Nuclear Energy Program and Technology in China

China National Nuclear Corporation
2019.6
目录

1. Nuclear Energy in China
2. CNNC/CZEC Profile
3. HPR1000 Overview
4. HTGR Overview
Distribution Map of Nuclear Power Plants in CHINA Mainland

- In operation
- Under construction
- To be constructed

45 Units
11 Units

Xudapu NPP
Hongyanhe NPP (1~4)
Hongyanhe NPP (5&6)
Shidaowan NPP
Haiyang NPP (1&2)
Haiyang NPP Phase II
Tianwan NPP (1~4)
Tianwan NPP (5&6)
Qinshan NPP Phase I (1)
Qinshan NPP Phase II (1~4)
Qinshan NPP Phase III (1&2)
Fangjiashan NPP (1&2)
Sanmen NPP (1&2)
Sanmen NPP Phase II
Ningde NPP (1~4)
Fuqing NPP (1~4)
Fuqing NPP (5&6)
Zhangzhou NPP
Lufeng NPP
Daya Bay NPP (1&2)
### Operational NPP

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>CNP-300</td>
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<tr>
<td>CNP-600</td>
<td>6</td>
</tr>
<tr>
<td>CNP1000/CPR 1000</td>
<td>23</td>
</tr>
<tr>
<td>Candu 6</td>
<td>2</td>
</tr>
<tr>
<td>M310</td>
<td>4</td>
</tr>
<tr>
<td>EPR</td>
<td>1</td>
</tr>
<tr>
<td>VVER</td>
<td>4</td>
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<td>AP1000</td>
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### Under Construction NPP

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>HPR1000</td>
<td>4</td>
</tr>
<tr>
<td>CNP1000/CPR 1000</td>
<td>5</td>
</tr>
<tr>
<td>EPR</td>
<td>1</td>
</tr>
<tr>
<td>HTR-200</td>
<td>1</td>
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</table>

- The government's mid-long term target, as outlined in its Nuclear Energy Development Plan 2014-2020, is 58 GWe in operation by 2020, with 30 GWe under construction.
Roadmap of PWR Development in China

- Construction of the 1st NPP (300MW PWR)
- Construction of 650 MWe NPP CNP600
- Construction of CNP1000
- R&D of ACP1000
- ACP1000/ACP1000+
- HPR1000

Timeline:

- 1980s: Introduction of Daya Bay NPP
- 2015: HPR1000 FCD 2015.5.7
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CNNC is the unique nuclear solution provider with a complete nuclear industry chain in China.
CHINA ZHONGYUAN ENGINEERING CORPORATION

SOLE Exporter of the Complete Nuclear Industrial Chain
FIRST Overseas Nuclear Project Constructor
LARGEST Overseas Nuclear Project Contractor in China

CZEC –
• Wholly-owned subsidiary of CNNC
• Overseas marketing platform of CNNC Nuclear Power Technology
• EPC company of overseas nuclear power plant with an integrated solution to customers
• With more than 30 years of experience in overseas nuclear project EPC, and strong support from global partners.
• With revenue of c. 2 billion USD in 2018, 1000 employees.
Chashma CP300 x 4 units (C1, C2, C2, C4)
Karachi HPR1000 x 2 (K2, K3)

Commercial NPPs
Research Reactors

Ghana
Pakistan
Jordan
Nigeria

Miniature Neutron Source Reactor (MNSR)

We Have Exported 10+
Commercial NPPs & Nuclear Research Facilities to Global Market
China National Nuclear Corporation

- National High-Tech Enterprise
- National Defense Science and Technology Award
- National Prize for Progress in Science & Technology
- CNNC Performance Award for Outstanding Contributions

Ranks 89 in the 2018 ENR List of International Contractors

2014 - 149
2018 - 89

2014 - 110
2018 - 96
Integrated Solution

**Industrial Solution**
- Equipment Supply
- Nuclear fuel Supply
- Localization

**NPP Project**
- Advanced NPP design
- NPP construction and life cycle management support
- Life extension & Consulting
- Operation & Maintenance support
- Various Contract Models (EPC, EPCM, BOT, BOO, PPP etc.)

**Nuclear Management**
- Infrastructure Establishment
- Site selection
- Project Management

**Financial Solution**
- Government support
- Flexible Financing Options

**Nuclear Technology Transfer**
- Nuclear power
- Nuclear fuel

**HRD**
- HRD Services
- Joint educational program

**R&D**
- Cooperation in R&D
- Research and Test Facilities

**Equipment Supply**
- Nuclear fuel Supply
- Localization

**Advanced NPP design**
- NPP construction and life cycle management support
- Life extension & Consulting
- Operation & Maintenance support
- Various Contract Models (EPC, EPCM, BOT, BOO, PPP etc.)
Project Solution

Self-Reliance Generation III nuclear technology Series (HPR1000, ACP600, ACP100, HTR-200, HTR-600)

Various Contract Models (EPC, EPCM, BOT, BOO, etc.)

Technical Services covering the entire fuel cycle (Feasibility Study, Technical Consulting, Life Extension, Plant Modification, NPP operation & Maintenance, HRD etc.)
• Necessary knowledge and skills identified
• Develop and maintenance of HR base planned
• HRD master plan for nuclear new build
• Training, Technical exchanges and educational program

• Localization Guideline
• Joint assessment of local industries
• NPP technology development plan
• Cooperation proposal on localization

• Survey of potential sites
• Selection of candidate sites
• Site Characterization, etc
1. Nuclear Energy in China
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Roadmap of HPR1000 R&D

1999
- CNP1000
  - Gen II+
  - 157 FAs in reactor core
  - Twin-unit layout
  - Single containment

2007
- CP1000
  - Gen III-
  - 177 FAs in reactor core
  - Single-unit layout
  - D.-shell containment
  - Other 19 improvements

2010
- ACP1000
  - Gen III+
  - Active + passive safety systems
  - SA countermeasures
  - Protection against external hazards
  - Fukushima feedbacks
  - Latest safety requirement

2013
- HPR1000
  - Gen III+
  - Twin-unit layout
  - Single containment

CNP1000
- Gen II+
- 157 FAs in reactor core
- Twin-unit layout
- Single containment
3rd Generation PWR
Satisfying latest nuclear safety codes and standards with advanced technology

3 Design Improvements
• 177-fuel-assembly core
• Single unit layout
• Double shell containment

Active + Passive Systems
• Residual heat removal from secondary side
• Containment heat removal
• Cavity injection and cooling
• Emergency core cooling

3 Enhanced Protection Capabilities against
• Seismic
• Commercial aircraft crash
• Plant emergency
### General Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Reactor Core Thermal Output</td>
<td>3050 MWt</td>
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<tr>
<td>Nominal Power</td>
<td>$\geq 1150$ Mwe</td>
</tr>
<tr>
<td>Design Life</td>
<td>60 years</td>
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<tr>
<td>Fuel Assembly Number</td>
<td>177</td>
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<tr>
<td>Refueling Cycle</td>
<td>18 months</td>
</tr>
<tr>
<td>Average Availability</td>
<td>$\geq 90%$</td>
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<tr>
<td>Nuclear Island Layout</td>
<td>Single-unit</td>
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<tr>
<td>Containment</td>
<td>Double-shell</td>
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<tr>
<td>Final Waste Volume</td>
<td>$&lt; 50$ m$^3$/unit·year</td>
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<tr>
<td>Safe Shutdown Earthquake (SSE)</td>
<td>0.3g</td>
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<tr>
<td>Load Following Capability</td>
<td>Yes</td>
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<tr>
<td>Operator Nonintervention Period</td>
<td>30 mins</td>
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<tr>
<td>Plant Autonomy</td>
<td>72 hours</td>
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<tr>
<td>Occupational Exposure Dose</td>
<td>$&lt; 1$ m·Sv/reactor·year</td>
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<tr>
<td>Safety Systems Concept</td>
<td>Active &amp; Passive</td>
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<tr>
<td>CDF</td>
<td>$&lt; 10^{-6}$</td>
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<tr>
<td>LRF</td>
<td>$&lt; 10^{-7}$</td>
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</table>
Active + Passive Safety Design

Active: proven and reliable

Passive: no need for power

Active + Passive: diverse approaches to perform safety functions

- Emergency core cooling
- Core residual heat removal
- Cavity flooding and cooling (IVR)
- Containment heat removal
BDBA/SA Prevention & Mitigation Measures

- Passive Containment Heat Removal
- Containment Hydrogen Combination
- RPV High-point Venting
- Fast Depressurization
- Passive Residual Heat Removal (Secondary Side)
- Containment Filtration and Exhaust
- Cavity Injection and Cooling
- IRWST
BDBA/SA Prevention & Mitigation Measures

**Phenomena**
- Hydrogen detonation
- High pressure molten corium ejection, DCH
- Long term overpressure
- Basement melt-through
- Station blackout
- Other

**Countermeasures**
- Containment Hydrogen Combination System
- Fast Depressurization System for RCS
- Passive Containment Heat Removal System, Containment Filtration and Exhaust System
- Reactor Cavity Injection and Cooling System
- Passive systems, Diverse power sources
- RPV High-point Venting System, Habitability Design of Main Control Room, SAMG and etc.
Fukushima Feedback

- Additional emergency water makeup and associated interfaces
- Extension of nonintervention period
- Spent fuel pool monitoring and cooling
- Improvements of power supply: SBO (Station Black Out) generator
- More conservative seismic margin
- Habitability and availability of emergency facilities
Diversity of Power Sources

- **Turbine generator**
  - During normal operation

- **Two trains of independent Off-site power**
  - If turbine tripped

- **Trains of diesel generators for each unit**
  - As emergency power

- **SBO Diesel Generator**
  - In case of SBO

- **Extra diesel generator**
The configuration and operation of normal operating systems and “active” engineered safety features have been validated by long term engineering practice from existing PWR NPPs.

The design concept and technologies adopted for “passive” systems have been verified by natural science or specific experiments/tests.

The manufacture and supply capability of almost all key equipments/components is compatible with existing NPPs.

Benefiting from rich construction experience and outstanding feedback of operating experience, the construction period and performance of HPR1000 can be ensured.
- All the key equipments based on mature technology and proven
- Equipments compatible with existing manufacturing capability
Passive Systems Verification Test

- Test of Passive Containment Heat Removal System
- Test of Cavity Injection and Cooling System
- Passive residual heat removal test for secondary side
Fuqing NPP Unit 5

- 2015.05.07 FCD
- 2017.05.25 Dome in place
- 2017.10.12 Polar crane available
- 2019.01 Installation of NI main equipment completed
- 2019.4.28 Cold test successful
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HTR is a helium-cooled, graphite-moderated reactor with full ceramic coated particle spherical fuel elements.

Helium is heated to 750°C in the core and sent to the steam generator.

Feed-water is heated to 571°C high temperature steam in the steam generator unit to generate electric power.
- **Thermal Power of Reactor**: 6×250MWt
- **Reactor Inlet Temperature**: 250/750°C
- **Helium Working Pressure**: 7 MPa
- **Steam Generator’s Outlet Steam Temperature/Pressure**: 571°C/13.9MPa
- **Power Generation**: 660MWe
- **Power Efficiency**: 42%
- **Nuclear Safety Feature**: Core Melt Free
High Performance Fuel Elements

- Contain all radioactive substances to prevent from releasing
- No need of offsite emergency technically
- Four layers of high temperature resistant materials which has excellent high temperature performance
- The highest temperature of fuel elements will not exceed the safety limit 1620°C under any operation or accident condition

Negative Temperature Coefficient of Reactivity

- HTR is the Generation IV advanced nuclear reactor with inherent safety.
- Even if under severe accident condition, such as station black out and all safety measures failure, the reactor would automatically shutdown because the negative temperature coefficient of reactivity inhibits power up quickly.
Low Core Power Density

The Highest Temperature Curve of Cladding Surface after Loss of Coolant

- **Beginning**
  Because of HTR’s low core power density, large thermal inertia and slow temperature responses, core temperature rises slowly for dozens of hours.

- **Middle**
  The residual heat falls below the heat removal capacity. As a result, the temperature of core gradually goes down.
HTR utilizes multi-module combination to gradually expand the capacity and flexibly meet different market demands.

Based on standardization and serialization of equipment production, the construction period is shortened and economic efficiency is improved.
On-line Refueling

Sphere fuel elements are used in HTR-PM power plant and fuel cycling and handling is conducted without shutdown of the reactor.
Thanks for your Attention!