

PRELIMINARY PROPOSAL

Deployment of Nuclear Power Project in Portugal



China National Nuclear Corporation Overseas Ltd.,

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1 Competence of CNNC

China National Nuclear Corporation (CNNC), a state-owned enterprise with nearly 70 years' experience in the nuclear field, is the sole party holds a complete nuclear industry chain in China. It is the main body of the national nuclear science and technology industry, the backbone of nuclear energy development, construction and nuclear technology application. Backed up by its integrated nuclear research and design system, CNNC can independently complete design, construction, and operation of 100MWe, 300MWe, 600MWe and 1000MWe nuclear technology. CNNC has independent intellectual property rights of a series of Generation III technologies, i.e., ACP100, ACP600 and HPR1000. CNNC also constructed two types of Generation IV technology demonstration project: CFR600 fast reactor and High Temperature Gas-cooled Reactor.

In January 2018, CNNC merged with China Nuclear Engineering and Construction Co., Ltd (CNEC) and reorganized. The new CNNC has established core industries such as advanced nuclear energy utilization, natural uranium, nuclear fuel, nuclear technology application, engineering construction, nuclear environmental protection, equipment manufacturing, financial investment, and market-oriented emerging industries such as nuclear industry services, renewable energy, trade, and health care, forming a higher-level innovation and industry chain in the nuclear industry, to provide better services to global clients.

As the sole exporter of the complete nuclear industry chain in China, CNNC works on a global scale to provide comprehensive services that range from uranium exploitation to nuclear waste treatment, along with an integrated solution that includes design and construction of NPPs with various capacity and research reactors, development of nuclear infrastructure, financing solutions, human resources development, localization, fuel supply, operation and maintenance, reprocessing and decommissioning solutions. CNNC had established partnerships of scientific and technological exchanges and built economic and trade cooperation with over 40 countries including UAE, KSA, Russia, France, Germany, UK, USA, Canada, Japan, Jordan, South Korea, etc.

2 Recommended Route for Cooperation

Based on the international nuclear power project development experience of CNNC, it takes a long time for a country without nuclear power projects before to start the construction of its first nuclear unit. For Portugal, relevant important issues for nuclear power project include government support, compilation of nuclear laws and regulations, establishment of nuclear regulatory system, human resource development, public acceptance, technology, and site evaluation. CNNC is willing to cooperate with Portuguese partners for achieving the goal.

2.1 Total System Cost (TSC) Analysis

The capital expenditure (CAPEX) for nuclear power projects encompasses comprehensive costs related to site preparation, reactor construction, equipment procurement, and project management. Generally, CAPEX includes engineering costs, fuel loading and contingency funds. CAPEX varies due to different technologies, and the details are as follows:

Table 2-1 The construction period and CAPEX for different technology

Technology	Construction Period * (One Unit, Month)	CAPEX (One Unit, \$/kW)	CAPEX (Two Unit, \$/kW)
ACP100	48~54	8,000~10,000	6,000~8,000
HTR-PM	48~54	6,000~7,000	5,000~6,000
HPR1000	66~72	4,500~5,500	4,000~5,000
AHPR1000	66~72	4,000~5,000	3,500~4,500

* The construction period in the table refers to the time from the First Concrete Date (FCD) to the Commercial Operation Date (COD) of the unit. The CAPEX is generally estimated figure which would be subject to practical situation in Portugal.

As to the Levelized cost of electricity (LCOE), it can be different between various technologies and unit scale. Currently, the LCOE of HPR1000 would be cheapest in all Chinese independent nuclear power technologies. However, the LCOE for one HPR1000 unit in Portugal would be subject to terms and conditions including local price, total project investment, operation scheme and costs, related laws and regulations of the project.

2.2 Cooperative Commercial Mode

Based on the previous overseas NPP projects' successful financing experience, CNNC recommended ECA facility as the financing instrument for potential NPP Project cooperation between CNNC and Portugal. The ECA facility and medium and long-term export credit insurance are aimed to support by the state to promote Chinese exports of goods, technologies and services, especially the exporting of high-tech and high-value-added capital products such as Chinese nuclear technologies.

For the past decades, CNNC has delivered 6 nuclear power units to Pakistan successfully, by providing ECA facility through banks in China, and rich financing experience have been accumulated. The average time from the completion of an EPC contract signing to financial closure has been reduced to around one year. CNNC has won the support of 20 Fortune 500 financial institutions, including the Export-Import Bank of China (EXIMBANK), Industrial and

Commercial Bank of China (ICBC), China Development Bank (CDB), etc. CNNC has established strategic partnerships with most of these institutions.

In terms of equity investment, CNNC is open to discuss the possibility of a minority equity investment, to show the strong willingness to share risks and in-depth cooperation with Portugal.

2.3 Potential Approaches for Near-term Cooperation

Joint hosting of exhibitions, forums and other dissemination-related events to improve the public acceptance of nuclear power.

CNNC can provide professional consulting services, conduct a comprehensive analysis of Portugal's nuclear power infrastructure, and formulate targeted improvement plans.

Both parties can carry out cooperation in aspects such as training and site selection according to the improvement plans.

3 TECHNOLOGY

3.1 HPR1000

- **Technology Overview**

HPR1000 is a Gen-III advanced 1000MWe-class PWR developed by CNNC. The technology was developed by an evolutionary approach based on nearly 40 years of experiences on design, construction, operation and maintenance of NPPs in China. HPR1000 meets the requirements of the nuclear safety regulations and guidelines currently in effect issued by the Chinese nuclear regulator (NNSA), and refers to the requirements of the latest safety standards issued by IAEA.

As a self-reliant PWR technology, CNNC owns full intellectual property rights of HPR1000, covering reactor core design with 177 fuel assemblies, CF3 fuel assembly design and manufacturing technologies, design of NSSS main equipment, design of systems, structures and essential components, as well as a full set of specific design tools or computer codes supporting the whole scope of plant design.

- **General Parameters**

The general parameters of HPR1000 are listed in following table:

Table 3-1 General parameters of HPR1000

	Unit	Value
Type of the Plant		3 loops pressurized water reactor
Service life	Years	60
Refueling cycle	Months	18
Reactor nominal thermal power	MWt	≈3180

	Unit	Value
NSSS thermal power	MWt	≈3190
Nominal power	MWe	≈1200
Plant availability	%	≥90
Safe Shutdown Earthquake SL-2	g	0.3
Plant Layout		Single unit
Core damage frequency	/reactor·year	$< 1 \times 10^{-6}$
Large release frequency	/reactor·year	$< 1 \times 10^{-7}$
Collective occupational exposure dose	person·Sv/reactor·year	< 0.5
Number of fuel assemblies		177
Containment type		Double-shell containment

• Project & Progress

Fuqing NPP Unit 5 is the world's first HPR1000 reactor. Its construction progressed smoothly with a construction period of 68.7 months and was completed ahead of the planned schedule, demonstrating the outstanding engineering management and technical capabilities of CNNC. The Karachi NPP Unit 2, Pakistan, as the first overseas HPR1000 unit, has also achieved remarkable results in construction with a construction period of 69 months.

Currently, 4 HPR1000 units have been built and put into commercial operation. Since then, these units have been in safe and stable operation, further demonstrating the safety and efficiency of HPR1000 technology.

HPR1000 units have entered a new stage of batch construction. Multiple HPR1000 projects at China and abroad are advancing steadily. This not only injects new impetus into the development of China's nuclear power industry, but also provides more choices for the global nuclear power market. In the future, HPR1000 will continue to exert its technological advantages and contribute more Chinese wisdom and strength to promoting global energy transformation and sustainable development.

Table 3-2 The project adopting HPR1000 technology

NPP	Unit No.	COD	Role of CNNC
Fuqing	5	2021.1	Investor, constructor, operator
	6	2022.3	Investor, constructor, operator
Karachi (Pakistan)	2	2021.5	Constructor
	3	2022.4	Constructor

NPP	Unit No.	COD	Role of CNNC
Zhangzhou	1	2025.1	Investor, constructor, operator
	2	under construction	Investor, constructor, operator
	3	under construction	Investor, constructor, operator
	4	Planned	Investor, constructor, operator
Changjiang	3	under construction	Investor, constructor, operator
	4	under construction	Investor, constructor, operator
Jinqimen	1	under construction	Investor, constructor, operator
	2	under construction	Investor, constructor, operator
Chashma (Pakistan)	5	under construction	Constructor

3.2 AHP1000

• Technical Overview

CNNC gained a great amount of feedback from experience in design, construction and operation of HPR1000 thanks to its batch deployment in both China and abroad. Taking in such feedback and through extensive discussion on technical objective and route, CNNC formally launched the development of AHP1000 in 2020. The design of AHP1000 is streamlined, intelligent and environmental-friendly. The safety of AHP1000 reaches the safety level of Gen III+ technologies, and was greatly improved in terms of economic efficiency, intelligent operation, and minimum waste discharge and resource consumption, thus to some extent solving these three issues.

The standard preliminary design and standard preliminary safety analysis report for AHP1000 have been completed by the end of 2023. The independent evaluation for preliminary design is carried out. Nuclear power units adopting AHP1000 is expected to launch deployment in China in 2026.

• General Parameters

The general parameters of AHP1000 are listed in following table:

Table 3-3 General parameters of AHP1000

	Unit	Value
Reactor thermal output	MWt	≈3210
Power plant output	MWe	≥1230
Fuel assembly type		Improved CF3
Fuel assembly number		177
Refueling cycle	Months	18

	Unit	Value
Mode of operation		Load following without boron adjustment
Plant design life	Years	80
Plant availability target	%	≥93
Safety shutdown earthquake (SSE)	g	0.3
Core damage frequency (CDF) for internal events	/reactor·year	$< 1 \times 10^{-6}$
Large release frequency (LRF) for internal events	/reactor·year	$< 1 \times 10^{-7}$
Occupational radiation exposure	person·Sv/ reactor·year	< 0.5
Operator non-intervention period	Hours	72
Plant autonomy period	Days	7
Production of radioactive solid waste package	m ³ / reactor·year	≤30

3.3 Other Technology Option Recommended by CNNC

- **ACP100**

The ACP100 is an integrated pressurized water reactor (PWR) developed by CNNC, which is designed to meet the safety requirements of Generation III nuclear technology. It is designed as a small modular reactor (SMR) with a power output of 125 MWe. The ACP100 has received approval from the International Atomic Energy Agency (IAEA) as the first SMR of its kind. The ACP100 incorporates passive safety features and an integrated reactor design, enhancing its safety and reliability. Construction of the first ACP100 demonstration project commenced at the Changjiang Nuclear Power Plant in Hainan Province, China, on July 13, 2021. This project represents the world's first commercial onshore SMR. The reactor module integrates the reactor vessel, steam generators, and primary coolant pumps into a single unit, simplifying the overall system layout.

Main parameters of ACP100 are listed in Table.

Table 3-4 General parameters of ACP100

	Unit	Value
Type of the Plant		3-loop pressurized water reactor
Service life	Years	60
Refueling cycle	Months	24
Reactor nominal thermal power	MWt	≈385

	Unit	Value
Nominal power	MWe	≈125
Plant availability	%	≥90
Safe Shutdown Earthquake SL-2	g	0.3
Core damage frequency	/reactor·year	$< 1 \times 10^{-6}$
Large release frequency	/reactor·year	$< 1 \times 10^{-7}$
Collective occupational exposure dose	man· Sv/reactor·year	< 0.5

- HTR**

CNNC's HTR technology originates from German HTGR technology developed in the 2nd half of 20th century. Through the implementation of prototype test reactor HTR-10 project in 1990s and commercial HTR demonstration project in Shidao Bay which achieved operation in 2023 together with lesson learned during the whole research and development (R&D) and project construction, China has mastered and is further developing HTR technology. HTR technology adopts features including ceramic coated tri-structural isotropic (TRISO) fuel, graphite reactor core, helium cooling, on-line refueling and passive safety system. It also complies with safety requirement of 4th Generation nuclear reactor technology.

A standard module of HTR has 210 MWe electricity output, comprising 2 reactors and related nuclear steam supply system (NSSS) circuits. Main parameters of HTR module are listed in Table.

Table 3-5 Major technical parameters of HTR module

	Unit	Value
Total thermal power of two reactors	MWt	500
Overall Electrical power	MWe	210
Number of reactors in module		2
Helium inlet /outlet temperatures	°C	250/750
Helium pressure in the primary circuit	MPa	7
Steam temperature/pressure	°C/MPa	541/13.9
Feed water temperature	°C	205
Efficiency		41%
Heat-power co-generation efficiency (estimated)		>90%