IBR™

CHINA ENRICHMENT INDUSTRY.
STATE & PROSPECTS OF DEVELOPMENT.
2017

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Moscow, 2017

About INTERNATIONAL BUSINESS RELATIONS, LLC (IBR^{TM})

INTERNATIONAL BUSINESS RELATIONS, LLC (IBR^{TM}) was set up in 1991 by a group of researchers and engineers who previously worked at enterprises under the USSR Ministry of Atomic Power and Industry. IBR^{TM} is specialized in consulting & engineering along with project management in nuclear power and nuclear fuel cycle. Leading Russian and foreign companies, as well as state organizations, are constant clients of IBR^{TM}. The IBR^{TM} successful activities are based on high professionalism of the company staff, which implies:

- ***Deep knowledge of technologies and operational experience in nuclear power and nuclear fuel cycle;***
- ***Knowledge of the tools for economic and investment analysis of nuclear technologies;***
- ***Experience in successful management of "nuclear" projects.***

IBR^{TM} strives for expansion and intensification of cooperation with its constant clients and welcomes collaboration with new clients in the interests of further improvement of safety and efficiency of nuclear technologies.

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PROJECT TEAM 2017

- **The IBR™ staff**
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Executive Summary

1. China has an ambitious Program of National nuclear power development (~ 150 GW (e) in 2030 and ~ 200 GW (e) in 2035) and plans of nuclear technology export (NPPs construction abroad). China National Program of nuclear power development, contemplated export of nuclear technologies (NPP construction abroad) and CNNC plans of SWU export expansion should be supported by the relevant development of CNNC uranium enrichment industry.

2. [redacted] Strategy of CNNC Technology Platform development bases on:

   ✓ [redacted]

   [redacted]

3. Strategy of CNNC uranium enrichment capacity expansion is based on the need of meeting the demand in EUP of the significant part of the national nuclear power (~ 85-90%) and SWU export.

4. CNNC uranium enrichment capacity has reached [redacted] mln. SWU as of the end of 2016.

5. IBR™ forecasts the China nuclear power development dynamics more pessimistically (~ [redacted] GW (e) in 2035) than China Communist Party and China Government. IBR™ forecasts that CNNC uranium enrichment capacity will reach [redacted] mln. SWU by 2035.

6. According to the results of the IBR™ analysis, CNNC enrichment industry is competitive in the relations to URENCO/AREVA and can provide prices for SWU on the domestic market of China at [redacted] per SWU, and transfer prices of CNNC [redacted] per SWU and lower when moving to the next generation centrifuges (payback period ~ 12 years). The level of CNNC transfer prices puts CNNC's uranium enrichment industry at second place in the world in terms of economic efficiency after the TVEL's (Rosatom) uranium enrichment industry (TVEL's transfer prices are at the level of $ [redacted] per SWU (2016)).

Introduction

The first IBR^{TM} non-exclusive report on the China (CNNC) uranium enrichment industry provides objective and valid information on the state and prospects of the development of the CNNC uranium enrichment industry, including the following data:

- ✓ Characterization of the CNNC's technology platform and the feasibility study of the technology platform's choice by CNNC;
- ✓ Characteristics of all sites and plants of CNNC that are using for uranium enrichment, including design capacities, capacities as of the end of 2016, timing of design, construction and commissioning of the plants and GC cascades;
- ✓ Technical and economic analysis of existing CNNC's technological platform for uranium enrichment (specific investments, specific operating costs, SWU cost and price) and CNNC's technological platform development forecast;
- ✓ CNNC's strategy and plans for the uranium enrichment industry development;
- ✓ IBR^{TM} forecast of the CNNC's uranium enrichment industry development through 2035;
- ✓ IBR^{TM} forecast of CNNC's main equipment manufacturing industry development.

The data presented in the report are obtained by processing the entire array of information on the CNNC industry on uranium enrichment using the IBR^{TM} model, which includes, among other things, engineering calculations of the mechanical, electrical, thermal, other uranium enrichment equipment and the technological processes. In order not to load the readers of the Report with the methods used for CNNC enrichment industry analyzing, by the initial data used for engineering calculations, and also to protect the IBR^{TM}'s model and the original data from copying and use in other models, the methodology and intermediate results of engineering calculations are not presented in the Report.

The push for the IBR^{TM}'s report development devoted to the CNNC's uranium enrichment industry was the acquaintance of IBR^{TM} specialists with the report "China's Uranium Enrichment Capacity: Rapid Expansion to Meet Commercial Needs", Harvard Kennedy School, August 2015. IBR^{TM} specialists are engaged in technical and economic analysis of nuclear power and nuclear fuel cycle technologies for more than 30 years. Therefore, the IBR^{TM}'s specialists were amazed at the almost complete discrepancy between the data presented in the report of the Harvard Kennedy School Belfer Center for Science and International Affairs, to the results of the analysis of the CNNC's uranium enrichment industry on that is performed annually by IBR^{TM} specialists in the interests of the certain organizations. Apparently, the authors of the report from the Belfer Center for Science and International Affairs Harvard Kennedy School not only are not nuclear engineers, but also engineers in general. Because only one comparative analysis of cooling systems of CNNC plants on uranium enrichment (Russian origin technology and domestic (CNNC) origin technology), could already lead them to think about the technologies used in these plants. Not to mention other less noticeable parameters of the CNNC plants, which can quite definitely say about the technologies used in the plants, and the capacity of these plants. Unfortunately, we have to state that the report of the Harvard Kennedy School not only failed to provide the world nuclear community with objective information on the CNNC uranium enrichment industry, but also led the world nuclear community into delusion about the state and prospects for the development of the CNNC industry on uranium enrichment.

Chapter 1
CNNC Enrichment Industry Background & Status

The China National Nuclear Corporation (CNNC) is a large State-owned enterprise under direct management by the central Government. CNNC has established a complete nuclear technology industry framework. It is a main part of the China national nuclear technology industry and a leading element of national strategic nuclear forces and nuclear power development.

The Corporation integrates 246 industrial enterprises, companies, research and design institutes and institutions. The Corporation focus areas are nuclear energy, nuclear materials, nuclear fuel, handling of SNF and radioactive waste, uranium prospecting and mining, nuclear equipment, isotopes, applications for nuclear technologies and adjacent areas of research and developments, construction and operation of NFC enterprise, foreign economic cooperation and import-export business.

Table 1.1

CNNC uranium enrichment industry enterprises

Company Title	Functions
China National Nuclear Corporation (CNNC)	Nuclear fuel cycle industry management
Shaanxi Uranium Co., Ltd	Uranium enrichment: Hanzhong & Emeishan sites
Lanzhou Uranium Co., Ltd.	Uranium enrichment: Lanzhou site
CNNC's Research Institute of Physical and Chemical Engineering of the Nuclear Industry at Tianjin	GC and cascades R&D & design
CNNC (Tianjin) Machinery Co., Ltd	GC and cascades manufacture
CNNC Xinneng Nuclear Engineering Co., Ltd.	Enrichment plants engineering design, construction, procurement, installation and facility adjustment

Tables 1.1 - 1.3 present data on the operating CNNC uranium enrichment plants and on the plants to be commissioned (or to be commissioning) in future through year 2035 inclusive.

Figures 1.1 - 1.4 show satellite images of the sites accommodating the uranium enrichment plants.

Figures 1.5 – 1.8 depict data on CNNC uranium enrichment industry development in the period of 1997-2016.

All the data provided in the tables and figures are IBR^{TM} analytical results.

Table 1.2

Identification of the operating uranium enrichment plants and plans (projects) of uranium enrichment capacity expansion

Enrichment site general designation	Site location	China National Nuclear Safety Administration nuclear facilities classification	Chinese nuclear facilities classification by IBR	Operator	Facility status	Facility commissioning dates
Plant 405	Hanzhong region	The project of 405-1A	Hanzhong CEP 1, Russian-supplied, Phase I	Shaanxi Uranium Co., Ltd / CNNC	In operation	[redacted]
			Hanzhong CEP 2, Russian-supplied, Phase II		In operation	
			Hanzhong CEP 3, Russian-supplied, Phase IV		In operation	
		Phase IV Centrifugation Project	Hanzhong CEP 4 of plant 405		In operation	
Plant 504	Lanzhou region	Lanzhou uranium centrifugation separation facility phase I	Lanzhou CEP 1, Russian-supplied, Phase III	Lanzhou Uranium Co., Ltd. / CNNC	In operation	
		Domestic Centrifuge Commercial Paradigm Project	Lanzhou CEP 2 Phase I of plant 504		In operation	
			Lanzhou CEP 2 Phase II of plant 504		In operation	
		Uranium Enrichment Project, Phase III	Lanzhou CEP 3 Phase I of plant 504		In operation	
			Lanzhou CEP 3 Phase II of plant 504		Planned	
			Lanzhou CEP 4 Phase I & II of plant 504		Planned	
Plant 814	Emeishan region	Plant is not under CNNSA supervision	Emeishan CEP 0 of plant 814	Shaanxi Uranium Co., Ltd / CNNC	In operation	
		North Region Centrifuge Extension Project, Phase I	Emeishan CEP 1 of plant 814		In operation	
		North Region Centrifuge Extension Project, Phase II	Emeishan CEP 2 of plant 814		In trial operation	
			Emeishan CEP 3 of plant 814		Planned	

Table 1.3

Design and actual capacity of the uranium enrichment plants as of the end 2016

Chinese nuclear facilities classification by IBR	**Designed nominal capacity (average for the service life), Mln. SWU**	**Operation capacity as of the end of 2016, Mln. SWU**	**Main equipment (GC) - Technology**
Hanzhong CEP 1, Russian-supplied, Phase I	[redacted]	[redacted]	[redacted]
Hanzhong CEP 2, Russian-supplied, Phase II	[redacted]	[redacted]	[redacted]
Hanzhong CEP 3, Russian-supplied, Phase IV	[redacted]	[redacted]	[redacted]
Hanzhong CEP 4 of plant 405	[redacted]	[redacted]	[redacted]
Lanzhou CEP 1, Russian-supplied, Phase III	[redacted]	[redacted]	[redacted]
Lanzhou CEP 2 of plant 504	[redacted]	[redacted]	[redacted]
Lanzhou CEP 3 of plant 504	[redacted]	[redacted]	[redacted]
Emeishan CEP 0 of plant 814	[redacted]	[redacted]	[redacted]
Emeishan CEP 1 of plant 814	[redacted]	[redacted]	[redacted]
Emeishan CEP 2 of plant 814	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]

Figure 1.4
General view of Emeishan site (IBR™ plants classification)

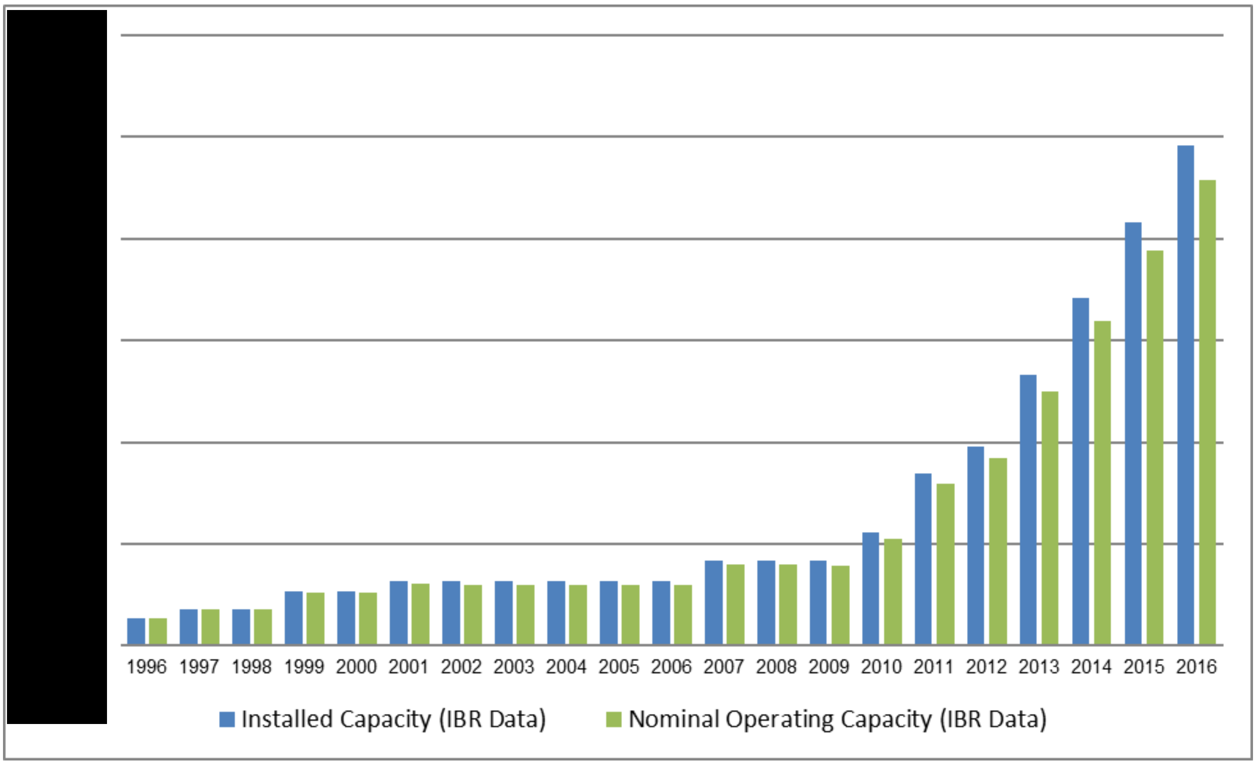


Figure 1.5
CNNC installed / nominal operating capacity. Mln. SWU
IBR™ analysis

[redacted]

Figure 1.6
The number of GC different models in CNNC uranium enrichment industry, Pieces
IBR™ analysis

Chapter 2
CNNC uranium enrichment industry development strategy and development program. IBR™ forecast of CNNC uranium enrichment industry development

China has an ambitious Program of National nuclear power development and plans of nuclear technology export (NPP construction abroad). China National Program of nuclear power development, contemplated export of nuclear technologies (NPP construction abroad) and CNNC plans of SWU export expansion should be supported by the relevant development of CNNC uranium enrichment industry.

CNNC develops own Technology Platform for uranium enrichment. Strategy of CNNC Technology Platform development bases on:

- ✓ Maximum using of the URENCO / ETC Technology Platform (by replication, wherever it possible, or by development of self-designed equipment and technology processes approximated to the fullest in terms of performance attributes to the URENCO / ETC equipment and technology, if replication proved impossible);

- ✓ Use of certain elements of the Russian Technology Platform when developing certain elements of the CNNC Technology Platform (design of the GC upper and lower units, cascades control, etc.).

Strategy of CNNC uranium enrichment capacity expansion is based on the need of meeting the demand in EUP of the significant part of the national nuclear power (85-90%) and SWU export.

"CNNC has the integrated ability for centrifuge enrichment plant design, building and operation management:

- ✓ *In 2013, CNNC has realized the industrial application of self-designed centrifuge technology in Lanzhou uranium Enrichment Corporation, which makes it easy for CNNC to increase the enrichment capacity when needed;*

- ✓ *The capacity of Uranium enrichment in China can meet the market requirement now and for the future nuclear power development."*[1]

Strategy and plans of CNNC uranium enrichment industry development are built on the guideline documents approved by the State Council and other state governing bodies. Hence, in the medium-term for uranium enrichment industry production capacity expansion the following documents are the guidelines for CNNC:

[redacted]

[redacted]

[1] Report The Nuclear Fuel Supply in China to Match the Development of Nuclear Power, ZHENG JISHI, Nuclear Fuel Corporation Beijing, China, December 10, 2014.

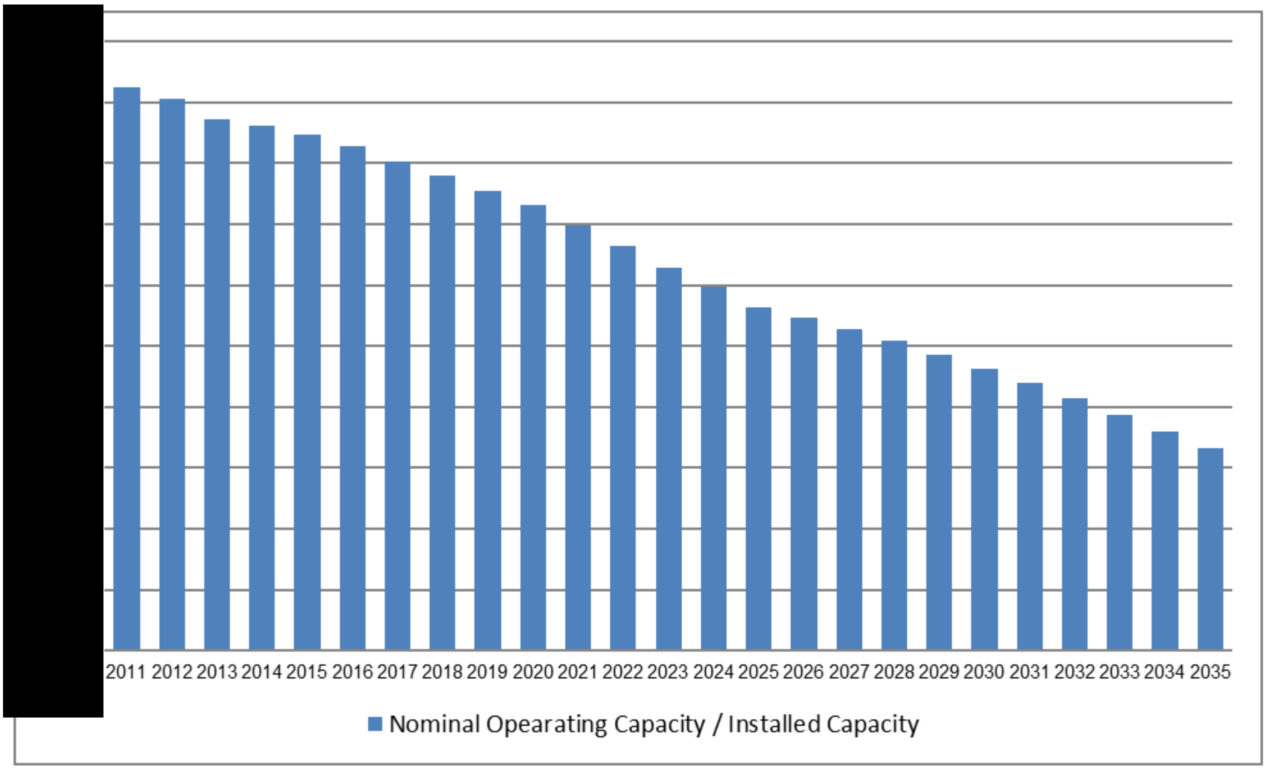


Figure 2.6
Ratio of CNNC nominal operating capacity to installed capacity, %
IBRTM forecast

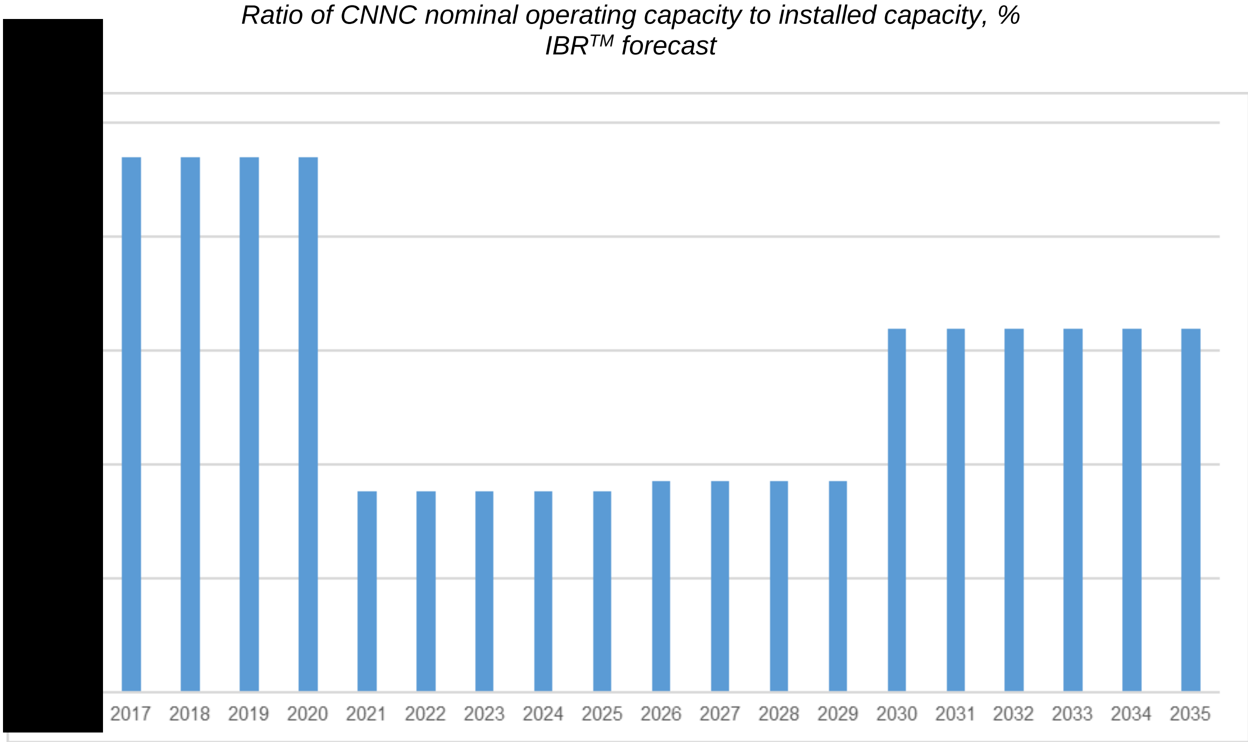
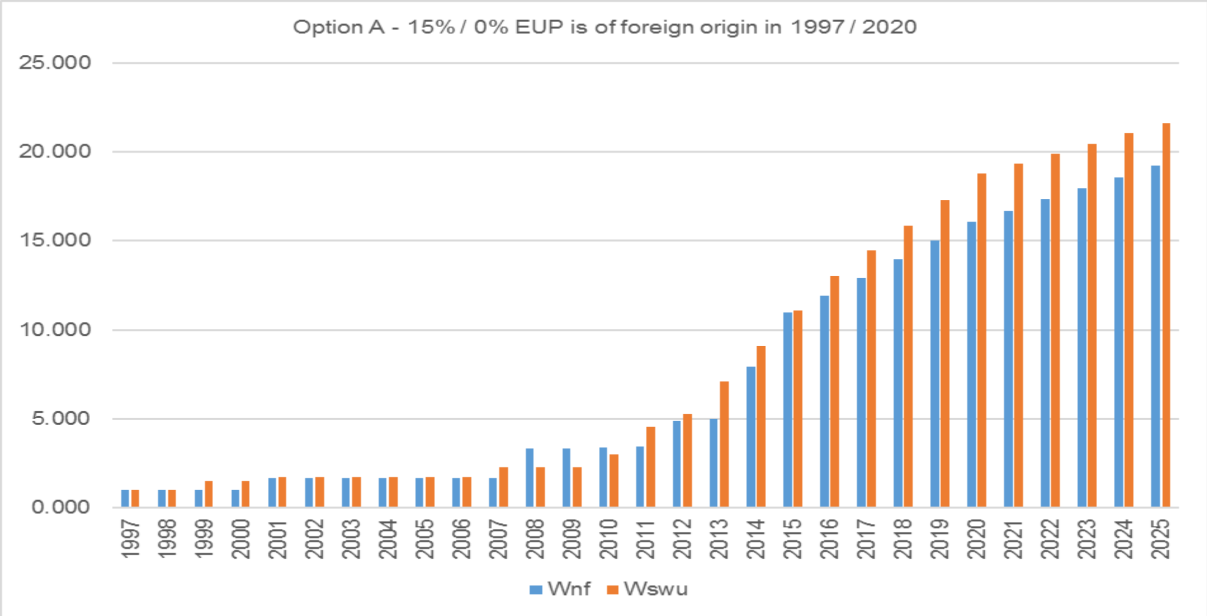


Figure 2.7
CNNC capital investments in the uranium enrichment industry development, $ Mln.
IBRTM forecast

Comparison of relative capacity of the CNNC nuclear fuel fabrication plants (powder, pellets, FA) that are using EUP of CNNC production, and relative capacity of the CNNC enrichment plants



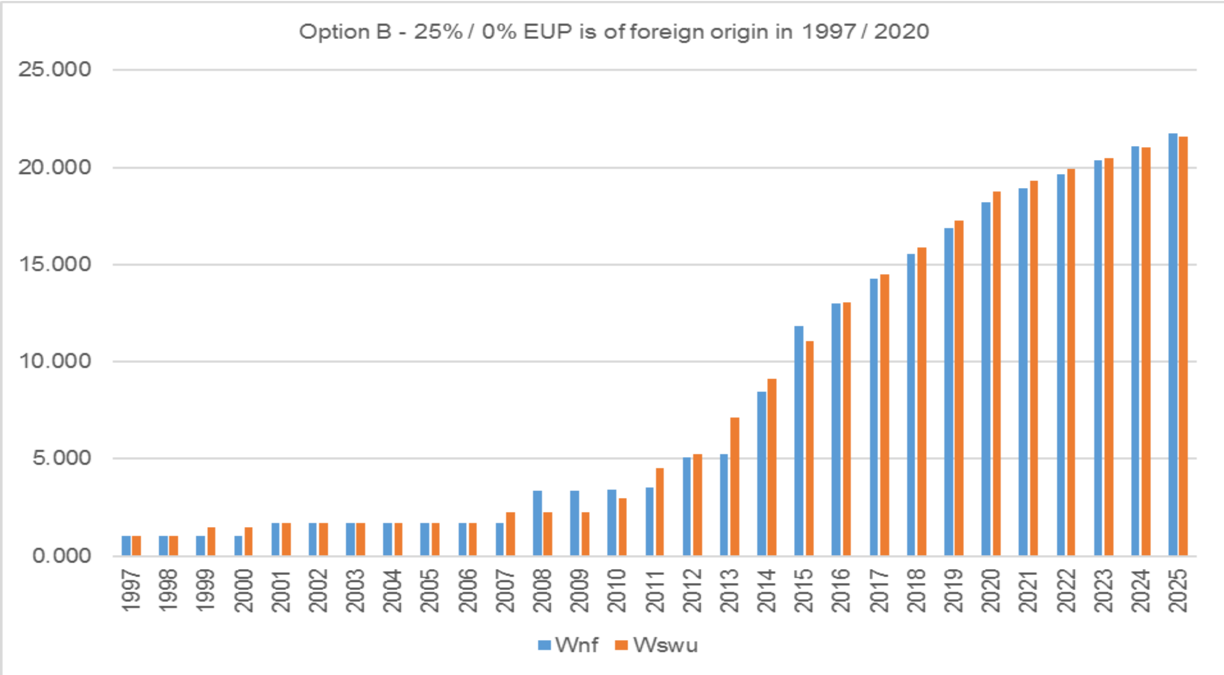


Figure 2.8
The relative capacity of the CNNC nuclear fuel fabrication plants (powder, pellets, FA) that are using EUP of CNNC production. The relative capacity of the CNNC enrichment plants. The plants capacities (1997-2025) are rationed at the corresponding capacities of 1997.

Legend:

- ✓ Wnf – relative capacity of the CNNC nuclear fuel fabrication plants (powder, pellets, FA) that are using EUP of CNNC production. The rationing is made at the CNNC's nuclear fuel fabrication plants capacity (powder, pellets, FA) that used EUP of CNNC production as of 1997;
- ✓ Wswu – relative capacity of the CNNC enrichment plants engaged in SWU production. The rationing is made at the CNNC's enrichment plants capacity as of 1997.

Chapter 3

CNNC Technology Platform for uranium enrichment industry development

The complex of data about the CNNC Technology Platform for uranium enrichment industry development available to IBR™ includes:

- ✓ Vast technical and economic, as well as customs, information on the Russian technology and equipment transferred / supplied to CNNC by the Russian enterprises;
- ✓ Data of the Russian experts cooperating with the Chinese research institutes and design offices engaged in the development of the China GC, including GC with a composite rotor consisting of several subcritical rotors joined by bellows;
- ✓ Vast technical and economic information on the ETC / URENCO technology, including licensing documentation on URENCO and AREVA plant projects in the USA from the NRC US database along with licensing documentation on URENCO European plants;
- ✓ Satellite images of the CNNC sites accommodating uranium enrichment plants at different stages of construction and operation.

All the globally used technology platforms of uranium enrichment based on employment of uranium isotope separation using gas centrifuges can be subdivided into two classes:

- ✓ Technology platforms based on subcritical / supercritical GC, its uniform (one section) rotor height up to 1 meter, which are assembled into assemblies (the assemblies are made by manufacturers and delivered to the enrichment plants, where they are mounted in several tiers, transfer of the GC from transport to operating mode is provided by unscrewing one threaded member);
- ✓ Technology platform based on the use of supercritical GC with a composite rotor made up of several subcritical rotors joined by bellows.

Subclasses can be identified in the two technology platforms above:

- ✓ The Russian Technology Platform makes use of subcritical / supercritical GC, the uniform (one section) rotor, its height up to 1 meter, assembled into units and [redacted] in the cascade halls ([redacted]°C);
- ✓ The URENCO / ETC Technology Platform makes use of supercritical GC with a composite rotor, consisting of several subcritical rotors joined by bellows and [redacted] in the cascade halls (~ [redacted]°C)[3].

Each of the technology platforms has its own advantages and drawbacks. Among the advantages of the Russian Technology Platform, the following should be mentioned:

- ✓ Providing of the assemblies with a GC by the manufacturer;
- ✓ No need for the building accommodating qualified personnel to be engaged in assembly, testing and mounting of GC on the uranium enrichment plant site;
- ✓ [redacted][4].

The drawbacks of the Russian Technology Platform include:

- ✓ Higher material consumption per unit of installed capacity versus the high centrifuge technology;
- ✓ [redacted]

[redacted]

[redacted]

Table 3.1

Indices characterizing the technologies specific capacity per unit of the plant floor space

CNNC Enrichment Plant Actual Technology / Technological Limit	Technology	Plant Specific Capacity (average for 30 years' service life), SWU / m^2
Hanzhong CEP 3 Actual Technology	351D2 Assemblies in 2 tiers	22
Hanzhong CEP 3 Technological Limit for GC in assemblies	K379R Assemblies in 7 tiers[5]	258
Emeishan CEP 1 Actual Technology	C1	45
Emeishan CEP 1 Technological Limit for high GC	C4	133

[redacted]

[redacted]

[redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted]

Table 3.5

Technical and economic characteristics of the CNNC centrifuge lineup (results of analysis and forecasting of IBR™)

GC Model	351D2	C1	C2	C3	C4
Capacity, SWU	[redacted]	[redacted]	[redacted]		
URENCO / ETC analogue		[redacted]	[redacted]	[redacted]	[redacted]
<u>Rotor</u>					
Rotor diameter (across the inner wall), mm	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rotor height, mm	[redacted]	[redacted]	[redacted]		
Rotor rotation frequency, Hz	[redacted]	[redacted]	[redacted]		
Rotor rotary speed, m/sec	[redacted]	[redacted]	[redacted]		
GC design and materials used	[redacted]				
Power concumption, kWh/SWU	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Reliability, 1/год	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Designated service life, years	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table A.2.1

IBR™ estimation of SWU production net cost of CNNC enrichment plants for the currently used technology and running projects as of 2016

Technology	URENCO / ETC TC-12	URENCO / ETC TC-21	CNNC C1 [redacted]	CNNC C2 [redacted]	CNNC C3 [redacted]	CNNC C4 [redacted]
Specific investments in installed capacity of separation module without acount of investment in the site general infrastructure, EUR/SWU	[redacted]					
Specific investments in installed capacity of separation module with acount of investment in the site general infrastructure, EUR/SWU						
Specific operating expenses, EUR/SWU						
SWU specific price for ~ 12 years Discounted Pay-Back Period, EUR/SWU						
SWU specific price for ~ 12 years Discounted Pay-Back Period, $/SWU						

[redacted]