3 // Rosatom. URL: https://rusatom-energy.com/media/rosatom-news/engineering-division-of-rosatom-and-jnpc-signed-the-acceptance-statement-confirming-the-transfer-of-/ (accessed:18.08.2023).
[16] Kontrakt na stroitel'stvo Rossiej dvuh energoblokov Tyan'van'skoj AES v KNR vstupil v silu [Contract for Russia to build two units of Tianwan NPP in China entered into force] // AtomInfo. September 15, 2011. URL: http://www.atominfo.ru/news8/h0092.htm (accessed: 18.08.2023).
[17] The first video conference with the Chinese customer under project TNPP-2 has been held // Atomstroyexport. URL: http://www.atomex.ru/show/press/702 (accessed: 18.08.2023).

cooperation pattern[18]. It broadly obligated both parties to assist in supplying the necessary documents, equipment, materials, and services, with China to facilitate the registration of Russian suppliers and specialists' entry (Article 3). In the unspecified part, the parties were to follow the 1996 Agreement (Article 5). Practically, the sides guaranteed their obligations as per contract terms between the authorized organizations (Article 4).

This time, the PRC oversaw the design and supply of non-nuclear components and equipment, profitably increasing its share of localization of power unit production and construction work up to 70%[19], using the experience of Phase I. Russia kept responsibility for the core NPP technology, nuclear island design, the reactor and associated equipment supply, and plant commissioning[20].

The Tianwan NPP construction

Source: www.rosatom.ru

Phase II units replicated Phase I with agreed modifications: the upgraded AES-91 design with the V-428M reactor of improved 1,126 MW output was used. Notably, the project required minimal modifications to meet IAEA requirements after the Fukushima Daiichi accident based on the NPP's resistance to external natural factors[21]. The 2012 start of Phase II symbolized the lift of the NPP construction ban in the PRC after the Fukushima disaster[22]. Units 3 and 4 powered up in 2017 and 2018, with their acceptance documents signed in 2020 after the warranty period.

Phases III and IV

The Tianwan NPP site is the first site in China designed for eight units[23]. Although Russia was ready to build all of them, the PRC decided to construct Phase III indigenously[24], turning to Russian assistance only in Phase IV. A new Protocol to the 1992 Agreement and a framework contract for units 7 and 8 of the AES-2006 project were signed on 8 June 2018[25], during President Vladimir Putin's visit to Beijing, followed by a General Contract a year later. Identical to

[18] Protocol between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of units 3 and 4 of the Tianwan nuclear power plant in China of December 06, 2012 // The Bulletin of International Treaties. 2014. No. 1. P. 99–101.
[19] Sozoniuk V. Case study of the VVER project at Tianwan // OECD WPNE Workshop. Moulineaux, 2014. URL: https://www.oecd-nea.org/jcms/pl_30721/wpne-workshop-3-4-case-study-of-the-vver-project-at-tianwan-china?details=true (accessed: 18.08.2023).
[20] Ibid.
[21] Lankevich A. VVER - istoriya, sostoyanie i razvitie: chast' 2 [VVER - history, status, and development: part 2] // AtomInfo. June 13, 2021. URL: http://www.atominfo.ru/newsz03/a0759.htm (accessed: 18.08.2023).
[22] Stroyashchiesya AES [NPPs under construction] // Rosatom. URL: https://www.rosatom.ru/production/design/stroyashchiesya-aes/ (accessed: 18.08.2023).
[23] The usual maximum is six.
[24] China's Hongyanhe 5 achieves first criticality // Nuclear Engineering International. June 22, 2021. URL: https://www.neimagazine.com/news/newschinas-hongyanhe-5-achieves-first-criticality-8840178 (accessed: 18.08.2023).
[25] Protocol between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of units 7 and 8 of the Tianwan nuclear power plant in China of 08.06.2018 // The Bulletin of International Treaties. 2019. No. 4. P. 51.

Phase II, Russia is responsible for the nuclear island design and supply of the key equipment with related technical services[26].

The VVER-1200/V-491 design of Phase IV units belongs to Generation III+, compared to Generation III reactors of the previous Phases. This reactor has 20% more capacity at a comparable size to the VVER-1000, can maneuver it, and ensures that Fukushima-type accidents can be ruled out[27]. Launched in 2019, Phase IV units are set to be operational by 2026-2027.

Funding

After a comprehensive financial analysis[28], the PRC Government received a state loan of up to $2,5 billion at a 4% annual interest rate (Article 6 of the 1992 Agreement). The debts were to be paid equally through monetary payments and deliveries of Chinese goods to Russia (Paragraph 7.3 of Article 7). Since this mechanism did not meet Russia's import needs, the PRC conditioned the transition to full monetary repayment by applying a discount to each payment on the debt other than the overdue amount. In 2010, Russia ratified a Protocol to the 1992 Agreement, addressing the requests of both sides[29]. The revised Article 8 allowed for early repayment of the loan by mutual consent, agreed upon through a relevant Addendum in 2016[30]. China largely self-financed the project, using only $1,3 billion of the total loan[31]. Thus, the financing scheme proved its efficiency, guaranteed repayment on terms relevant to Russia, and reduced China's financial burden.

The shift in rhetoric was primarily because Soviet NPP technology was easier to master than Western one

Fuel

The 1992 Agreement (Article 5) stipulated Russian nuclear fuel supply for at least initial loading and the first three reloads of the reactors under construction, mentioning the possible sale of fuel fabrication technology. Under a contract to supply the UTVS fuel for the start-up and three reloads of units 1 and 2 of the Tianwan NPP

[26] Tyan'van'skaya AES (Kitaj) [Tianwan NPP (China)] // Rosatom. URL: https://ase-ec.ru/about/projects/aes-tyanvan/ (accessed: 18.08.2023).
[27] Sovremennye reaktory: reaktor VVER-1200 [Modern reactors: the VVER-1200 reactor] // Rosenergoatom. URL: https://www.rosenergoatom.ru/stations_projects/atomnye-elektrostantsii-rossii/sovremennye-reaktory/ (accessed: 18.08.2023).
[28] While the credit basis of such projects is a well-established international practice, this condition was strongly opposed by the Russian Ministry of Finance. See Kozlov V. Rossijskaya atomnaya energetika za rubezhom: razvitie, krizis, vozrozhdenie [Russian nuclear power abroad: development, crisis, revival]. Moscow: Vash Format, 2018. P.130.
[29] Protocol of March 23, 2010, to the Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of a nuclear power plant in China and for the provision of state loan by Russia to the PRC of December 18, 1992: ratified by Federal Law No. 330-FZ of the Russian Federation of December 08, 2010 // The Bulletin of International Treaties. 2011. No. 2.
[30] Addendum of June 25, 2016, to the Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of a nuclear power plant in China and for the provision of state loan by Russia to the PRC of December 18, 1992 // The Bulletin of International Treaties. 2016. No. 10. P. 83-84.
[31] Kitaj dosrochno pogasil rossijskij kredit na stroitel'stvo AES [China has repaid a Russian NPP loan ahead of schedule] // Interfax. June 29, 2016. URL: https://www.interfax.ru/business/516036 (accessed: 18.08.2023).

with TVEL of 1997, 638 fuel assemblies were manufactured in Russia under Chinese control[32]. It also covered further production of the UTVS fuel through technology transfer at the Yibin Nuclear Fuels Factory, qualified by TVEL in 2010.

The new TVS-2M assemblies additionally enabled TVEL to switch Chinese plants to more fuel-efficient cycles. In 2010, units 1 and 2 were set to use the TVS-2M with eighteen-month fuel cycles, and six pilot fuel assemblies were delivered for licensing. For unit 1, a new fuel supply of six reloads was arranged (with a seventh agreed later); for unit 2, the TVS-2M production was planned in China from the seventh reload[33]. This $500 million contract package also covered zirconium components supplies for the UTVS and the TVS-2M fuel production at the Yibin Factory.

In 2013, an over $1 billion contract for the initial fuel load of both Phase II units and six subsequent reloads of unit 3 until 2025 was signed, with an addendum to convert units 3 and 4 to long-term fuel cycle operation in 2015[34]. In 2017, TVEL secured the fuel partnership for Phase I and II units through a $1 billion deal for supplying zirconium components, fuel, and engineering services[35], and since 2019, it has had contracts for the initial load and reloads of units 7 and 8[36].

Launch of construction of the Tianwan NPP units 7 and 8 and the Xudapu NPP units 3 and 4

Source: www.kremlin.ru

Conclusion

The Tianwan NPP project is Russia's key post-Soviet nuclear energy collaboration with China, which showcased its NPP tech, financial flexibility, and long-term commitment worldwide. Its outstanding safety is credited to mutual adherence to best practices, rigorous testing, and new design standards. Beyond technological gains, the project enabled China to refine its localization strategy for NPPs, while Russia, driven by economic and reputational benefits, remains eager to construct more reactors in the PRC. Notably, in 2017, plans were announced for a new Russian-designed NPP near the Tianwan site[37].

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[32] Chinese to take over fuel manufacture for Tianwan // Nuclear Engineering International. March 01, 2010. URL: https://www.neimagazine.com/news/newschinese-to-take-over-fuel-manufacture-for-tianwan (accessed: 18.08.2023).

[33] TVEL signs package of Chinese fuel contracts // World Nuclear News. November 02, 2010. URL: https://www.world-nuclear-news.org/Articles/TVEL-signs-package-of-Chinese-fuel-contracts (accessed: 18.08.2023).

[34] TVEL signs further Tianwan fuel contracts // World Nuclear News. April 28, 2017. URL: https://www.world-nuclear-news.org/Articles/TVEL-signs-further-Tianwan-fuel-contracts (accessed: 18.08.2023).

[35] Godovoj otchyot 2017: povyshenie effektivnosti i ustojchivoe razvitie [Annual report 2017: improving efficiency and sustainability] // TVEL. Moscow, 2018. P. 10. URL: http://tvel2017.ru/downloads/AR-2017_TVEL_Zoran_2018_12_RUS_WEB_10-01-2018.pdf (accessed: 18.08.2023).

[36] Russia's Tvel to supply fuel for Tianwan 7&8 // Nuclear Engineering International. July 26, 2019. URL: https://www.neimagazine.com/news/newsrussias-tvel-to-supply-fuel-for-tianwan-7-8-7331132 (accessed: 18.08.2023).

[37] Kitaj predlozhil Rossii postroit' novuyu AES v provincii Czyansu [China proposes Russia to build a new NPP in Jiangsu Province] // Kommersant. August 17, 2017. URL: https://www.kommersant.ru/doc/3385928

POWER UNITS AT THE XUDAPU NPP

Background

Work on the Xudapu NPP in Xingcheng City began in 2010, planning to equip all six units with the AP-1000 or CAP-1000 rectors[38]. While the CAP-1000 reactor contract for units 1 and 2 is still in the preparatory stage[39], China turned to Russian help for units 3 and 4 as a part of its Northeast China Recovery Plan to replace thermal power plants[40,41]. The relevant Protocol and framework contract were signed on 8 June 2018[42], bypassing a separate intergovernmental agreement. As in Phases II and IV of the Tianwan NPP, the Protocol only outlines the organizational and documentary obligations of the parties and the contract-based nature of cooperation, referring to the 1996 Agreement in an unspecified part (Articles 4 and 5).

Implementation

In 2019, a technical project and a $1,7 billion General Contract were signed by authorized organizations[43]. Russia oversees the nuclear island and the supply of key equipment and machinery for both units (manufacturing began in 2019)[44], installation management, and overall on-site control. China is responsible for the conventional island, as well as the corresponding equipment and balance of plant works. The labor division mirrors the Tianwan NPP's Phases II and IV, but due to the site's distance, a new representative structure was required.

Like in Phase IV of the Tianwan NPP, these two units belong to the AES-2006 project with the VVER-1200/V-491 reactor and are built with site-specific modifications to reference units of the Leningrad II NPP. The project was inaugurated in 2021, after which the first large-size equipment arrived. Despite geopolitical issues, the construction continues with a peak workload, targeting a 2027-

[38] Nuclear power in China // World Nuclear Association. URL: https://world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx (accessed: 18.08.2023).
[39] Contract for nuclear islands of Xudabao Phase I // World Nuclear News. October 14, 2016. URL: https://www.world-nuclear-news.org/NN-Contract-for-nuclear-islands-of-Xudabao-Phase-I-1410164.html (accessed: 18.08.2023).
[40] Zhenxing dongbwi lao gongye jidi [Revitalising the old industrial base in Northeast China] // Xinhua News Agency. November 10, 2019. URL: http://www.xinhuanet.com/politics/2019-11/10/c_1125214362.htm (accessed: 18.08.2023).
[41] If units 1 and 2 are built, the Xudapu NPP could pioneer the coexistence of Russian and American design reactors at one site.
[42] Protocol between the Government of the Russian Federation and the Government of the PRC for cooperation in the serial construction of nuclear power units at the Xudapu nuclear power plant in China of June 08, 2018 // The Bulletin of International Treaties. 2019. No. 4. P. 51-54.
[43] Nuclear power in China // World Nuclear Association. URL: https://world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx (accessed: 18.08.2023).
[44] "Atommash" has started manufacturing equipment for Xudapu NPS (China) // Atomenergomash. February 12, 2021. URL: https://www.aem-group.ru/en/mediacenter/news/"atommash"-has-started-manufacturing-equipment-for-xudapu-nps-(china).html (accessed: 18.08.2023).

2028 finish[45], which could lead to further collaboration on units 5 and 6 at the site as per the 2018 Protocol (Paragraph 4 of Article 1).

Integrated offer

In 2019, TVEL was contracted for the initial fuel loading and subsequent reloads of units 3 and 4 at the Xudapu NPP[46]. In addition, Rosatom's NUKEM Technologies won a contract to design and provide equipment for the NPP's waste (wet and dry) treatment facility, covering installation and maintenance services[47].

The Xudapu NPP construction

Source: www.chinadaily.com.cn

Conclusion

The Xudapu NPP contract anchors Russian nuclear tech in the booming atomic market and reveals a replicable partnership model, but also confirms that China no longer needs to turn to foreign partners for turnkey NPP construction. Nevertheless, two more reactor units could be built at the Xudapu NPP, and Rosatom could be awarded the contract to build them because choosing the same technological route for most of the reactors of one NPP would offer greater operational convenience.

URANIUM ENRICHMENT

Prerequisites

For the past decade, Russia has been the world leader in enriched uranium production, with almost half of the global capacity[48]. However, forecasts predict Russia's share to fall to 36% by 2030 while China's one to rise from 10% to 25%[49], and this shift seems underway[50]. China's enrichment skills improvement was boosted by years of Russian mentorship: in the 1950s, they jointly established the Lanzhou plant with gaseous diffusion tech; in the late 1980s and

[45] The first batch of equipment from Russia to the Xudapu NPP arrived in China // Greater Asia. November 29, 2021. URL: https://bigasia.ru/en/content/news/business/the-first-batch-of-equipment-from-russia-for-the-xudapu-npp-arrived-in-china/ (accessed: 18.08.2023).
[46] TVEL Fuel Company of Rosatom inks fuel contract for China's Xudapu NPP new units // Rosatom. November 06, 2019. URL: https://www.rosatom.ru/en/press-centre/news/tvel-fuel-company-of-rosatom-inks-fuel-contract-for-china-s-xudapu-npp-new-units/?sphrase_id=3712939 (accessed: 18.08.2023).
[47] Construction of Xudapu 4 under way // World Nuclear News. May 19, 2022. URL: https://www.world-nuclear-news.org/Articles/Construction-of-Xudapu-4-under-way (accessed: 18.08.2023).
[48] Uranium enrichment // World Nuclear Association. URL: https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx (accessed: 18.08.2023).
[49] Foltynova K. Russia's stranglehold on the world's nuclear power cycle // Radio Free Europe. September 01, 2022. URL: https://www.rferl.org/a/russia-nuclear-power-industry-graphics/32014247.html (accessed: 18.08.2023).
[50] Gilbert A., Bazilian M. Russia's energy clout doesn't just come from oil and gas – it's also a key nuclear supplier The Conversation. April 18, 2022. URL: https://theconversation.com/russias-energy-clout-doesnt-just-come-from-oil-and-gas-its-also-a-key-nuclear-supplier-179444 (accessed: 18.08.2023).

early 1990s, Russia facilitated China's transition to cheaper centrifuge-based methods[51].

Phases I and II

On December 18, 1992, during Russian President Boris Yeltsin's first official visit to China, an intergovernmental Agreement for cooperation in constructing a gaseous centrifuge plant in the PRC to enrich uranium for nuclear power was signed as part of a package deal to build the first two units of the Tianwan NPP[52]. Phase I (0,2 million SWU/year) was ready by 1996, and Phase II (0,3 million SWU/ year) by 1998 at the Hanzhong site[53].

Russia agreed to sell its technology and expertise for building and operating a centrifuge enrichment plant (Paragraphs 1.1 and 1.2 of Article 1). Besides documentation, technical aid involved engineering consultation and supplying essential process and auxiliary equipment. In turn, China committed to buying 30% of uranium hexafluoride and enriched uranium to produce 30% of the Daya Bay NPP's fuel for five years starting in 1994 (Paragraphs 1.3 and 1.4 of Article 1). These terms ensured Russia's stable uranium sales and China's supply amidst its reduced uranium exploration in the 1990s[54].

Phase III

China's 1996-2002 plan for eight new nuclear reactors required capacity expansion to 1 million SWU/year, resulting in a new Protocol with Russia for Phase III construction at the Lanzhou plant of 1996[55]. The 0,5 million SWU/ year project was added in 2001, while all obsolete capacities were closed. Thus, China's early XXI century enrichment demands were mostly met by Russian centrifuges and even enabled China to initiate the accumulation of some SWU surplus[56].

The Xudapu NPP contract anchors Russian nuclear tech in the booming atomic market and reveals a replicable partnership model, but also confirms that China no longer needs to turn to foreign partners for turnkey NPP construction

[51] Skomorokha T., Khlopkov A. Rossijsko-kitajskoe sotrudnichestvo v oblasti obogasheniya urana: ot gazovoj diffuzii k centrifuge [Russian-Chinese cooperation in uranium enrichment: from gas diffusion to centrifuge] // Nuclear Club. 2010. Vol. 3. No. 2. P. 18-19.
[52] Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of a gaseous centrifuge plant in China to enrich uranium for nuclear power of December 18, 1992 // The Bulletin of International Treaties. 2008. No. 8. P. 38-41.
[53] Russia and China sign enrichment plant agreement // World Nuclear News. May 27, 2008. URL: https://www.world-nuclear-news.org/Articles/Russia-and-China-sign-enrichment-plant-agreement (accessed: 18.08.2023).
[54] Zhang H, Bai Y. China's access to uranium resources. Cambridge: Belfer Center for Science and International Affairs, 2015. P. 14.
[55] Protocol of December 27, 1996, to the Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of a gaseous centrifuge plant in China to enrich uranium for nuclear power of December 18, 1992 // The Bulletin of International Treaties. 2008. No. 8. P. 41-43.
[56] Zhang H. China's uranium enrichment capacity: rapid expansion to meet commercial needs. Cambridge: Belfer Center for Science and International Affairs, 2015. P. 34.

Phase IV

China's shift to *active* nuclear power use in 2004 required a new 0,5 million SWU centrifuge facility under Phase IV at the Hanzhong plant, which was formalized in a new Protocol to the 1992 Agreement in 2007[57]. This time, equipment supply and advisory services were expanded with training for Chinese specialists in Russia, and the parties agreed on a parallel contract with an option period of eleven years for the provision of uranium enrichment services and/or the supply of low-enriched uranium from Russia, capped at 1 million SWU/year and commencing in 2010. The contract aimed to bridge the gap between reactor needs and domestic low-enriched uranium production, so the supplied products couldn't be exported. In 2008, Rosatom's Techsnabexport established interaction procedures via a technical assistance contract for Phase IV construction and low-enriched uranium deliveries, signed during Russian President Dmitry Medvedev's visit to Beijing[58]. Phase IV deals exceeded $1 billion, and the facility was launched in 2011, with Russia meeting its technical obligations by 2014[59].

Nonproliferation, safety, and security

To reinforce nuclear nonproliferation, the contractual framework prohibits the use of materials, components, technology, equipment, knowledge, expertise, and know-how obtained to produce nuclear weapons or any other nuclear explosive device, as well as for any other military purpose (Paragraph 5.1 of Article 5 of the 1992 Agreement). All received equipment, devices, materials, technology, information, experience, knowledge, and know-how must be used in China's territory and could be transferred from its jurisdiction only after Russian written consent (Paragraph 5.2). Moreover, Russia retained oversight over the use of the supplied resources and technologies without affecting the plant's construction and operation (Paragraph 5.3). An Agreement of 23 July 1993 detailed such procedures and provided for regular visits of Russian specialists to the separation process[60].

[57] Protocol of November 06, 2007, to the Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction of a gaseous centrifuge plant in China to enrich uranium for nuclear power of December 18, 1992 // The Bulletin of International Treaties. 2008. No. 8. P. 43-45.

[58] Russia and China sign enrichment plant agreement // World Nuclear News. May 27, 2008. URL: https://www.world-nuclear-news.org/Articles/Russia-and-China-sign-enrichment-plant-agreement (accessed: 18.08.2023).

[59] OAO "Tekhsnabeksport" vypolnilo vse obyazatel'stva po kontraktu s CNEIC (Kitaj) [Techsnabexport Has Fulfilled All Contractual Obligations with CNEIC (China)] // Atomic Energy 2.0. August 05, 2014. URL: http://www.energyland.info/analitic-show-125100 (accessed: 18.08.2023).

[60] Skomorokha T.,Khlopkov A. Rossijsko-kitajskoe sotrudnichestvo v oblasti obogashheniya urana: ot gazovoj diffuzii k centrifuge [Russian-Chinese cooperation in uranium enrichment: from gas diffusion to centrifuge] // Nuclear Club. 2010. Vol.

Moreover, under the 1992 Agreement and its Protocols, the supplied centrifuge facilities (Phases I-III) were to be under IAEA safeguards; China offered to list them as eligible under its Voluntary Offer Safeguards Agreement (INFCIRC/369). Phases I-II centrifuge facilities were actually placed under IAEA safeguards via a Tripartite Safeguards Agreement between the IAEA, the Ministry for Atomic Energy of the Russian Federation, and China's Atomic Energy Authority, which was designed as a safeguards approach for any plant equipped with Russian centrifuge technology, characterized by a high degree of operational flexibility[61]. Phase III facilities were excluded due to IAEA funds shortage, but China's offer to allow IAEA inspection affirms their civilian use[62].

In turn, safety and security requirements are reciprocal: Russia to ensure project technical standards as per IAEA (Paragraph 3.1 of Article 3), and China to provide physical protection of nuclear materials and equipment at a level not lower than IAEA-recommended (Paragraph 4.3 of Article 4).

Technology protection

Russia and China agreed to transfer equipment per the best practices available at the time of the 1992 Agreement (Paragraph 3.1 of Article 3), which raised concerns about China gaining secret technology. For Phases I-III, Russia supplied sixth-generation centrifuges[63]. Given the 50% higher capacity of the Phase IV facility, it's inferred that Russian seventh- and eighth-generation centrifuges have also been installed[64]. However, the arrangements didn't include technology transfer to preserve Russian competitive edge[65], yet the 1992 Agreement allows potential consideration of such a sale (Paragraph 1.5 of Article 1). The 1992 Agreement and subsequent Protocols mandated strict safeguards for equipment, documents, and confidential data involved in technical projects. Besides the necessary protection, such data can only be shared with a third party with Russia's written consent (Paragraphs 4.1 and 4.2 of Article 4). Moreover, prior to the first actual technology transfer, a specific Agreement regarding the handling of confidential information

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3. No. 2. P. 20.

[61] Tripartite enrichment project: safeguards at enrichment plants equipped with Russian centrifuges (IAEA-SM-367/8/02) / A. Panasyuk, A. Vlasov, S. Koshelev [et al.]; ed. by T. Shea. Vienna: IAEA, 2001. P. 1. URL: https://www-pub.iaea.org/MTCD/publications/PDF/ss-2001/PDF%20files/Session%208/Paper%208-02.pdf (accessed: 18.08.2023).

[62] Zhang H. China's uranium enrichment and plutonium recycling 2020-2040: current practices and projected capacities / H. Zhang; ed. H. Sokolski // China's Civil Nuclear Sector: Plowshares to Swords? Arlington: Nonproliferation Policy Education Center, 2021. P. 39-40.

[63] Zhang H. China's uranium enrichment complex // Science & Global Security. 2015. Vol. 23. No. 3. P. 175-176.

[64] Ibid. P. 176.

[65] Russia began installing seventh-generation centrifuges in 1996 and eighth-generation ones in 2003. Today, it operates supercritical ninth and nine-plus generations, tests the tenth, and works on the eleventh. See Struny centrifug [Centrifuge strings] // Strana Rosatom. November 27, 2017. URL: https://strana-rosatom.ru/2017/11/27/struny-centrifug/ (accessed: 18.08.2023).

and ensuring physical protection measures for equipment and data was reached in 1993. Given China's nuclear ties with Pakistan, these safeguards remain crucial.

The 2007 Protocol also blocked the unauthorized reproducing or exporting of Russian gas centrifuge plants as integrated facilities, components, materials, technology, and know-how (Article 3). Given that China has already tried to copy Russia's sixth-generation centrifuges, the fears were not unfounded[66]. The Protocol also added China's duty to dispose of unfunctional centrifuges, with Russia granted the right to monitor this process. All provisions remain in force even after the termination of the Agreement in relation to the relationship arising from the Agreement prior to its termination, securing Russian tech in the long term.

Russia enabled China's initial uranium enrichment capacity, but future bilateral ties hinge on the PRC's tech advancement

Conclusion

Russia enabled China's initial uranium enrichment capacity, but future bilateral ties hinge on the PRC's tech advancement. Besides the risk that Chinese centrifuges will not meet SWU demand by 2025-2030, China might also seek Russian-enriched uranium as part of package deals to build Russian reactors in China or its projects in third countries[67].

FAST NEUTRON REACTORS

Prerequisites

Fast neutron reactors could increase the energy yield of uranium resources, enable China's transition to closed fuel cycle technologies, and overcome the self-sufficiency bottleneck in reactor fuel and fissile materials via breeding[68]. Historically, the Soviet Union led in assessing fast neutron properties for nuclear reactors[69], aiding China's research in the field since 1964. In 1987, the 863 Program for high-tech development included the breeder program led by the China Institute of Atomic Energy[70], and five years later, China turned to Russia for its pilot fast project to save time and costs.

[66] Leskov S. Uran na Angare [Uranium on Angara] // Umnye parni [Smart guys]. Moscow: Vremya, 2011. P. 545.
[67] For example, the first of the regular shipments from the Uranium Enrichment Centre in Novouralsk to the joint Sino-Kazakhstani Ulba Fuel Assembly plant took place in 2021.
[68] Fast neutron reactors // World Nuclear Association. URL: https://world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx (accessed: 18.08.2023).
[69] Reaktory na bystryh nejtronah [Fast neutron reactors] // Institute of Physics and Power Engineering. URL: https://www.ippe.ru/nuclear-power/fast-neutron-reactors (accessed: 18.08.2023).
[70] Silin B., Sedakov V. Russian companies' involvement in CEFR RP (China) construction // International Conference on Fast Reactors and Related Fuel Cycles: Next Generation Nuclear Systems for Sustainable Development. Yekaterinburg, 2018. P. 1. URL: https://media.superevent.com/documents/20170620/9d4920c56cf4b3cc2aeee88c9c89e262/fr17-423.pdf (accessed: 18.08.2023).

China's experimental fast reactor

The China Experimental Fast Reactor (CEFR) aimed to master safety and equipment, conduct research, and train human capital to operate such an advanced facility[71]. For three years, Russian and Chinese institutions co-developed the reactor concept and technical requirements. Approved in 1995, the design took another year to meet the heightened safety standards. To prepare the site near Beijing, test prototypes, and organize supply chains, the parties were guided by an inter-agency Agreement of 24 March 1995 in the field of developing the experimental sodium-cooled fast reactor. To better coordinate the design, construction, and commissioning phases, a new intergovernmental Agreement was signed on 18 June 2000[72].

Its Article 2 indicated the main responsibilities of each party through the key areas of cooperation. Among those reliant on the participation of both parties were the design of the CEFR, fuel elements, equipment and instrumentation, control and management system, as well as complex development and research works (Paragraphs 1 and 2). In fact, high-tech equipment manufacturing and supplying was Russia's primary obligation (Paragraph 3), and its technical design formed the basis for the Chinese part of the work[73]. Though the CEFR's installation, commissioning, start-up, testing, and commercial operation were identified as mainly China's domain, Russian assistance was deemed essential throughout (Paragraph 4). Moreover, regular experience exchanges between both states' nuclear and radiation safety regulators were envisaged (Paragraph 8), as well as consulting and training services for Chinese personnel, including exercises at Russian fast reactors (Paragraph 7). Ultimately, work specifics and schedules were set in enterprise contracts (Paragraph 2 of Article 4). In 2000, a Sino-Russian coordinating group for the CEFR became operational, and construction began in 2001[74].

The China Experimental Fast Reactor (CEFR)

Source: www.neimagazine.com

The CEFR is a pool-type sodium-cooled reactor of the BN-20 model (65 MW thermal and 20 MW electrical output). Its solutions are based on the Russian BN-600 reactor and were proven at Russian facilities for the enhanced safety concept[75], while Chinese staff trained at Russian reactors (including the BOR-60)[76]. Today, Russian testing and analytical services continue, with adjustments made

[71] China Experimental Fast Reactor (CEFR) // China Institute of Atomic Energy. URL: http://www.ciae.ac.cn/eng/cefr/index.htm (accessed: 18.08.2023).
[72] Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction and operation of an experimental fast neutron reactor in China of June 18, 2000 // The Bulletin of International Treaties. 2000. No. 12. P. 52-56.
[73] Sedakov V. Pervyj kitajskij bystryj [China's first fast] // Atomvestnik. May 24, 2022. URL: https://atomvestnik.ru/2022/05/24/pervyj-kitajskij-bystryj/ (accessed: 18.08.2023).
[74] Kostin V. Uchastie predpriyatij otrasli v proektirovanii i sooruzhenii reaktora na bystryh nejtronah v Kitae [Industry involvement in the design and construction of a fast neutron reactor in China] // Atomic Energy Bulletin. 2007. No. 7. P. 64-70.
[75] Sedakov V. Pervyj kitajskij bystryj [China's first fast] // Atomvestnik. May 24, 2022. URL: https://atomvestnik.ru/2022/05/24/pervyj-kitajskij-bystryj/ (accessed: 18.08.2023).
[76] Silin B. Russian Companies' involvement in CEFR RP (China) Construction. P. 5.

due to COVID-19. The 2000 Agreement targeted 2003, but the CEFR reached criticality in 2010 and was connected to the grid a year later. In 2014, it achieved its design goal of 72 hours at full power[77]. After an emergency shutdown test, the CEFR started its second operating cycle and high-power operations in 2021[78].

China's demonstration fast reactors

The CEFR project led to a memorandum with Russia on constructing a fast neutron demonstration reactor consisting of two BN-800-type units[79]. A contract for pre-project studies and a draft commercial proposal were prepared between 2009 and 2012, but their construction, scheduled to start in 2013-2014 at the Sanming NPP, remains uncertain due to cost and tech transfer disputes[80].

The CFR-600 construction

Source: www.neimagazine.com

Thus, China prioritized the indigenous China Fast Reactor 600 (CFR-600), which retains many characteristics similar to the Russian BN-600. An intergovernmental Agreement for cooperation in the construction and operation of the CFR-600 with 600 MW of electrical power capacity was signed on 8 June 2018[81]. The Russian side made a commitment: to supply key reactor and spent nuclear fuel management equipment, their spare parts, tools, and other devices; to allow the use of Russian computer programs; to offer installation, commissioning, technical support, and personnel training services; to conduct expert reviews of the technical documentation with recommendations (Paragraph 1 of Article 5). In turn, China's main duty was to ensure payment for Russian supplies and services (Paragraph 4 of Article 5), besides the mutual duty to facilitate the timely issuance of the necessary documents (Paragraph 5 of Article 5).

The first unit construction began in Xiapu County in 2017; and in 2020, China announced the start of construction of a second similar unit to the west of the first one[82]. They are expected to be operational in 2023 and 2026. In addition, the 1,000-1,200 MW commercial-scale CFR-1000 has been planned since 2013, with construction expected in 2028 and commissioning around 2034, but its approval status is unclear[83].

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[77] CEFR completes first-cycle trial operations // CNNC. August 07, 2020. URL: https://en.cnnc.com.cn/2020-08/07/c_527271.htm (accessed: 18.08.2023).
[78] Chinese fast reactor begins high-power operation // World Nuclear News. February 17, 2021. URL: https://www.world-nuclear-news.org/Articles/Chinese-fast-reactor-begins-high-power-operation (accessed: 18.08.2023).
[79] Godovoj otchet Atomenergoproekt 2012 [Atomenergoproekt annual report 2012] // Atomenergoproekt. Nizhny Novgorod, 2013. P. 56. URL: https://report.rosatom.ru/go/ASE/podrazdel/niaep/go_2012_1.pdf (accessed: 18.08.2023).
[80] Bunn M. The cost of reprocessing in China / M. Bunn, H. Zhang, L. Kang. Cambridge: Belfer Center for Science and International Affairs, 2016. P. 32-33.
[81] Agreement between the Government of the Russian Federation and the Government of the PRC for cooperation in the construction and operation of a demonstration fast neutron reactor in China of June 08, 2018 // The Bulletin of International Treaties. 2019. No. 4. P 54-64.
[82] China starts building second CFR-600 fast reactor // World Nuclear News. December 29, 2020. URL: https://world-nuclear-news.org/Articles/China-starts-building-second-CFR-600-fast-reactor (accessed: 18.08.2023).
[83] Chinese fast reactor begins high-power operation // World Nuclear News. February 17,

Nonproliferation

The CEFR Agreement (Paragraph 1 of Article 6) and CFR-600 Agreement (Paragraph 2 of Article 8) contain similar provisions: nuclear material, facilities, equipment, and special non-nuclear material and technology supplied, as well as those produced from them, cannot be military used, will be provided with physical protection measures at a level not lower than IAEA standards, and need Russian written approval for third-party transfer or re-export. The CFR-600 Agreement also covered the control of supplied dual-use equipment and materials, banning unapproved modifications and replications and their use in nuclear explosives (Paragraph 3 of Article 8). These conditions are designed to mitigate the debate regarding China's intention to use reactor-grade plutonium in its fast breeder reactors to produce weapon-grade plutonium, which has political rather than practical justifications[84].

Intellectual rights

The CEFR Agreement contains only Article 7 on handling sensitive and confidential information and notes that the protection and allocation of intellectual property rights will be regulated in specific contracts (Paragraph 3 of Article 4), while the CFR-600 Agreement has an Annex detailing such issues. Its Paragraphs 3 and 4 state that previous intellectual property belongs to its original owner and is not alienable, being used by the receiving party solely for the Agreement's purposes; any modification requires the owner's consent. Transfer terms for prior intellectual property were systematized into IT *portfolios*, and a tailored protection and enforcement strategy for the CFR-600 project was drafted[85]. Thus, the regime, being originally a core demand of Rosatom, protects both sides equally[86].

Nuclear liability

Due to China's scattered nuclear liability and compensation rules and resistance to the Vienna Convention on Civil Liability for Nuclear Damage of 1963, targeted provisions were needed to prevent disputes and define liability limits. Article 9 of the CEFR Agreement sets the strict liability of the Chinese operator for nuclear damage caused by an incident during the CEFR's construction and life cycle on Chinese soil[87]. The CFR-600 Agreement introduced the concept

Fast neutron reactors could increase the energy yield of uranium resources, enable China's transition to closed fuel cycle technologies, and overcome the self-sufficiency bottleneck in reactor fuel and fissile materials via breeding

2021. URL: https://www.world-nuclear-news.org/Articles/Chinese-fast-reactor-begins-high-power-operation (accessed: 18.08.2023).

[84] Zhang H. China's uranium enrichment and plutonium recycling 2020-2040: current practices and projected capacities. P. 52.

[85] OKBM Afrikantov: publichnyj otchyot 2017 [OKBM Afrikantov: public report 2017] // OKBM Africantov. Nizhny Novgorod, 2018. P. 120. URL: https://raex-a.ru/annual_reports/reports/2017_okbm.pdf (accessed: 18.08.2023).

[86] Kitajskij masshtab [Chinese scale] // Atomvestnik. August 1, 2021. URL: https://atomvestnik.ru/2021/08/01/kitajskij-masshtab/ (accessed: 18.08.2023).

[87] This term is consistent with the Vienna Convention on Civil Liability for Nuclear Dam-

of a nuclear facility *operator* and imposed the contractual obligation of a Chinese-authorized entity to bear the absolute liability for damage caused by a nuclear incident at the site, as well as from the receipt of Russian fuel assemblies, following Chinese law and international treaties (Paragraph 2 of Article 12), except force majeure. In turn, Russian-authorized entities bear civil liability for nuclear damage only in connection with the manufacture and transportation of fuel assemblies until they are transferred to the Chinese side, following Russian law and international treaties (Paragraph 1 of Article 12).

Fuel

The CEFR Agreement covered the fuel supply for the reactor and related technologies for the fabrication and use of uranium and uranium-plutonium fuel (Paragraphs 5 and 6 of Article 2). The CEFR was designed to operate on mixed oxide (MOX) fuel, with highly enriched uranium fuel only at the initial stage. However, expert estimates and multi-million contracts with TVEL for the production and supply of highly enriched uranium fuel assemblies of 2013 and 2016 indicate that it will use highly enriched uranium indefinitely[88].

The CFR-600 is also fuel-flexible. The CFR-600 Agreement contained interrelated responsibilities for supplying fuel assemblies and technical support for such supplies over the reactor's lifetime, considering Chinese demands and Russian capabilities (Paragraph 2 of Article 5). A subsequent contract with TVEL required a major upgrade of the Russian fast reactor fuel fabrication facility, resulting in a new site for the serial production of fuel assemblies for a Chinese-designed reactor in 2021[89]. Next year, uranium fuel for the initial load and first refueling were delivered, as well as reactor control and protection assemblies[90].

The transition of Chinese fast reactors to MOX fuel is uncertain, but news of Russia's BN-800 switching to MOX fuel is promising[91]. Moreover, under the terms of the CFR-600 Agreement, Russian-Chinese fuel ties can grow in equipment supply and tech support once the uranium-plutonium pellets production in China is initiated (Paragraph 2 of Article 5)[92], and analysts speculate that the

age of 1963.

[88] Hibbs M. Rethinking China's fast reactor // Arms Control Wonk. February 17, 2017. URL: https://www.armscontrolwonk.com/archive/1202830/rethinking-chinas-fast-reactor/ (accessed: 18.08.2023).

[89] TVEL shipped equipment to China for testing CFR-600 // Rosatom. December 23, 2021. URL: https://rosatom-europe.com/press-centre/news/tvel-shipped-equipment-to-china-for-testing-cfr-600/ (accessed: 18.08.2023).

[90] Rosatom ships fuel for China's CFR-600 fast reactor launch // Rosatom. December 28, 2022. URL: https://rosatom.ru/en/press-centre/news/rosatom-ships-fuel-for-chinas-cfr-600-fast-reactor-launch/ (accessed: 18.08.2023).

[91] Beloyarsk BN-800 fast reactor running on MOX // World Nuclear News. September 13, 2022. URL: https://www.world-nuclear-news.org/Articles/Beloyarsk-BN-800-fast-reactor-running-on-MOX (accessed: 18.08.2023).

[92] Today, the PRC's independent progress in building MOX fuel plants is minimal. In the early 2000s, the experimental scale fabrication line of MOX fuel with a capacity of 0,5 tons annually was built up. A demonstration line for the production of MOX fuel with a

second CFR-600 unit is being built precisely to test Chinese MOX fuel[93], which may require some Russian help.

Conclusion

The CEFR advanced the BN-type technology, honed sodium equipment skills, and retained the human resource capacity in Russia and China. In the demonstration phase, the PRC has already opted for the domestic CFR-600 design, narrowing Russian responsibilities[94]. Nevertheless, legal experience with fast reactors has greatly clarified China's nonproliferation responsibilities and the allocation of intellectual property rights.

Lacking the capacity to reprocess and produce fast reactor fuel, China risks developing a plutonium-based system and depends on Russian fast reactor expertise to build an industrial park of fast reactors[95]. The Comprehensive Long-Term Cooperation Program in the area of fast reactors and nuclear fuel cycle closure between Rosatom and the China Atomic Energy Authority, signed during China's President Xi Jinping's state visit to Russia in March 2023, and the expected Roadmap for a specific work program strongly manifest this trend and boost support for established and new projects[96]. Looking forward, joint efforts on economically efficient systems for fast reactors over 1,000 MW and their construction seem mutually beneficial. Given the bilateral interest in lead/lead-bismuth coolant technologies and small modular reactors (SMRs), the joint commercialization of the SVBR-100 fast reactor is also relevant[97,98], while China's plans to develop the so-called IFRES complex could be realized by replicating the Russian ODEC complex[99,100].

Russian-Chinese talks in the Kremlin
Source: www.kremlin.ru

capacity of 20 tons per year is just being built to support the future CFR-600 reactors.

[93] Kitaj pristupil k stroitel'stvu vtorogo CFR-600 [China begins construction of the second CFR-600] // AtomInfo. December 31, 2020. URL: http://atominfo.ru/newsz02/a0825.htm (accessed: 18.08.2023).

[94] In the mid-2010s, China eyed American TerraPower tech. But US export policy changes removed them as competitors to Russia in China's market. See Yurman D. TerraPower to leave China, but Bill Gates is still in the game // Neutron Bytes. January 06, 2019. URL: https://neutronbytes.com/2019/01/06/terrapower-to-leave-china-but-bill-gates-is-still-in-the-game/ (accessed: 18.08.2023).

[95] Construction start of second fast reactor in China // WNISR. January 03, 2021. URL: https://www.worldnuclearreport.org/Construction-Start-of-Second-Fast-Reactor-in-China.html (accessed: 18.08.2023).

[96] Rosatom and the Atomic Energy Agency of China signed the long-term cooperation program in the area of fast reactors and nuclear fuel cycle closure // Rosatom. March 22, 2023. URL: https://www.rosatom.ru/en/press-centre/news/rosatom-and-the-atomic-energy-agency-of-china-signed-the-long-term-cooperation-program-in-the-area-o/ (accessed: 18.08.2023).

[97] Chinese lead-bismuth test reactor starts up // World Nuclear News. October 16, 2019. URL: https://www.world-nuclear-news.org/Articles/Chinese-lead-bismuth-test-reactor-starts-up (accessed: 18.08.2023).

[98] Pershukov V. Russian-Chinese cooperation in the field of "Fast reactors and closed nuclear fuel cycle" // 18th INPRO Dialog Forum on Partnerships for Nuclear Development and Deployment. Vienna, 2021. URL: https://nucleus.iaea.org/sites/INPRO/df18/4.2-V.Pershukov-Russia.pdf (accessed: 18.08.2023).

[99] Ibid.

[100] IFRES – the future of Chinese fast program // AtomInfo. April 27, 2022. URL: http://atominfo.ru/en/news4/d0859.htm (accessed: 18.08.2023).

THE MULTIPURPOSE FAST NEUTRON RESEARCH REACTOR

Specifics

A nuclear facility with the Multipurpose Fast Neutron Research Reactor (MBIR) is Rosatom's unique project, which meets the scientific and engineering needs for the next half of a century and enables safety and cost-effectiveness experiments on a wide range of Generation IV concepts, closing the nuclear fuel cycle, and resolving back-end issues[101,102]. Its projected capacity of 150 MW thermal and 55 MW electrical would make it the most powerful research reactor in the world, while a high neutron flux and isolated constructions can expedite experiments significantly. Under the Russian federal program for the Development of equipment, technology, and scientific research in the use of nuclear energy, its construction at the Nuclear Reactor Research Institute site in Dimitrovgrad began in 2015 and is set to finish by 2028 or earlier[103].

International format

Since the MBIR's capacity exceeds the domestic needs, the concept of the International Research Centre (IRC) was presented in 2014[104]. Based on the MBIR's national program for 2028-2040, up to 50% of its capacity is allocated to foreign partners and is provided on a *flux sharing* model[105,106]. A consortium legal platform, with two primary types of cooperation (core and associate participants), ensures an open stance on engaging partners to the IRC MBIR, and China's representatives are already involved in international collaboration on its basis[107]. An Advisory Board has also been established to shape

[101] II. Itogi 2021 goda i plany na 2022 god: federal'nyj proekt: sozdanie sovremennoj eksperimental'no- stendovoj bazy dlya razrabotki tekhnologij dvuhkomponentnoj atomnoj energetiki s zamknutym yadernym toplivnym ciklom [II. Outcomes for 2021 and plans for 2022: establishment of a modern experimental and test-bed facility for the development of two-component nuclear power technologies with a closed nuclear fuel cycle] // Rosatom. Moscow, 2022. P. 6. URL: https://www.rosatom.ru/upload/iblock/4a5/4a558f-f483a04bcee121ed48880d29eb.pdf (accessed: 18.08.2023).

[102] Mnogocelevoj issledovatel'skij reaktor na bystryh nejtronah IYAU MBIR [MBIR multipurpose fast neutron research reactor] // CEMPC Rosatom. URL: https://ocks-rosatoma.ru/events-projects/mbir/ (accessed: 18.08.2023).

[103] Russia's MBIR research reactor scheduled for start up in 2028 // Nuclear Engineering International. February 18, 2021. URL: https://www.neimagazine.com/news/news-russias-mbir-research-reactor-scheduled-for-start-up-in-2028-8531994 (accessed: 18.08.2023).

[104] Zagornov A., Korchagina O. MBIR International Research Center // INPRO Dialog-Forum. Vienna, 2016. URL: https://nucleus.iaea.org/sites/INPRO/df12/Presentations/025_a._zagornov_mbir_international_research_center.pdf (accessed: 18.08.2023).

[105] Zagornov A., Konstantinov V. Multipurpose fast research facility MBIR as a unique research platform // International Conference on Fast Reactors and Related Fuel Cycles: Sustainable Clean Energy for the Future. Vienna, 2022. P. 1-4.

[106] This system allows considering the title for the flux share as a market product, which can be used for the shareholder's research, sub-lease to other members or third parties, merged with other members, assigned in exchange for research results, or swapped in time. See MBIR project roadmap and layout // Moscow Engineering Physics Institute. URL: https://mbir.mephi.ru/o-proekte/ (accessed: 18.08.2023).

[107] Researchers and experts from 14 countries and international organizations discussed

the science program, allowing partners who have yet to decide on the engagement format (e.g., China) to join meetings, with the first held in 2022[108].

China's interest

China is one of the most enthusiastic potential partners since the IRC MBIR could provide additional time and a cost-effective opportunity for strategic decision-making in search of a suitable nuclear energy infrastructure for China's future and testing new technologies at specialized installations. The CEFR and the CFR-600 units advance sodium technology but cannot support a broad research program, while the MBIR's capabilities are very extensive and enhanced by collaborating with world-renowned experts. Secondly, early accession to the project allows China to shape the research agenda and equipment configuration priorities. Committed to the industrial introduction of fast reactors, Chinese colleagues have already proposed focusing the MBIR on testing materials for lead-cooled plants[109]. Thirdly, while the *creative* part is provided by the IRC and requested by the Consortium members, the Research Institute of Atomic Reactors technically manages the MBIR and ensures experiments[110]. This institution has over sixty years of experience, a compactly located infrastructure, and deep ties with China's nuclear corporations (e.g., commissioned research practice, a joint venture, and training courses for Chinese operators).

The MBIR concept

Source: www.rosatom.ru

Conclusion

The MBIR is the best platform under construction worldwide for the flexible use of reactor resources, which is in the interest of China. Its functionality meets the PRC's experimental needs, reducing the cost of capital investment and routine scientific missions. The American Versatile Test Reactor is the only potential competitor but faces funding issues and is unlikely to allow international cooperation at the facility, especially with China's involvement[111,112].

the areas of their future joint research at the MBIR reactor facility // World-Energy Media. July 26, 2022. URL: https://www.world-energy.org/article/25998.html (accessed: 18.08.2023).

[108] JINR took part in first meeting of MBIR IRC Advisory Board // Joint Institute of Nuclear research. July 26, 2022. URL: http://www.jinr.ru/posts/jinr-took-part-in-first-meeting-of-mbir-irc-advisory-board/ (accessed: 18.08.2023).

[109] Ganjur O. Uchenye konkretiziruyut programmu issledovanij na reaktore MBIR [Scientists specify research programme at the MBIR reactor] // Strana Rosatom. July 28, 2022. URL: https://strana-rosatom.ru/2022/07/28/uchenye-konkretizirujut-programmu-iss/ (accessed: 18.08.2023).

[110] MBIR project roadmap and layout // Moscow Engineering Physics Institute. URL: https://mbir.mephi.ru/o-proekte/ (accessed: 18.08.2023).

[111] Yurman D. DOE Decides to build the Versatile Test Reactor at INL // Neutron Bytes. July 30, 2022. URL: https://neutronbytes.com/2022/07/30/doe-decides-to-build-the-versatile-test-reactor-at-inl/ (accessed: 18.08.2023).

[112] Thomas W. FY23 budget outcomes: DOE applied energy R&D // AIP Publishing. March 03, 2023. URL: https://www.aip.org/fyi/2023/fy23-budget-outcomes-doe-applied-energy-rd (accessed: 18.08.2023).

SPACE NUCLEAR POWER TECHNOLOGIES

Prerequisites

In the space sector, nuclear power offers diverse applications and is being firmly integrated to improve the efficiency of its transportation system. Soviet prototype work towards space nuclear systems began in the 1950s and reached its heyday in the 1960s-1980s, showcasing effective space-based nuclear power technologies[113]. To revive the industry after some economic challenges, a Decree on the Concept of space nuclear energy development in Russia of 1998 was adopted[114]. Beyond the main project directions in the field, it contained Section 5 on international cooperation and its core principles. As a result, Russian-Chinese cooperation between high-tech entities has intensified and bolstered mutual understanding in the highly sensitive field[115]. In particular, from 2000 to 2007, Russia developed an improved space-based thermal emission reactor-converter with supporting systems based on China's technical assignment and Soviet designs[116].

Megawatt-class nuclear propulsion systems

After American funding restrictions on bilateral space cooperation with Chinese entities, China turned to Russia to jointly develop high-efficiency space power complexes[117], such as a megawatt-class nuclear power propulsion system, originally a project of Rosatom and Roscosmos. However, in the mid-2010s, rocket science regulations hindered considering such a sensitive exchange[118], and China embarked on a project of its own. By 2022, a Chinese 1 MW reactor to power and propel spacecraft passed an efficiency test,[119] but its specifics and usage plans remain unpublished. Overall, the

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[113] For example, the BES-5, the Topaz, and the Topaz-II. See Pervye yadernye ustanovki v kosmose [The first nuclear installations in space] // Rosatom History Digital Library. URL: http://www.biblioatom.ru/evolution/dostizheniya/pervye-yadernye-ustanovki-v-kosmose/ (accessed: 18.08.2023).

[114] On the Concept of development of space power engineering in Russia: approved by Decree No. 144 of the Government of the Russian Federation of 02.02.1998 // The Russian Federation Code. 1998. No. 6. P. 763.

[115] Namely, the Kurchatov Institute, Krasnaya Zvezda, Energotech, Central Design Bureau of Machine Building, Luch Scientific Production Association, China Institute of Atomic Energy, and China Nuclear Energy Industry Corporation. See Kuharkin N. Kosmicheskaya yadernaya energetika (yadernye reaktory s termoelektriche skim i termoemissionnym preobrazovaniem —"Romashka" i "Enisej") [Space nuclear power (thermoelectric and thermionic conversion nuclear reactors - Romashka and Yenisei)] / N. Kuharkin, N. Ponomarev-Stepnoy, V. Usov. Moscow: IzdAT, 2012. P. 197-198.

[116] Ibid.

[117] Young M. Bad idea: the Wolf Amendment (limiting collaboration with China in Space) // Center for Strategic and International Studies. December 04, 2019. URL: https://defense360.csis.org/bad-idea-the-wolf-amendment-limiting-collaboration-with-china-in-space/ (accessed: 18.08.2023).

[118] Cheberko I. Rossiya i Kitaj ne dogovorilis' o postavkah raketnyh dvigatelej [Russia and China fail to agree on rocket engine deliveries] // Izvestia. April 08, 2016. URL: https://iz.ru/news/609157 (accessed: 18.08.2023).

[119] Jones A. Chinese megawatt-level space nuclear reactor passes review // Space News. August 31, 2022. URL: https://spacenews.com/chinese-megawatt-level-space-nuclear-reactor-passes-review/ (accessed: 18.08.2023).

PRC expects a national breakthrough in nuclear-powered space shuttles only by 2040[120], while Russian efforts have already solved key design challenges[121].

Despite the results gap, today's partnership in the area is more relevant than a decade ago. Amid the halted Russian-European ExoMars mission and China's Mars and Neptune ambitions, both sides could boost tech exchanges to enhance deep space capabilities. Notably, a technology protection Agreement between the states for the peaceful exploration of space has been reached[122], equally securing innovations and mitigating the risks of unauthorized access, transfer, re-export, re-engineering, and modification (Articles 3 and 7).

Amid the halted Russian-European ExoMars mission and China's Mars and Neptune ambitions, both sides could boost tech exchanges to enhance deep space capabilities

Lunar exploration

The joint space agenda peaked with the 2018-2022 Program signed between Roscosmos and the Chinese National Space Administration[123], the first to focus on lunar exploration, fostering nuclear space power. Russian and Chinese lunar programs integrated over the years, leading to the 2022 Agreement on cooperation in the construction of the International Lunar Research Station and the renewal of the Program for 2023-2027[124]. No official texts have been published, but bilateral cooperation is expected in a wide range of domains, which can take advantage of nuclear energy science[125]. Currently, Russian scientists propose to integrate a hybrid unit with an autonomous high-temperature nuclear reactor and a Stirling converter into the lunar infrastructure[126].

Russia has already powered China's lunar program. Between 2009 and 2013: it shipped three of 120 W, one of 8 W, and two of 4 W radioisotope heater units (RHUs) and a 6,5 W engineering model radioisotope thermoelectric generator (RTG) under a lunar

[120] Goswami N. China in space: ambitions and possible conflict // Studies Quarterly. 2018. Vol. 12. No. 1. P. 76.

[121] Such as efficient cooling elements. See Russia successfully tests key element of nuclear propulsion spacecraft // Xinhua News Agency. October 29, 2018. URL: http://www.xinhuanet.com/english/2018-10/29/c_137566530.htm (accessed: 18.08.2023).

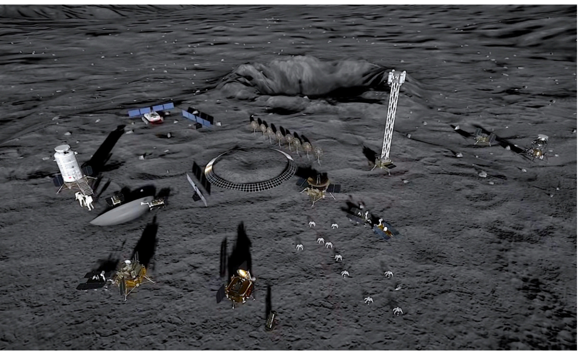
[122] Agreement between the Government of the Russian Federation and the Government of the PRC on technology protection measures in connection with cooperation in the exploration and use of outer space for peaceful purposes and in the development and operation of launch vehicles and ground-based space infrastructure of June 25, 2016: ratified by Federal Law No. 367-FZ of the Russian Federation of December 05, 2017 // Electronic collection of legislative and normative documentation of the Kodeks Consortium. URL: https://docs.cntd.ru/document/420371283 (accessed: 18.08.2023).

[123] Gaskova D., Lekontseva K. Cooperation between Russia and China in space exploration // Rossiya-Kitaj: razvitie regional'nogo sotrudnichestva v XXI veke [Russia-China: evolving regional cooperation in the XXI century]. Chita: Zabaikalsky State University, 2019. P. 44.

[124] Russia, China sign program of space cooperation development for 2023-2027 // Interfax. December 29, 2022. URL: https://interfax.com/newsroom/top-stories/86585/ (accessed: 18.08.2023).

[125] China and Russia sign a Memorandum of Understanding regarding cooperation for the construction of the International Lunar Research Station // China National Space Administration. March 09, 2021. URL: http://www.cnsa.gov.cn/english/n6465652/n6465653/c6811380/content.html (accessed: 18.08.2023).

[126] Russia proposes power plant for lunar base // World Nuclear News. January 17, 2023. URL: https://www.neimagazine.com/news/newsrussia-proposes-power-plant-for-lunar-base-10523205 (accessed: 18.08.2023).



The International Lunar Research Station concept

Source: www.youtube.com/c/RoscosmosMedia

sensing contract[127]. Presumably, they supported the lander and rover sub-systems of the Chang'e-3 mission during the lunar night[128], which makes sense since it was China's first space mission utilizing nuclear power sources, and Chinese designs at the time were less powerful and heavier[129]. For the Chang'e-4 mission, it was confirmed that a Rosatom-affiliated institution has provided 120 W and 4 W RHUs[130]. This time, one of the 120 W RHUs was swapped for an RTG, providing at least 2,5 W for night-time temperature measurements[131]. The sample return Chang'e-5 mission of 2020 lacked heating elements[132], and the expected Chang'e-6 mission will resemble its module. However, the subsequent exploration missions, Chang'e-7 and Chang'e-8, require RHUs and RTGs for broader functionality[133]. Lacking updates on China's progress in radioisotope systems, it is prudent to look to Russia, which continues to fabricate them and produce the needed plutonium-238.

Nuclear thermal rocket

A nuclear thermal rocket design could become central to Sino-Russian cooperation. Following the National Aeronautics and Space Administration's plans to relaunch nuclear thermal rocket engine tests and conduct a flight demonstration by 2027, the PRC will likely accelerate parallel studies[134]. Meanwhile, the Soviet Union was committed to the idea of a nuclear thermal rocket even longer than the United States, which resulted in a significant series of comprehensive tests before the program was suspended in the late 1980s[135], making modern Russia China's only potential partner in this research direction.

[127] AES v illyuminatore vidna [An NPP is seen through the porthole] // Strana Rosatom. January 28, 2019. URL: https://strana-rosatom.ru/2019/01/28/aes-v-illjuminatore-vidna/ (accessed: 18.08.2023).
[128] The plutonium-238 radioisotope thermoelectric generator in the deep space exploration / H. Luo, C. Hiu, S. Wu. [et al.] // Journal of Deep Space Exploration. 2020. Vol. 7. No. 1. P. 64.
[129] Lisov I. Tridcat' sem' let spustya. Chan'e-3 i Yujtu rabotayut na Lune [Thirty-seven years later. Chang'e-3 and Yuitu work on the Moon] // Novosti Kosmonavtiki [Space News]. 2014. Vol. 373. No. 2. P. 24.
[130] AES v illyuminatore vidna [An NPP is seen through the porthole] // Strana Rosatom. January 28, 2019. URL: https://strana-rosatom.ru/2019/01/28/aes-v-illjuminatore-vidna/ (accessed: 18.08.2023).
[131] Overview of the Chang'e-4 mission: opening the frontier of scientific exploration of the lunar far side / C. Li, Z. Wei, W. Wen [et al.] // Space Science Review. 2021. Vol. 217. No. 2. P. 3.
[132] Zheng L. Lights out for China's Chang'e 5 moon lander as day becomes lunar night // South China Morning Post. December 15, 2020. URL: https://www.scmp.com/news/china/science/article/3114079/lights-out-chinas-change-5-moon-lander-day-becomes-lunar-night (accessed: 18.08.2023).
[133] Jones A. China outlines pathway for lunar and deep space exploration // Space News. November 28, 2022. URL: https://spacenews.com/china-outlines-pathway-for-lunar-and-deep-space-exploration/ (accessed: 18.08.2023).
[134] NASA, DARPA will test nuclear engine for future mars missions // NASA. January 24, 2023. URL: https://www.nasa.gov/press-release/nasa-darpa-will-test-nuclear-engine-for-future-mars-missions (accessed: 18.08.2023).
[135] Wade M. Soviet Mars propulsion – nuclear thermal // Encyclopedia Astronautica. URL: http://www.astronautix.com/r/russianmarsucleartherma l.html (accessed: 18.08.2023).

Conclusion

Since the countries started their space activities at different times, China needs Russian experience to compete effectively with American and European agencies, while Russia depends on the co-financing of large-scale projects to ensure the positive dynamics of its space industry. In this context, lunar cooperation is an excellent start to bridge their space programs and improve fragmented regulations of the nuclear space-energy track.

SMALL MODULAR REACTORS FOR REMOTE AREAS

Prerequisites

Both Russia and China have remote areas and industrial offshore facilities in need of reliable and cost-effective energy sources, for which SMRs are the optimal solution, providing stable and environmentally friendly electricity, heat, and desalination services[136]. Using vast Soviet experience in the design and prototype operation of small-sized NPPs, modern Russia builds the world's most extensive portfolio of reactors for hard-to-reach areas, following the 2020 federal program for the Development of equipment, technology, and scientific research in the use of nuclear energy in the Russian Federation[137,138]. Its transportable modules with SMRs at different design stages are of particular interest, e.g., the VITYAZ, the ATGOR, the UNITHERM, the SHELF, the VKT, the KARAT, the VBER, and the ABV types[139]. In this category, the implemented KLT series and the subsequent RITM reactor line are particularly promising domestically and worldwide. As an outstanding achievement, two modular KLT-40S reactor systems (35 MW of electrical and 150 MW of thermal capacity each) were installed on the world's first floating nuclear power plant (FNPP) *Akademik Lomonosov* (project 20870) and connected to the grid in 2019 in the Chukotka region[140,141]. Its safe operation confirms the practical use of transportable nucle-

[136] Small nuclear power plants // Rosatom. URL: https://rosatom.ru/en/rosatom-group/small-nuclear-power-plants/ (accessed: 18.08.2023).
[137] Advances in small modular reactor technology developments // IAEA. Vienna, 2022. P. 307. URL: https://aris.iaea.org/Publications/SMR_Book_2020.pdf (accessed: 18.08.2023).
[138] V. Itogi 2021 goda i plany na 2022 god: federal'nyj proekt "Novaya atomnaya energetika, v tom chisle malye atomnye reaktory dlya udalyonnyh territorij" [V. Results of 2021 and plans for 2022: federal project "New nuclear power, including small nuclear reactors for remote areas"] // Rosatom. Moscow, 2022. P. 2-3. URL: https://rosatom.ru/upload/iblock/ea6/ea6b753462957747fc9990914dbd7251.pdf (accessed: 18.08.2023).
[139] Six Russian SMR designs // Nuclear Engineering International. January 16, 2019. URL: https://www.neimagazine.com/features/featuresix-russian-smr-designs-6939130/ (accessed: 18.08.2023).
[140] Advances in small modular reactor technology developments. P. 111.
[141] Lobner P. Russia's Akademik Lomonosov: the first modern FNPP // The Lyncean Group of San Diego. May 15, 2021. P. 9. URL: https://lynceans.org/wp-content/uploads/2021/05/Russia-Akademik-Lomonosov-FNPP-converted.pdf (accessed: 18.08.2023).

ar power and the referentiality of FNPP technologies, considering nonproliferation concerns[142]. The next generation of Russian nuclear icebreakers and FNPPs are based on the upgraded RITM-200 line reactors (55 MW electric and 175 MW thermal capacity)[143,144].

Cooperation attempts

China was able to evaluate Russian potential in FNPP development early on and, in 2005, offered highly favorable conditions to produce the hull of the FNPP Akademik Lomonosov at its shipyards[145]. In 2011, FNPPs were highlighted in the protocol of the Russian-Chinese sub-commission on nuclear issues[146]. By 2014, Rosatom and the China Atomic Energy Authority had agreed on a Memorandum of Understanding on cooperation in constructing small-capacity FNPPs, without clear timelines or collaboration forms[147]. Consequently, Russian and Chinese authorized organizations had reached a Memorandum of Understanding to develop both barge-mounted and self-propelled FNPPs from 2019[148], laying the groundwork for a bilateral working group to create a joint venture and tackle licensing issues. Through a series of FNPPs for Chinese oil companies, Russia aimed to cut production costs and provide fuel supplies but rejected the technology transfer option. Thus, no technology ownership agreement was reached, limiting actual cooperation to constructing non-nuclear hulls for two of the four Russian Modernized Floating Power Units by Chinese shipbuilders under a $226 million contract due to the workload of Russian shipyards and tight deadlines[149].

The *Akademik Lomonosov* FNPP

Source: www.rosatom.ru

[142] The required resource was obtained at fuel enrichment below 20%. See Yadernaya reaktornaya ustanovka dlya plavuchego energobloka proekta 20870 Akademik Lomonosov [Nuclear reactor plant for the project 20870 Akademik Lomonosov floating power unit] / V. Petrunin, V. Belyaev, A. Pakhomov [et.al.] // The Afrikantov Experimental Design Bureau for Mechanical Engineering. Moscow, 2021. P. 3. URL: https://minobrnauki.gov.ru/upload/2021/04/work/P21-032.pdf (accessed: 18.08.2023).
[143] Advances in small modular reactor technology developments. P. 57.
[144] Rosatom plans to commission four Modernized Floating Power Units in the Arctic version with the improved RITM-200S reactors by 2027- 2031, with referentiality ensured by six reactors of the RITM-200 type installed on Russian nuclear icebreakers. The next task is to develop an Optimized Floating Power Unit using the advanced RITM-200M reactors, including the possibility of its tropical version. At the same time, the start-up of the Russian pilot project of a low-capacity onshore NPP in Yakutia is planned for 2028 based on the RITM-200N modification. Two scaled-up RITM-400 reactors are also being built for the world's largest icebreaker.
[145] China to build barge for floating nuclear plant // Belonna. September 09, 2005. URL: https://bellona.org/news/nuclear-issues/nuclear-russia/2005-09-china-to-build-barge-for-floating-nuclear-plant (accessed: 18.08.2023).
[146] PATES doplyvut do Kitaya [FNPPs will reach China] // Kommersant. July 30, 2014. URL: https://www.kommersant.ru/doc/2535064 (accessed: 18.08.2023).
[147] Ibid.
[148] Ibid.
[149] Xu Y., Afanasiev V. Wison to build nuclear power floaters for Russia // Upstream. September 16, 2021. URL: https://www.upstreamonline.com/rigs-and-vessels/wison-to-build-nuclear-power-floaters-for-russia/2-1-1068362 (accessed: 18.08.2023).

China's competing projects

China has several competing lines of SMRs for remote areas, as well as small district heating reactors[150], with the ACP-100 and HTR-PM demonstration models being the most advanced[151]. While there is almost no data on Chinese civilian land-based transportable reactors, the PRC has accelerated its FNPP fleet development for its coastal areas, offshore oil production fields, and remote islands, relying on domestic SMR designs[152]. Generally, the 14th Five-Year Plan was the first to highlight floating nuclear platforms as a focus area, although three Chinese developers secured some permits during the previous plan period[153].

Among the major designs, China General Nuclear Power Corporation developed the ACPR-50S, a marine pressurized water reactor of 60 MW electric and 200 MW thermal power, and teamed with China's shipbuilding and oil corporations and shipboard institutions for a floating platform design[154]. However, after starting construction of the unit in 2016 and planning to commission it by 2022, the latest project news refers to 2020.

The ACP-10S, the ACP-25S, and the larger ACP-100S are competing reactor concepts by China National Nuclear Corporation[155]. While smaller reactors target icebreaker constructions[156], the ACP-100S (125 MW electric and 385 MW thermal power), is assumed for FNPPs and close to Russia's RITM-200M[157]. Also focusing on floating nuclear vessels, it collaborated with a British consultancy and set up two specialized joint ventures with China's shipbuilding and investment corporations. A platform with two ACP-100S reactors aimed for a 2024 launch but has just been suspended due to security concerns[158,159].

[150] For example, the DHR-400, the HAPPY-200, or the NHR-200-II designs to minimize waste and air pollution.
[151] China starts construction of demonstration SMR // World Nuclear News. July 13, 2021. URL: https://world-nuclear-news.org/Articles/China-starts-construction-of-demonstration-SMR (accessed: 18.08.2023).
[152] Nguyen V.-P. China's planned floating nuclear power facilities in South China sea: technical and political challenges // Belfer Center for Science and International Affairs. November 21, 2018. URL: https://www.belfercenter.org/publication/chinas-planned-floating-nuclear-power-facilities-south-china-sea-technical-and (accessed: 18.08.2023).
[153] CGN and CSIC achieved strategic cooperation to develop offshore SMR demonstration project // CGN. January 26, 2016. URL: http://en.cgnp.com.cn/encgnp/c100866/2016-01/26/content_f1591a27dafe4bf7a2668cdc17cb46b5.shtml (accessed: 18.08.2023).
[154] Lobner P. China's CGN ACPR50S FNPP concept // The Lyncean Group of San Diego. May 15, 2021. P. 7. URL: https://lynceans.org/wp-content/uploads/2021/05/China-CGN-ACPR50S-FNPP-converted.pdf (accessed: 18.08.2023).
[155] FNPP to start construction // CNNC. January 15, 2016. URL: https://en.cnnc.com.cn/2016-01/15/c_49469.htm (accessed: 18.08.2023).
[156] In 2019, China General Nuclear Power Corporation also advertised a tender to find a designer for an icebreaker with two 25-MW reactors, but there were no further updates.
[157] Lobner P. China's CNNC ACP100S and ACP25S FNPP concepts // The Lyncean Group of San Diego. May 15, 2021. P. 5. URL: https://lynceans.org/wp-content/uploads/2021/05/China-CNNC-ACP100S-FNPP-converted.pdf (accessed: 18.08.2023).
[158] China: CNNC may launch floating reactor by 2024 // Energy Intelligence. May 26, 2021. URL: https://www.energyintel.com/0000017b-a7dd-de4c-a17b-e7df5d540000
[159] Chen S. China suspends plan to build floating nuclear reactors in the South China Sea // South China Morning Post. May 31, 2023. URL: https://www.scmp.com/news/china/science/article/3222289/china-suspends-plan-build-floating-nuclear-reactors-south-china-sea (accessed: 18.08.2023).

Lastly, the 719 Research Institute designed the HHP-25 reactor (25 MW electric and 100 MW thermal power) for FNPPs and also worked on a submersible NPP concept[160]. The HHP-25 is a military-to-civilian project with no updates since its feasibility study in 2019.

Conclusion

Both states prioritize SMRs, especially transportable units, to power hard-to-reach areas and industries. In contrast to Russia, China's progress in land-based transportable models cannot yet be assessed, but FNPPs are already in its focus, and it is clear that after the unaccomplished FNPP partnership, Russia and China became motivated by competitive interests to develop original designs[161]. However, when such nuclear facilities enter the global market, both states will face similar challenges associated with their legal status, transit/navigational rights, and treaty compatibility beyond fundamental technical, security, and financial concerns[162].

The ACPR-50S concept

Source: www.en.cgnpc.com.cn

CONCLUSION

Due to a combination of overlapping technical, legal, economic, and political prerequisites, Russia is the most attractive partner for China in several critical nuclear power areas: uranium enrichment, construction and maintenance of nuclear power units, supply and production of nuclear fuel, and integration of fast reactors. Being relevant and promising, Russian-Chinese cooperation in nuclear energy is implemented under the direct supervision of the leaders of both states. Adaptable cooperation mechanisms that comply with international standards equally protect Russian know-how and close Chinese technological gaps. The space nuclear power partnership is promising but is just gaining momentum, while in the field of SMRs, especially floating units, Sino-Russian interests are likely to conflict in the medium term. Nevertheless, the Sino-Russian strategic rapprochement offers a chance for any future interactions rooted in mutual respect instead of the West's style competitive confrontation.

Through Russian experience and new-format economically and infrastructurally attractive initiatives their cooperation will continue, but China's strategy is to enhance domestic expertise, form

[160] 719 Research Institute - Wuhan Second Ship Design Institute // GlobalSecurity.org. August 24, 2019. URL: https://www.globalsecurity.org/military/world/china/719-institute.htm (accessed: 18.08.2023).
[161] Sajt PATES [FNPP website] // Rosenergoatom. URL: https://www.rosenergoatom.ru/stations_projects/sayt-pates/
[162] Lysenko M., Bedenko F., Dalnoki-Veress V. International legal regulations of floating nuclear power plants: problems and prospects // Moscow Journal of International Law 2019. No. 3. P. 59-67.

all links of the nuclear industrial chain, and localize or even obtain foreign production technology. Thus, as China's competencies grow Russia's involvement diminishes. This irreversible trend is evident in progressively negotiated partnership terms: from being an integrated supplier of nuclear and supporting non-nuclear technologies, Russia's role was limited mainly to supplying core nuclear equipment for jointly developed facilities, while China seeks to become an equal project contributor or even the lead developer at the earliest opportunity. ■

LIST OF ABBREVIATIONS

CEFR	China Experimental Fast Reactor
CFR-600	China Fast Reactor 600
CGN	China General Nuclear Power Corporation
CNNC	China National Nuclear Corporation
FNPP	floating nuclear power plant
IAEA	International Atomic Energy Agency
IRC	International Research Centre
MBIR	Multipurpose Fast Neutron Research Reactor
MOX	mixed oxide
MW	megawatt
NPP	nuclear power plant
PRC	People’s Republic of China
RHU	radioisotope heater unit
RTG	radioisotope thermoelectric generator
SMR	small modular reactor
SWU	separative work unit

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BRICS POTENTIAL FOR GLOBAL PEACE AND SECURITY

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