CGN

China General Nuclear Power Corporation

Natural Energy Powering Nature

Overview of HPR1000 and Status on Projects

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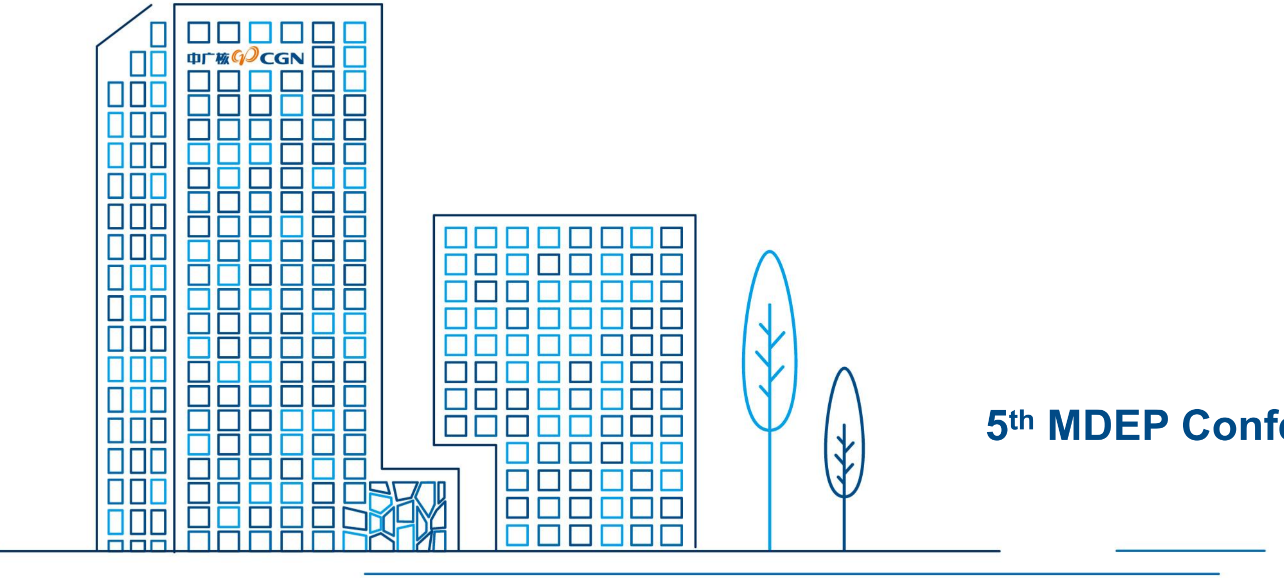


Successful Launch of FOAK-FCG Unit 3

On March 25, 2023, CGN's first HPR1000 unit (Fangchenggang Unit 3) was put into commercial operation. It has been verified that the quality and performance indexes of this first unit meet all the requirements of the relevant laws and regulations, and the number of unplanned turbine or reactor shutdown during the unit start-up stage is **zero**.

Key performance index	Result
Number of serious injury or worse safety accidents	Zero
Number of major equipment damage accidents	Zero
Cold test/CTT/hot test/steam turbine start up/connection to the grid	All success in one time
Results of FOAK tests	Meet design requirements
Unit performance test	Meet design requirements
Number of unplanned turbine or reactor shutdowns during the first start-up stage	Zero
Number of planned shutdown maintenance before commercial operation	Zero

HPR1000 FOAK Experience Summary and Mass Construction Promotion Summit

On April 13, 2023, CGN’s Chairman Yang Changli, along with senior executives from 13 industrial strategic cooperation partners who played key roles for the successful delivery of Fangchenggang Unit 3, held a meeting to summarize the HPR1000 FOAK experience and promote the HPR1000 mass construction.

01 An Overview of HPR1000 Design

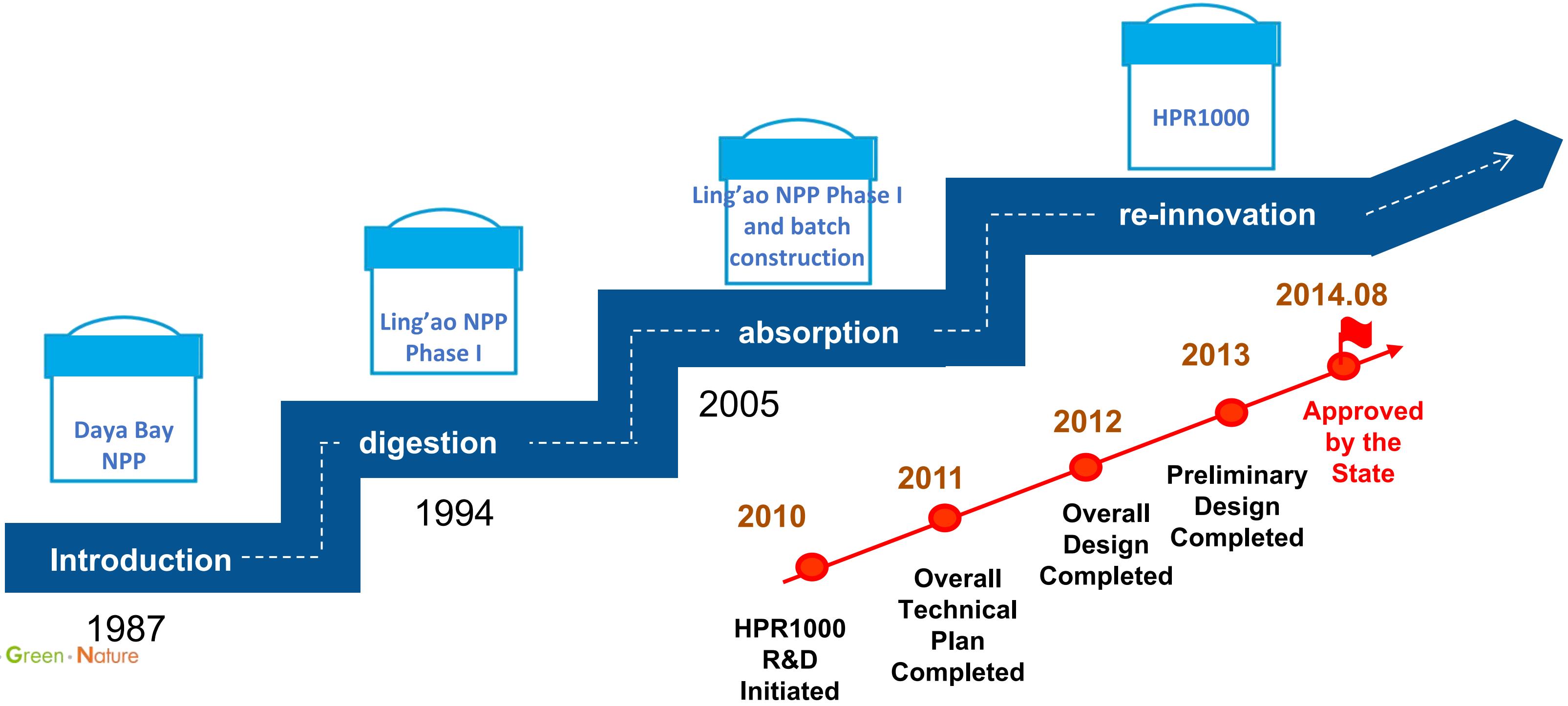
- Journey of CGN’s Nuclear Technology and AE Capabilities Development
- Key Features of HPR1000

1.1 Journey of CGN's Nuclear Technology and AE Capabilities Development

March 25, 2023
CGN's first HPR1000 reactor, unit 3 of Fangchenggang NPP put into operation

1.2 Key Features of HPR1000

HPR1000 is an advanced Gen III nuclear power technology developed by CGN on the basis of introduction, digestion, absorption, and re-innovation over the past decades, reliance upon the Chinese nuclear power industrial chain and taking into full account the need to accommodate customers' requirements at all times. Integration- and innovation-oriented approach has been followed in the development of HPR1000 with efforts made to the design concepts and construction feedback of advanced nuclear power technologies from home and abroad.



HPR1000: integrates nuclear power construction experience all over the world and advanced design concepts.

- Safety Standards: HAF102
- Uers' requirements such as URD, EUR, etc.
- Feedback from domestic nuclear power construction and operation
- Based on the nuclear power industrial chain of China
- Lessons learned from Fukushima accident
- Lessons learnt from international good practices

1.2 Key Features of HPR1000

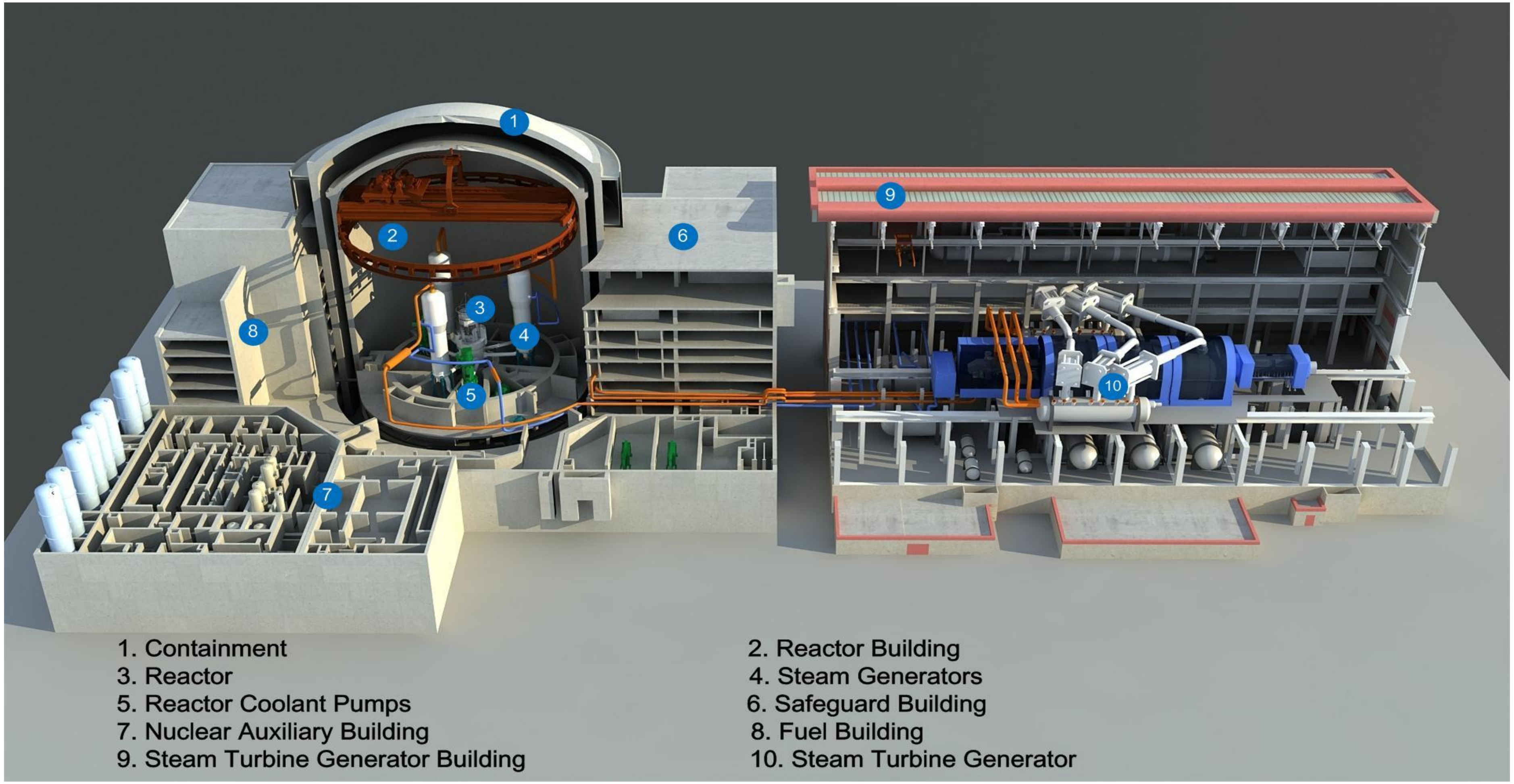
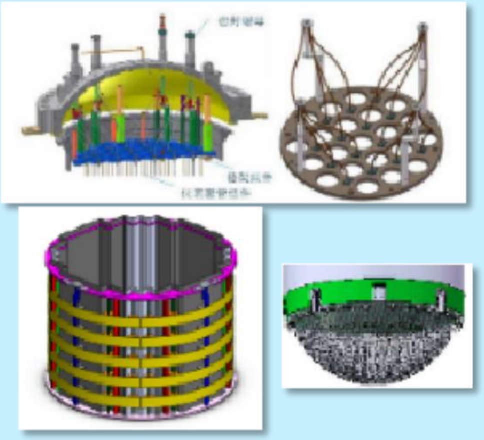


Figure: Section View of the Layout

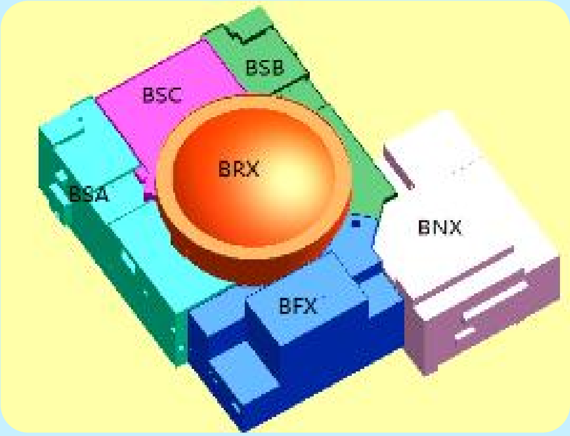
1.2 Key Features of HPR1000

CGN’s HPR1000 features a single-reactor layout, three separate and physically isolated safety series, and a combination of active and passive accident defense-in-depth safety systems. The design life of a HRP1000 plant is **60** years, and the fuel cycle is **18** months, with a designed utilization rate of more than **90%**.

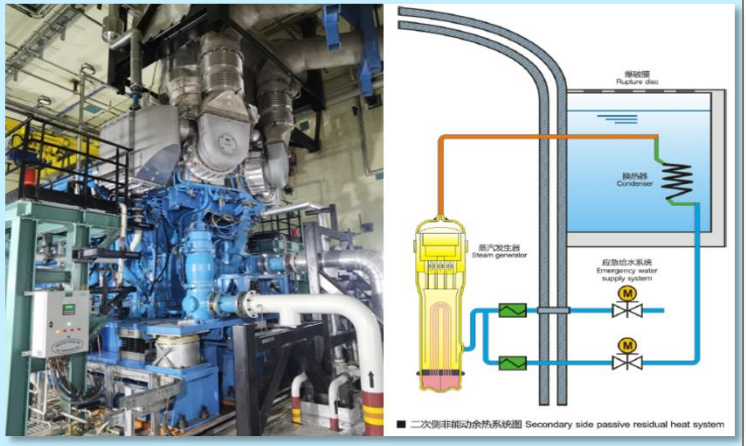
- Single-reactor layout, double containment, higher seismic design standard.



- Reactor structure design is more compact, flow field is more uniform.



- Three separate and physically isolated safety series assure higher safety performance.



- Multi-level and diversified power supplies and cooling systems ensure that the power plant has more than 72 hours of self-sustaining capacity.

1.2 Key Features of HPR1000

Main Parameters

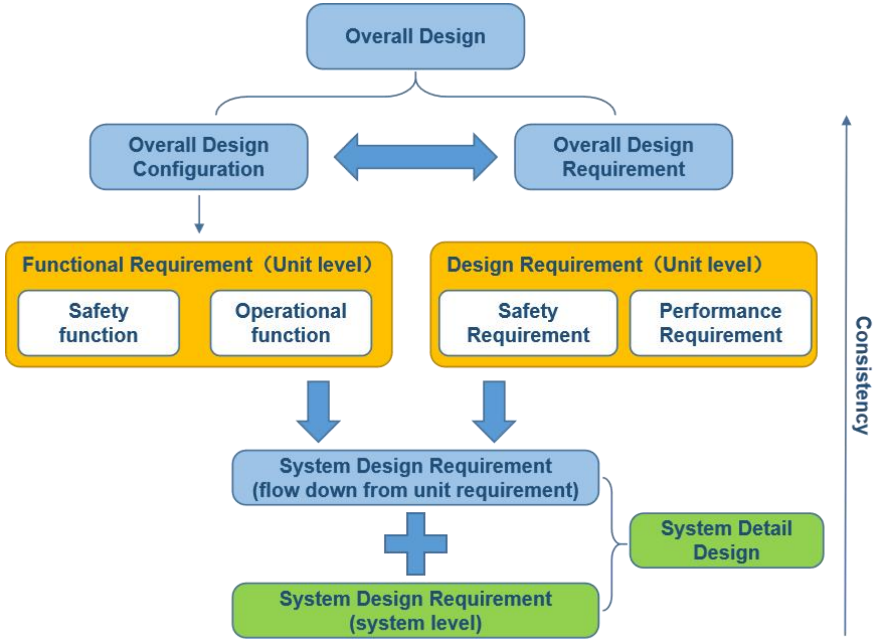
Parameters	Value
Reactor Type	PWR
Loop	3
Design Lifetime, year	60
Core Thermal Power, MW	3,180
Electric Output, MW	1,200
Primary Side Design Pressure	17.23 MPa (abs)
Primary Side Design Temperature	343 ℃
Number of Fuel Assemblies	177 (12 feet)

Parameters	Value
Fuel Cycle	18 months
Core Damage Frequency,/(reactor·year)	< 1×10-6
Large Release Frequency, /(reactor·year)	$< 1\times10^{-7}$
Core Thermal Margin	>15%
Design Basis Earthquake	0.3g
Operator Grace Time	≥30 min
Plant Thermal Efficiency	≈38%
Free Containment Volume	>75,000m^3

It’s worth to mention that the value of CDF and LRF has been further reduced by one order of magnitude on the basis of meeting the requirements of national regulations.

1.2 Key Features of HPR1000

The R&D process of HPR1000 follows the general rules of modeling with top-level design carried out from the user's needs, setting development goals, performance indicators, overall requirements as well as determining preliminary concept schemes. Based on this, the overall functions and requirements of the power plant are decomposed to determine the functions and requirements of the structures, systems, and equipment. Performance matching is achieved through iterative design. During the development process, a multi-disciplinary collaborative R&D system was established, advanced design tools and integrated platforms were adopted to improve efficiency, and technical status control management tools were deployed to ensure consistency.



1.2 Key Features of HPR1000

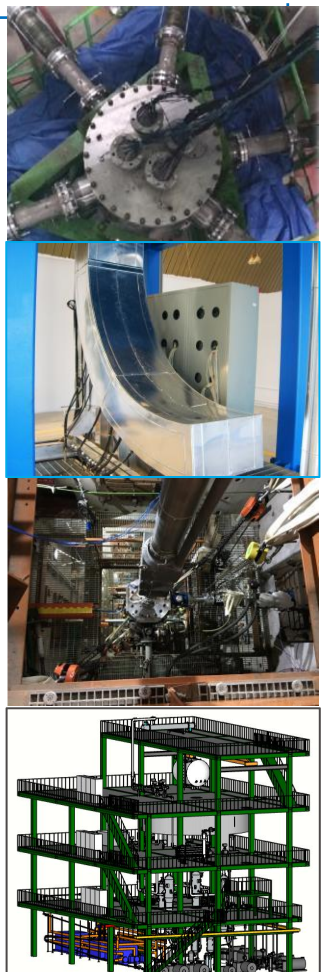
During the process of program iteration, demonstration and solidification in the R&D stage, based on the main design features of HPR1000, sufficient verification tests were planned for reactor, system configuration and key main equipment to ensure the accuracy of the design and ensure performance indicators meet the prescribed requirements.

New Design

- **Reactor Design** → New Reactor Structural Design
- **New System Design** → Safety System Design; Related Supporting System Design
- **Key Equipment Design** → SG R&D; CRDM R&D

Lab Tests

- Overall Hydraulic Test
- Flow-induced Vibration Test of Reactor Internals
- Core Circumference Bypass Test
- Molten Core Debris Retention Test
- Secondary Side Passive Engineering Test
- Control Rod Drive Line Test Verification
- SG R & D verification test



Overall demonstration test: comprehensive performance verification of the overall design features, design software, and accident treatment strategies of HPR1000.

1.2 Key Features of HPR1000

In the design and commissioning stages, to finally verify the engineering application efficacy of the new design, in accordance with the relevant standards, specifications and engineering practices and taking into consideration the design features of HPR1000, five pilot project tests were determined. The tests were successfully carried out in the hot test stage and the power-raising stage in one go.

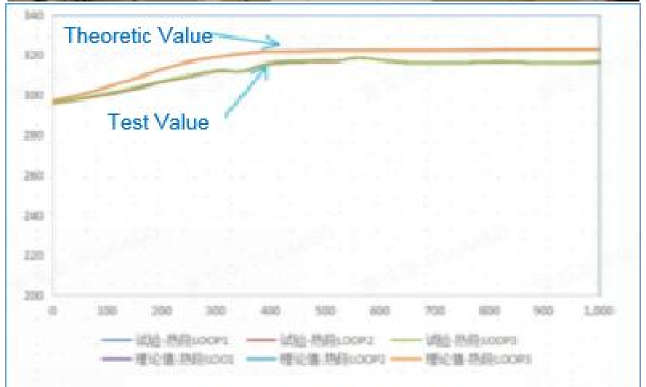
6 standards and specifications + **3 engineering practices** + **New Feature of HPR1000** = **5 Pilot Project Tests**

6 standards and specifications
- IAEA NS-G-2.9
- IAEA SSG-28
- NRC RG 1.68
- NRC RG 1.20
- NRC bulletin 88-11
- HAD 103/02

3 engineering practices
- Qinshan NPP Phase II
- AP1000
- EPR

New Feature of HPR1000
- New reactor structure
- Pressurizer surge line
- NSSS system
- ASP system design
- VDA medium pressure rapid cooling capability

5 Pilot Project Tests
- Flow-induced vibration measurement test of reactor internals
- Pressurizer surge line thermal stratification test
- Natural Circulation Test
- Thermal state functional test of secondary side passive waste heat removal
- Medium pressure rapid cooling function test



Natural Circulation Test

1.2 Key Features of HPR1000

Through continuous iteration and deepening of design, as well as sufficient verification through experiments, the construction of the HPR1000 pilot project commenced on December 24, 2015.

1.2 Key Features of HPR1000

Excellent performance has been made in the main equipment production and manufacture.

Reactor Pressure Vessel: the hydraulic test was successful in one go, creating the world's shortest record from forging to passing the test.

SG: Created a new record of 24 months for the production cycle of a third-generation nuclear power steam generator

1.2 Key Features of HPR1000

In the stage of construction and installation, vigorously carried out R&D and application of advanced construction technology to improve efficiency

ASP water tank stainless steel module

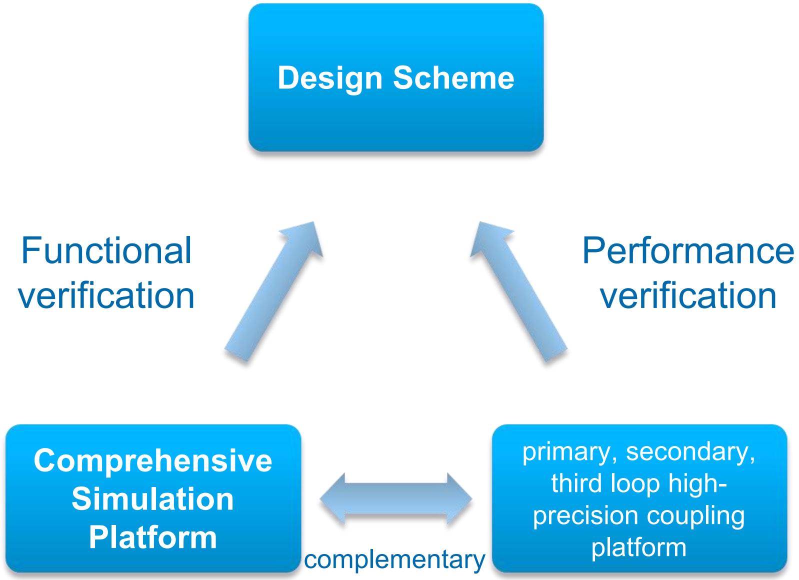
Non dismantling steel form work for outer containment

Automatic welding of SFP

Surge line automatic welding

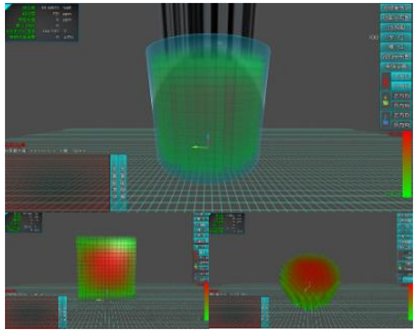
1.2 Key Features of HPR1000

During the design and commissioning process, we made full use of the functional simulation platform and performance simulation tools for verification; conducted "virtual commissioning" in advance, with over 200 simulations of commissioning risk items and typical transient conditions implemented before cold test, hot test and after loading to identify and eliminate risks in advance, creating conditions conducive to the realization of the objective of "zero trip, zero unplanned shutdown, zero repair, and zero major equipment damage".



- Conducted through engineering simulator
- Prioritize real-time computing
- Focus on the analysis and verification of the logic response of the unit

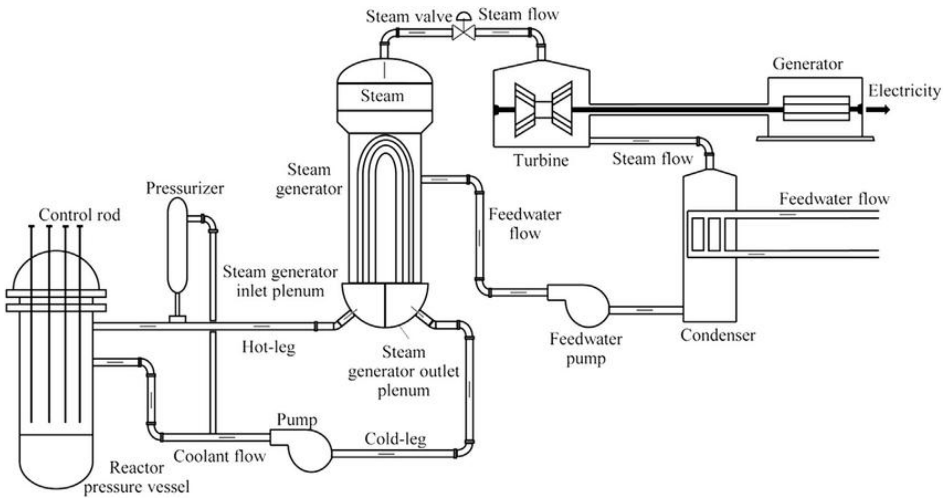
- Conducted through high-precision coupling platform
- Prioritize calculation accuracy
- Focus on realizing the design verification and dynamic matching evaluation of control parameters and fixed values



1.2 Key Features of HPR1000

Main performance indicators of the pilot unit which has been put in to operation are better than the design values.

Performance Indicators	Design Value	Actual Value
NSSS Thermal Power	3160（1±1%）MW	3141.5MW
Electricity Power	≥1185MW	1208.20MW
SG Outlet Steam Pressure	≥6.75MPa	6.88MPa
SG Outlet Steam Humidity	≤0.10%	0.035%



02 Feedback from Assessments

- NNSA Nuclear Safety Review and Construction Permit
- International Assessment

2.1 NNSA Nuclear Safety Review and Construction Permit

Safety Review

The National Nuclear Safety Administration(NNSA) conducted a safety review on Units 3 and 4 of Guangxi Fangchenggang Nuclear Power Plant (the first reactor demonstration project using HPR1000 technology), and concluded that the design principles adopted and nuclear safety-related activities met the requirements of China's nuclear safety laws and regulations and were qualified for construction.

Construction License

On December 23, 2015, the construction license of Unit 3 and Unit 4 of the Fangchenggang Nuclear Power Plant was issued, representing that HPR1000 technical proposal was approved by the regulatory authorities.

Other regulations

In addition, on the basis of fulfilling the responsibilities stipulated in the Nuclear Safety Law, NNSA further issued the Notice on Strengthening the Quality Management of Nuclear Power Project Construction, the Safety Regulations of the Nuclear Power Plant Management System and other regulations, and promoted the implementation through strict supervision.

HPR1000 has met all regulatory requirements and assessments,from design, license application to engineering implementation.

2.2 International Assessment

- UK Generi Design Assessment (GDA）, European Utility Requirement (EUR) Assessment and IAEA Generic Reactor Safety Review(GRSR)
  - ➢ Through a joint venture between CGN and EDF, HPR1000 entered GDA step 1 on 19 January 2017. It took five years to complete as planned, and obtained GDA certification on 19 Jan, 2022. UK HPR1000 successfully completed 95 design improvements.
  - ➢ Base on the UK's high standards for nuclear safety and security, Office for Nuclear Regulation (ONR)'s specialist inspectors in different areas have carried out a rigorous and detailed assessment of UK HPR1000 and concluded that UK HPR1000 design is suitable for the UK construction and comply with the conditions for issue of DAC certification.
  - ➢ UK HPR1000 has passed the rigorous evaluation of Environment Agency (EA) and complied with the conditions for issue of SoDA certification.
  - ➢ Compared with other technologies assessed by GDA in the UK, **UK HPR1000 is the only one without items of Regulatory Issue and GDA Issue throughout the assessment**. This once again proves the security and maturity of HPR1000.

2.2 International Assessment

- UK Generi Design Assessment (GDA）, European Utility Requirement (EUR) Assessment and IAEA Generic Reactor Safety Review(GRSR)
  - ➢ HPR1000 entered EUR certification process on March 2018. It obtained EUR certification on 20 October 2020, confirming that HPR1000 passed the latest E version of EUR's conformity assessment.
  - ➢ Based on the review documents submitted by CGN, EUR has completed the conformity analysis of more than 5,000 requirements of EUR and HPR1000, and the results show that the proportion of non-conformity items of HPR1000 is less than 1%.
  - ➢ HPR1000 also passed the IAEA Generic Reactor Safety Review in 2015.

IAEA Certification

EUROPEAN UTILITY REQUIREMENTS FOR LWR PLANTS

CEZ • EDF • EDF Energy • Energoatom • Fortum • GEN Energija • Iberdrola • NRG • Paks II • Rosenergoatom • Tractebel/Engie • TVO • VGB Powertech

The European Utility Requirements (EUR) Organisation certifies that the EU HPR1000 design has successfully passed all the steps of the analysis of compliance vs. EUR Revision E with the contribution of CGNPC, CGNP, CNPEC, CNPDC, CNPRI, CTEC and Hualong Tech.

Following this analysis, a specific subset of the EUR volume 3 dedicated to the EU HPR1000 design has been published by the EUR organisation.

October 20th 2020

Manuel Carrasco, chairperson of the EUR Steering Committee

EUR Certification

Office for Nuclear Regulation ONR-GDA-DAC-22-001

GENERIC DESIGN ASSESSMENT

DESIGN ACCEPTANCE CONFIRMATION

FOR THE UK HPR1000 NUCLEAR REACTOR

Signed

Date of Issue

Mr Mark Foy

Environment Agency

Generic Design Assessment of nuclear power plant designs

Statement of Design Acceptability for the UK HPR1000

Requesting Party:

China General Nuclear Power Corporation
Électricité de France S.A.
General Nuclear International Limited

GDA Certification

03 Progress on HPR1000 Projects

- Domestic Projects
- Overseas Project
- Continuous Improvements

3.1 Domestic Projects

	No.	Projects	Leading Developer	Operation/Start Date
In operation	1	Fuqing NPP Unit 5	CNNC	2021.03.30
	2	Fuqing NPP Unit 6	CNNC	2022.03.25
	3	Fangchenggang NPP Unit 3	CGN	2023.03.25
Under Construction	1	Fangchenggang NPP Unit 4	CGN	2016.12.26
	2	Zhangzhou NPP Unit 1	CNNC	2019.10.16
	3	Taipingling NPP Unit 1	CGN	2019.12.25
	4	Zhangzhou NPP Unit 2	CNNC	2020.09.04
	5	Taipingling NPP Unit 2	CGN	2020.10.15
	6	Sanao NPP Unit 1	CGN	2020.12.31
	7	Changjiang NPP Unit 3	CHNG	2021.03.31
	8	Changjiang NPP Unit 4	CHNG	2021.12.28
	9	Sanao NPP Unit 2	CGN	2021.12.30
	10	Lufang NPP Unit 5	CGN	2022.09.08

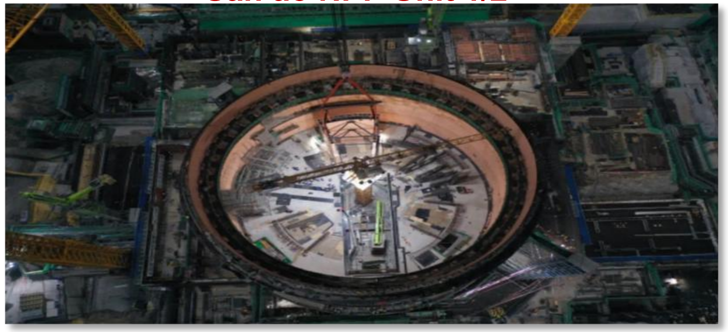
CNNC: China National Nuclear Corporation; CHNG: China Huaneng Group

3.1 Domestic Projects

Fangchenggang NPP Unit 3/4

Fuqing NPP Unit 5/6

San’ao NPP Unit 1/2



Lufeng NPP Unit 5

Changjiang NPP Unit 1/2

Taipingling NPP Unit 1/2

Zhangzhou NPP Unit 1/2

3.2 Overseas Project

Karachi NPP in Pakistan

- K2: was put into commercial use on May 20, 2021.
- K3: was put into commercial use on April 18, 2022.

Karachi NPP

3.3 Continuous Improvements

HPR1000 FOAK → HPR1000 Revision 0.0 → HPR1000 Revision 1.0 → HPR1000 Revision 2.0

Major Improvements

Key Tests

HPR1000 FOAK

- overall reactor hydraulic model
- reactor control rod driver line
- fluid vibration of reactor internals
- ASP test
- bypass flow and its characteristic tests
- IVR test

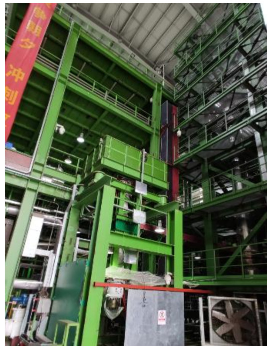
HPR1000 Revision 0.0

- self developed HL-T67 steam generator
- change of main parameters

- fluid vibration of SG tube bundles
- SG performance test

HPR1000 Revision 1.0

- DVI technology application
- passive reactor heat removal
- integration of reactor head
- advanced reactor controlling
- advanced reactor protection



- big LOCA DVI injection test
- EPS heat exchange unit test
- DVI guiding fluid characteristic test
- EPS engineering verification test research
- DVI resistance characteristic test
- fluid field of reactor upper chamber and head chamber

HPR1000 Revision 2.0

- passive containment heat removal
- passive safe injection
- habitable system for main control room
- active pressure relief of primary circuit
- integrated reactor head

- overall reactor hydraulic simulation
- test research on high temperature ventilation of reactor head
- passive environmental protection system characteristic test
- supplementary test of main pump hydrodynamic pressure shaft seal
- integral effect test of containment

integral effect tests of safety systems

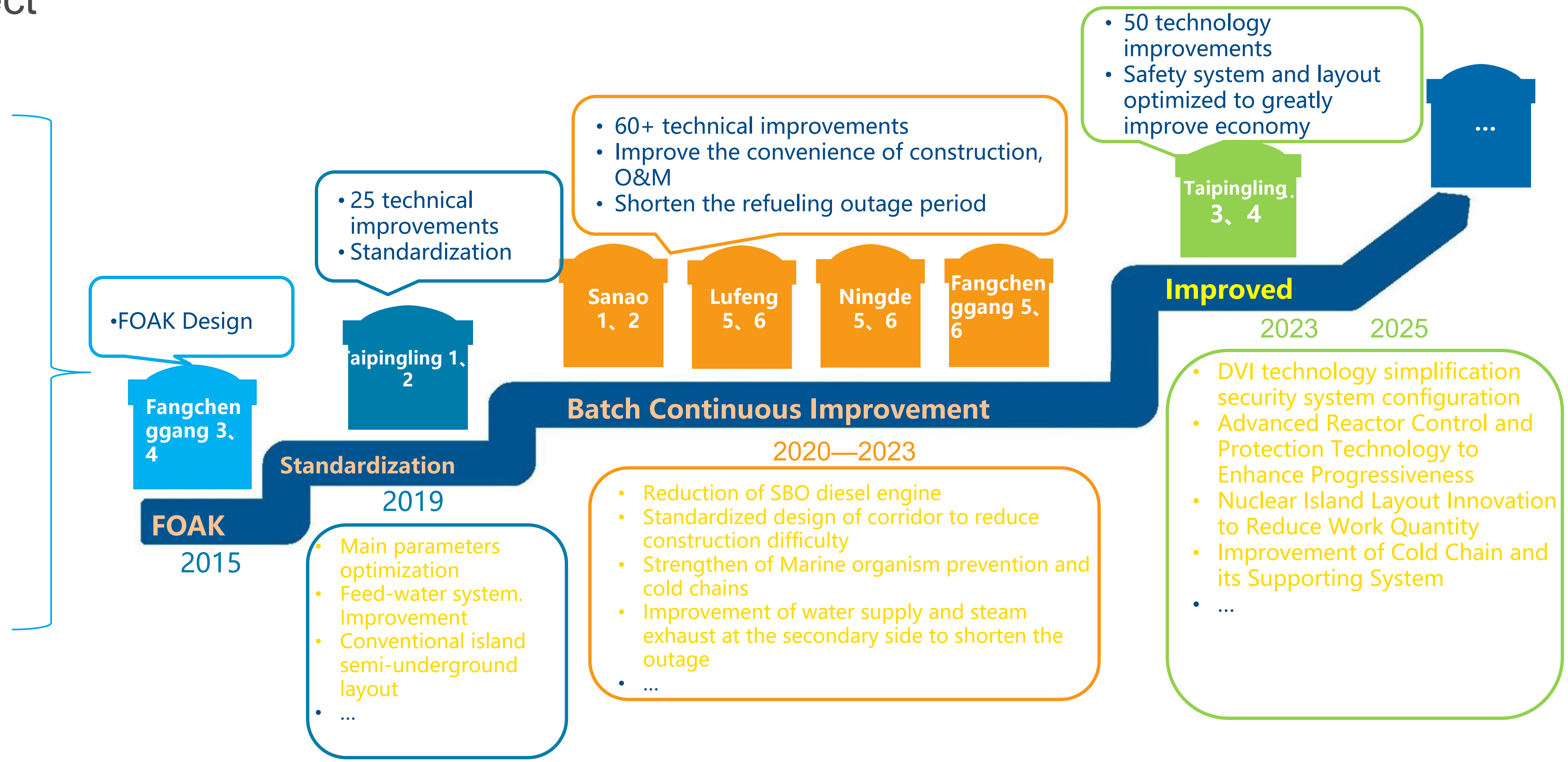
3.3 Continuous Improvements

Based on the successful delivery of FCG Unit1, CGN is leading HPR1000 continuous innovation through fleet effect

Engineering Design (E)
Design leading and system integration capacity

Project management (M)
Project refined management and capacity of project fleet operations

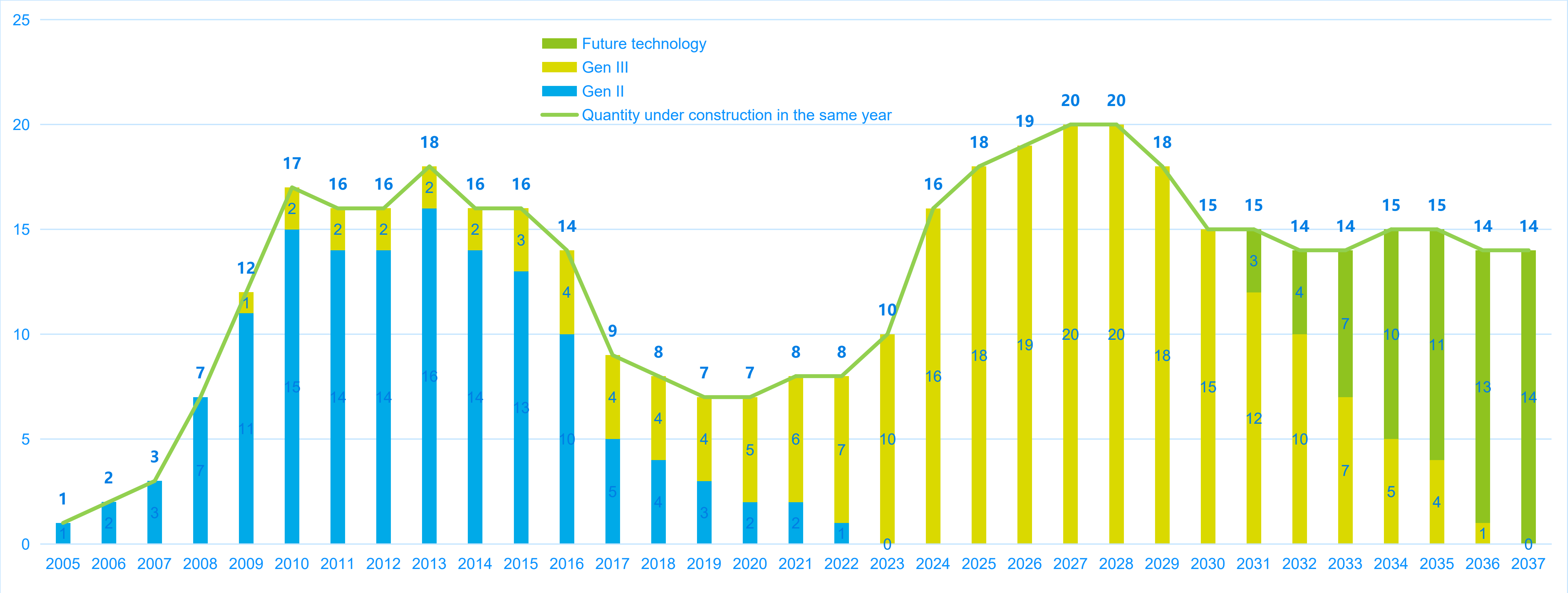
Resources integration (I)
Resource integration of industrial chain and collaborative innovation capacity



04 Prospect

4. Prospect

Under the "carbon dioxide emission and carbon neutrality" goal, China's installed capacity of nuclear power in 2030 and 2050 shall reach at least 150GW and 380GW separately. Based on such targets, China shall maintain a development rate of 10 or more nuclear power units annually over the next ten years. A new peaking of nuclear power construction is on the way.



CGN's forecast on the scale of China's nuclear power mass construction

After more than ten years of R&D / design / review and construction, first HPR1000 project has been successfully put into operation. As the first batch of HPR1000 projects started construction, CGN expects the subsequent HPR1000 project to be better one after another in terms of safety and economy. For this goal, we have been continuously improving and innovating HPR1000. We believe that HPR1000 will be the main reactor type of the second peak of nuclear power construction in China, and look forward to international cooperation on the delivery of HPR1000 projects.

Thank you!