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A China's Multi-purpose SMR-ACP100 Design and Project Progress

Dr. Danrong Song
Nuclear Power Institute of China
China

31 August 2022

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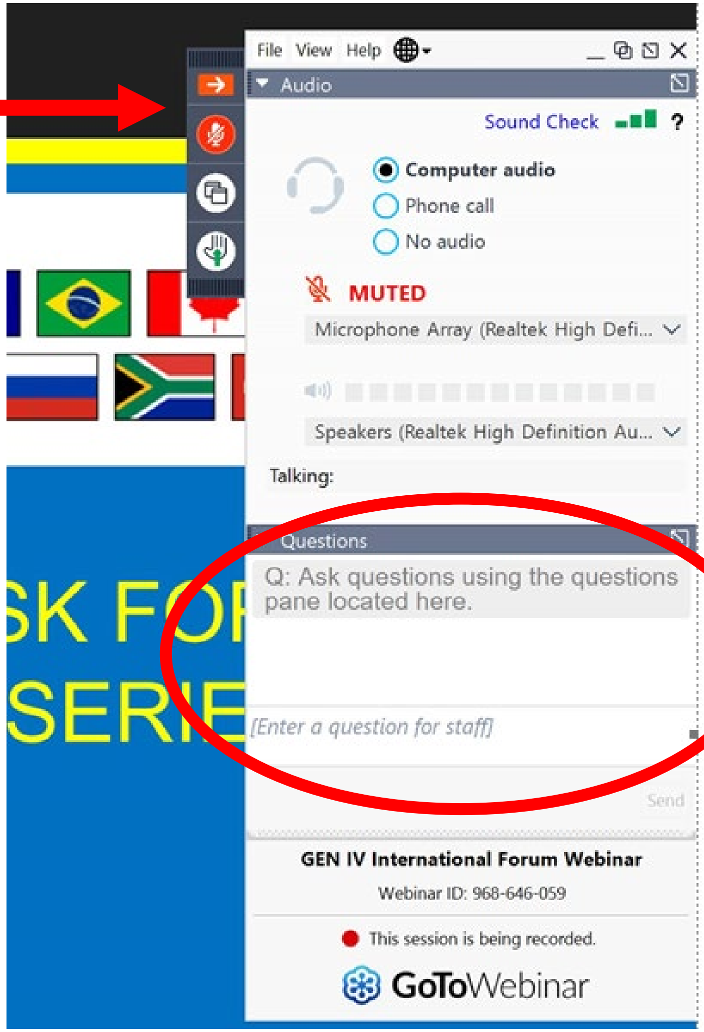

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Meet the Presenter

Dr. Danrong SONG is the chief designer at the Nuclear Power Institute of China. Dr. Song earned his Bachelor of Science Degree in Mechanical Engineering in 1991, his Master's Degree of Business Administration in 2003, and his Doctoral Degree in Nuclear Science and Engineering from the Nuclear Power Institute of China in 2009. Currently, he works as the Chief Designer of the SMR demonstration project ACP100 in China. Dr. Song specializes in small and medium reactor overall design, isotopic production reactor overall design, seawater desalination, and low temperature nuclear heating plant feasibility studies.

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Contents

Background

- （1-1）What is a Small Modular Reactor (SMR)？
  - SMR is a one kind of newer generation reactor designed to generate electric power up to 300 MW, whose components and systems can be shop fabricated and then transported as modules to the sites for installation.

Background

- (1-2）What is a Small Modular Reactor (SMR) ?
  - By adopting modular designs and construction concepts, the SMR is a passive safety technology.
  - Can reach high power by several modular combination.
  - Can be used in different places and in different conditions.

Background

- (2) Challenges in Increasing Large Nuclear Power Plant Power
  - Industry capacity and transportation
  - Marginal effect on the economy by increasing power
  - Difficulty with application of passive technology
  - Huge overnight investment
  - Not flexible for alternative use

Background

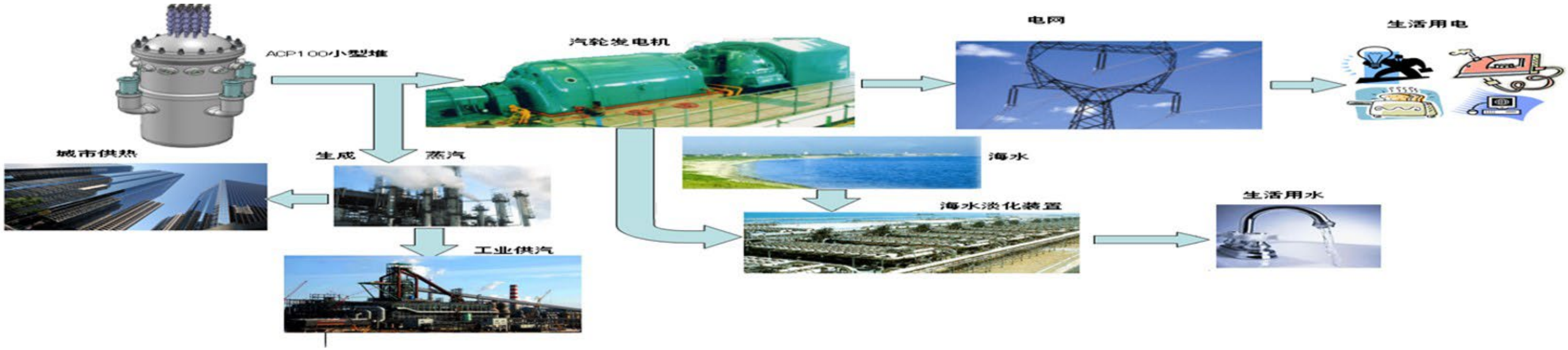
- （3）Nonelectrical applications for nuclear energy and the needs of developing countries for nuclear electricity
  - In 10 to 20 years，70% of the energy consumption in developing countries will be nonelectrical in application, such as heat and transportation.

Background

- （4）Improving the economy by modular design and construction
  - Not like that of large nuclear power plants, the SMR achieves its economic by simplifying modular design and increasing the number of the modular.
- （5）Advantage for safety
  - SMRs with lower power and lower residual heating are suitable for passive safety facilities application.

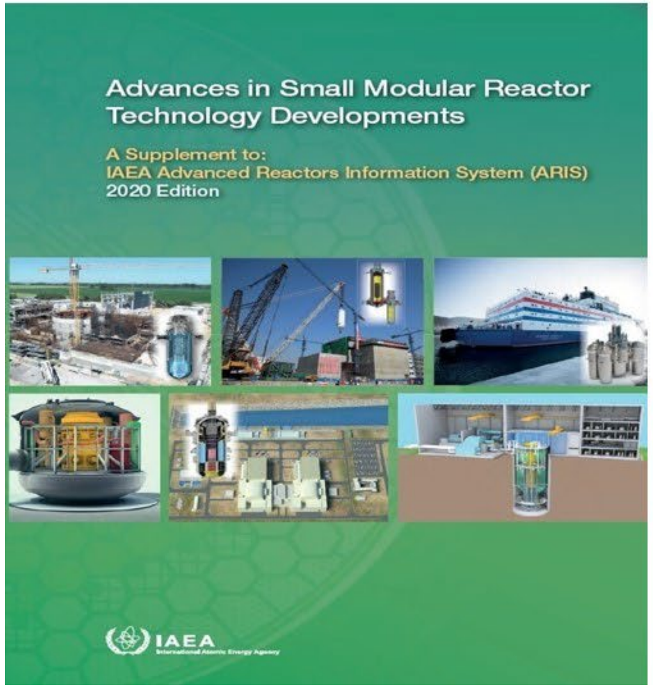
Background

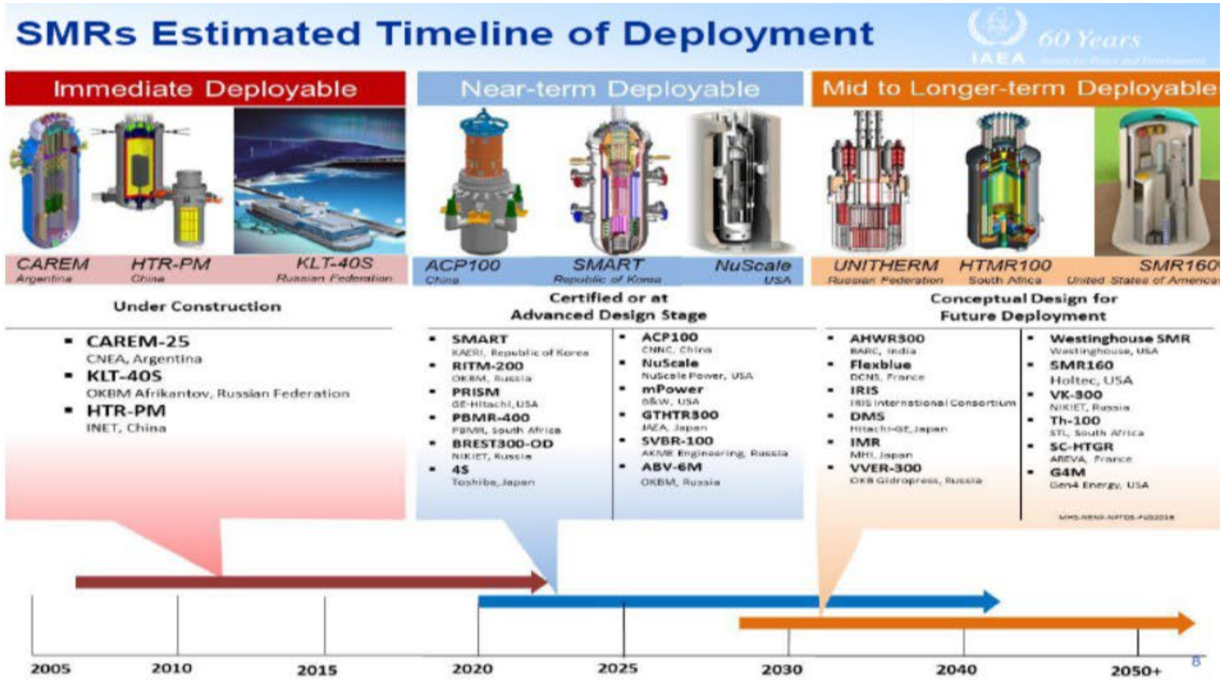
- The SMR is suitable for a small electricity grid, district heating, process heating supply, seawater desalination. According to varying conditions, different countries have different goals.



Background

- Mainly developed and innovated SMR in different countries
- 2020 SMR book gives 72 reactors in 18 countries, 1/3 are PWR, and most of them are integrated reactor





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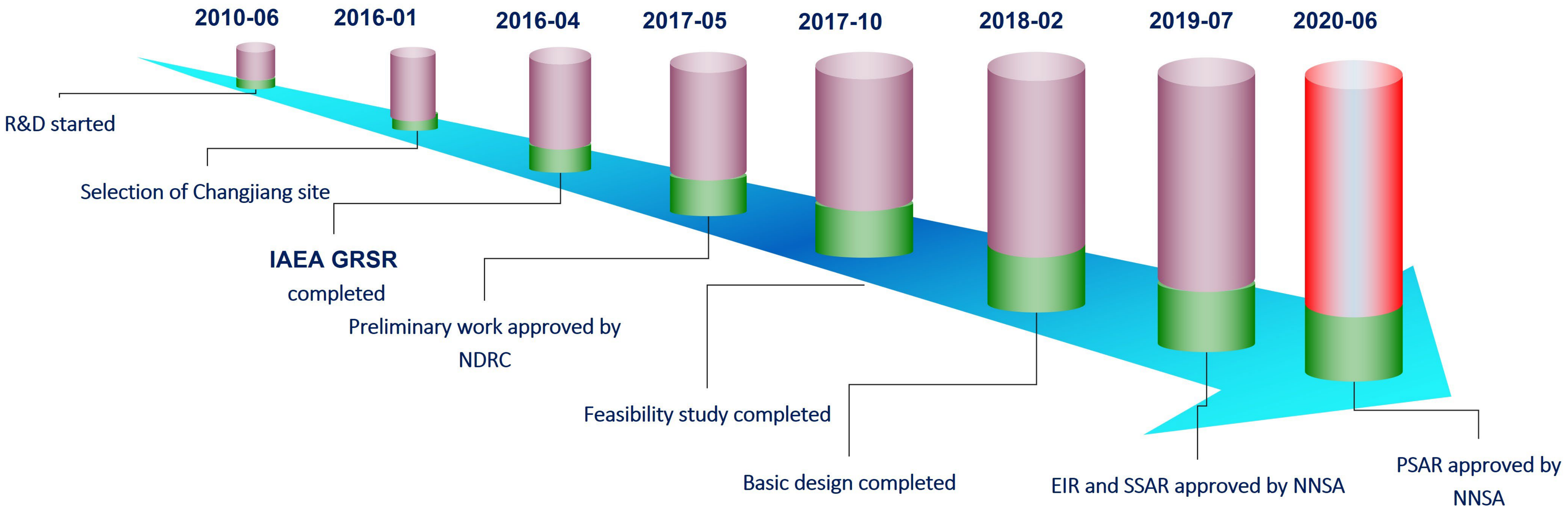
Introduction of ACP100

- CNNC SMR, named ACP100, is an innovative PWR based on existing PWR technology, adapting “passive” safety system and “integrated” reactor design technology
- CNNC started R&D on ACP100 in 2010
- The modular design technique is used to control the product quality and shorten the site construction period.

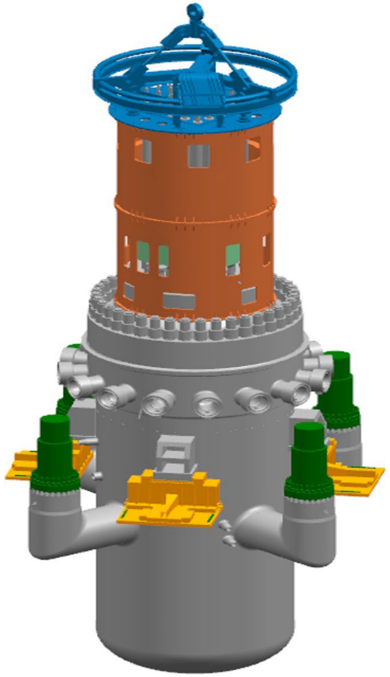
Introduction of ACP100

Roadmap of ACP100 development



Design parameters of ACP100

Main design parameters



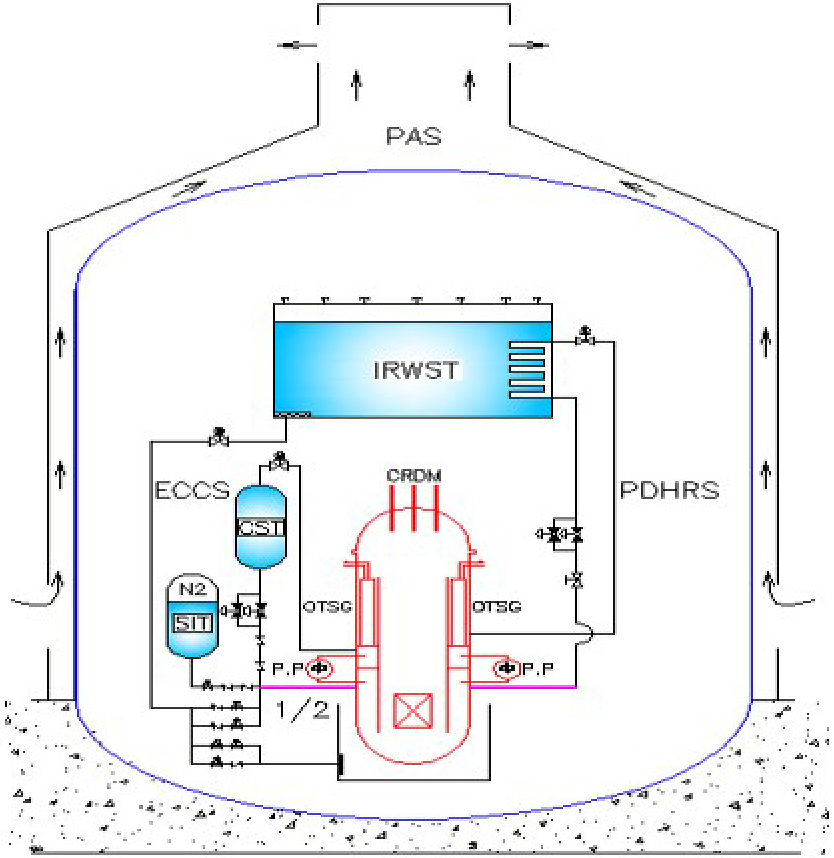
ACP100

Thermal power	*385MWt*
Electrical power	*～125MWe*
Design life	*60 years*
Refueling period	*2 years*
Coolant inlet temperature	*282 ℃*
Coolant outlet temperature	*323 ℃*
Coolant average temperature	*303 ℃*
Best estimate flow	*10000 m^3/h*
Operation pressure	*15MPaa*
Fuel assembly type	*CF3 shortened assembly*
Fuel active section height	*2150 ㎜*
Fuel assembly number	*57*

Design parameters of ACP100

Main design parameters

Fuel enrichment	4.45%
Drive mechanism type	Magnetism lifting
Control rod number	25
Reactivity control method	Control rod、solid burnable poison and boron
Steam generator type	OTSG
Steam generator number	16
Main steam temperature	>290 ℃
Main steam pressure	4.5MPaa
Main steam output	560t/h
Main feed water temperature	105 ℃
Main pump type	canned pump
Main pump number	4



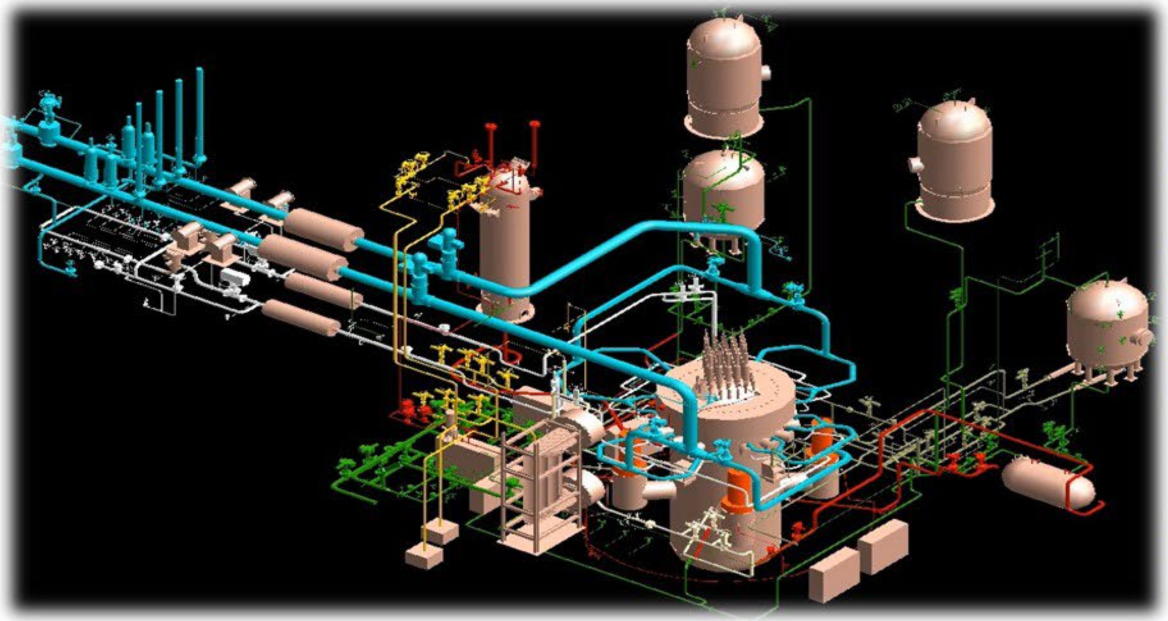
Design parameters of ACP100

Main design parameters

Reactor power-control operation program	primary constant average temperature
Thermal power plant operation model	Base load operation（Mode-A)
Plant design life	60 years
SSE level ground seismic peak acceleration	0.3g
Predicted Core Damage Frequency (CDF)	＜1E-7 Per reactor year
Predicted Large Release Frequency (LRF)	＜1E-8Per reactor year

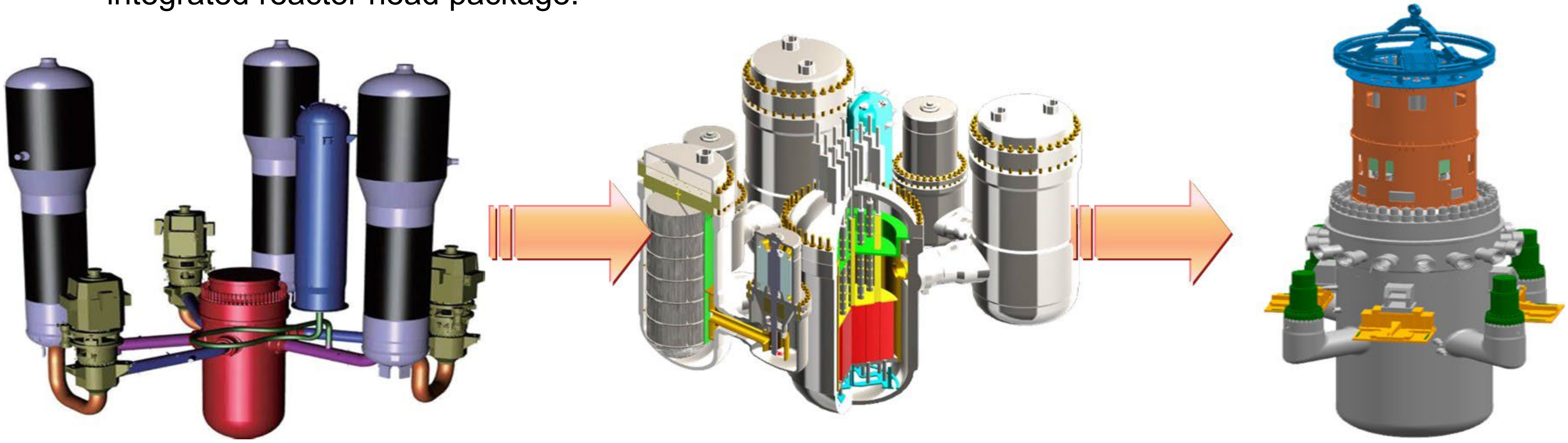
Design parameters of ACP100

- One reactor with one turbine



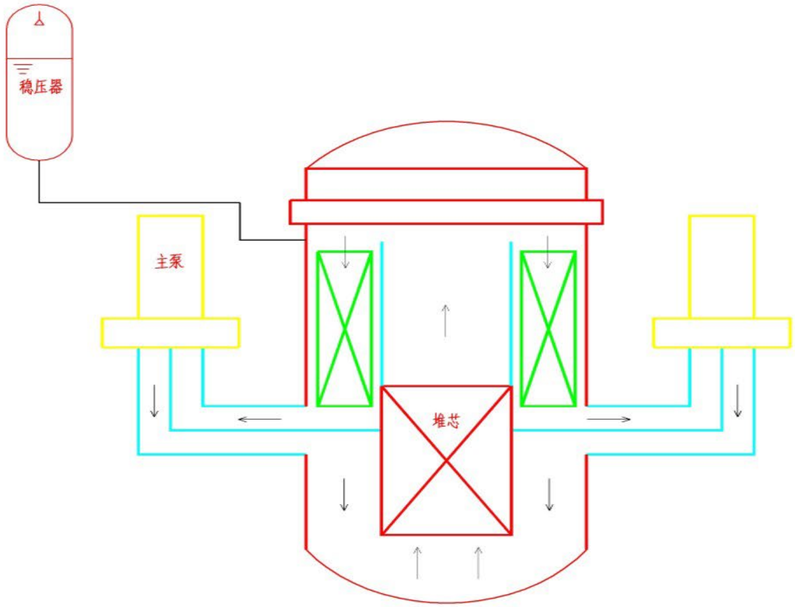
Technical Aspects

- Integral reactor module
  - The reactor coolant system has been integrated in the reactor module. The reactor module consists of a reactor vessel, once-through steam generators, canned motor pumps, reactor internals and an integrated reactor head package.



Technical Aspects

- (2) Reactor coolant system



反应堆冷却剂系统

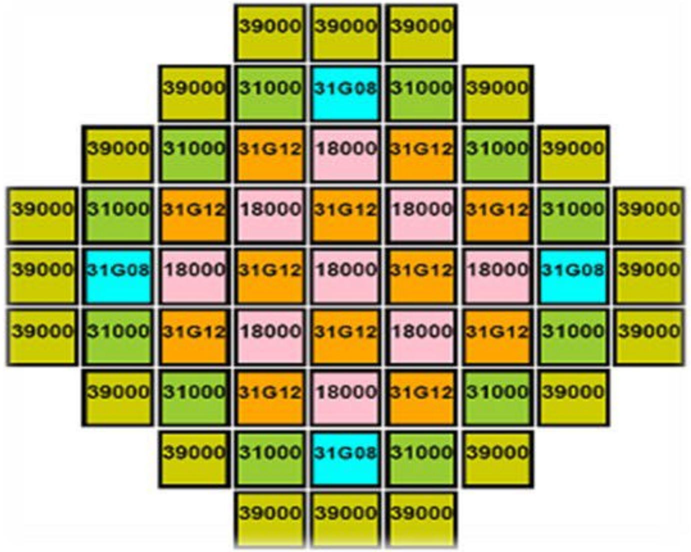
- system function and composition
  - 4 main pumps
  - 16 OTSG
  - 1 pressurizer

system description

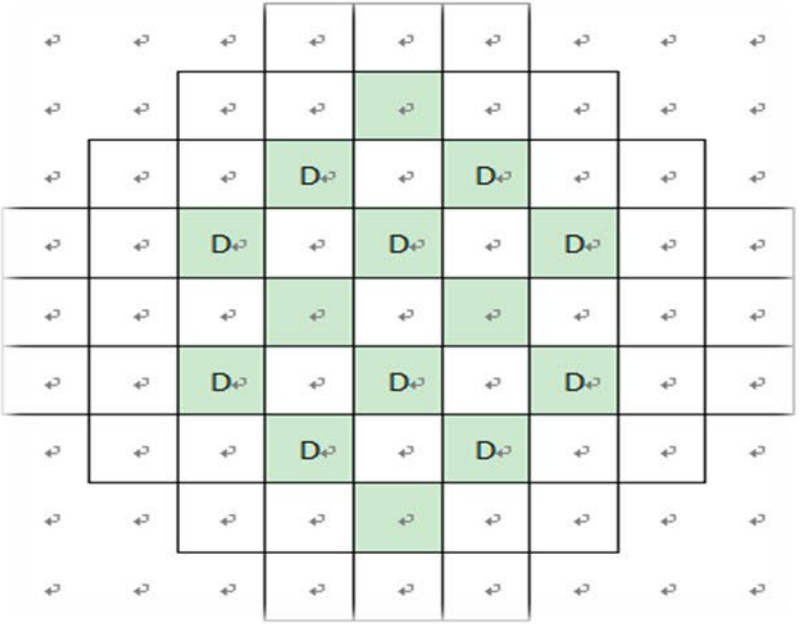
- operation pressure 15.0MPa
- core exit temperature 325℃

Technical Aspects

- (3) Reactor Core
  - 57 17X17 square fuel assembly with Gd2O3 solid burnable poison
  - Refueling period 24 months.



Core layout



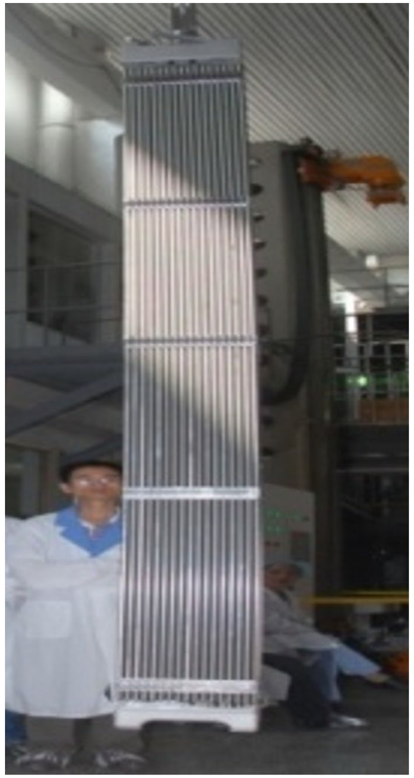
Advanced core detection system

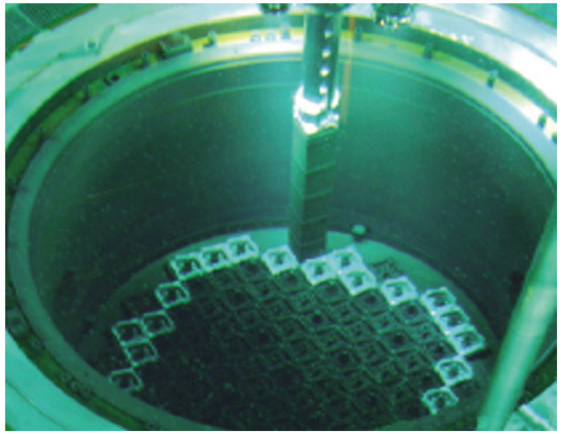
Technical Aspects

- (4) CRDM
  - step：15.875mm/min
  - max travel speed：72mm/min
  - electromechanical delay time ：≤150ms
  - temperature：200℃
  - pressure housing design life：60 years
  - Min. cumulative step number of non-service：6.0 E 6 steps

Technical Aspects

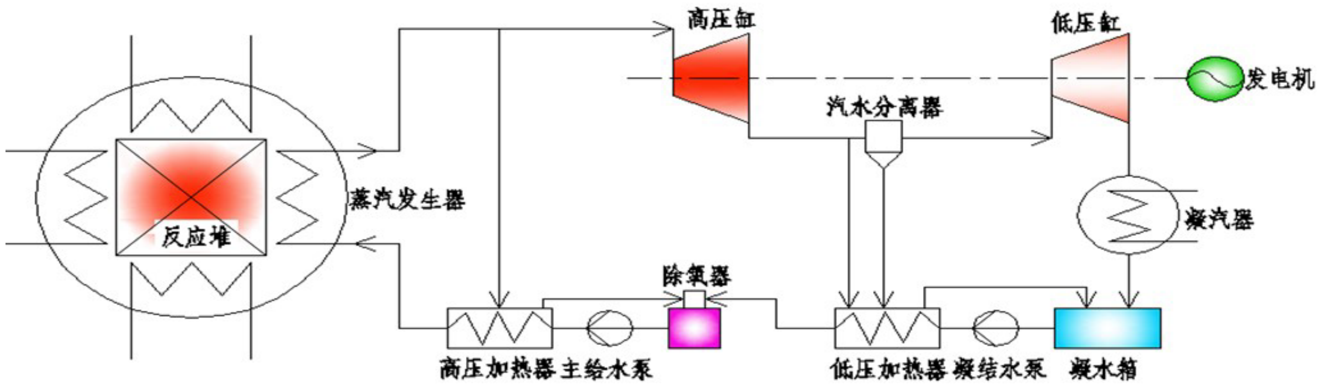
- (5) Fuel assembly
  - 17×17 square arrangement
  - Fuel rod：264
  - guide tube： 24
  - instrumentation tube： 1
  - total height: ～2500mm
  - active length: 2150mm





Technical Aspects

- (6) Main steam system
- system function and composition
  - main steam system
  - bypass system
  - moisture separator reheat system



- system description
  - operation pressure 4.5MPa
  - Temperature 285℃

Technical Aspects

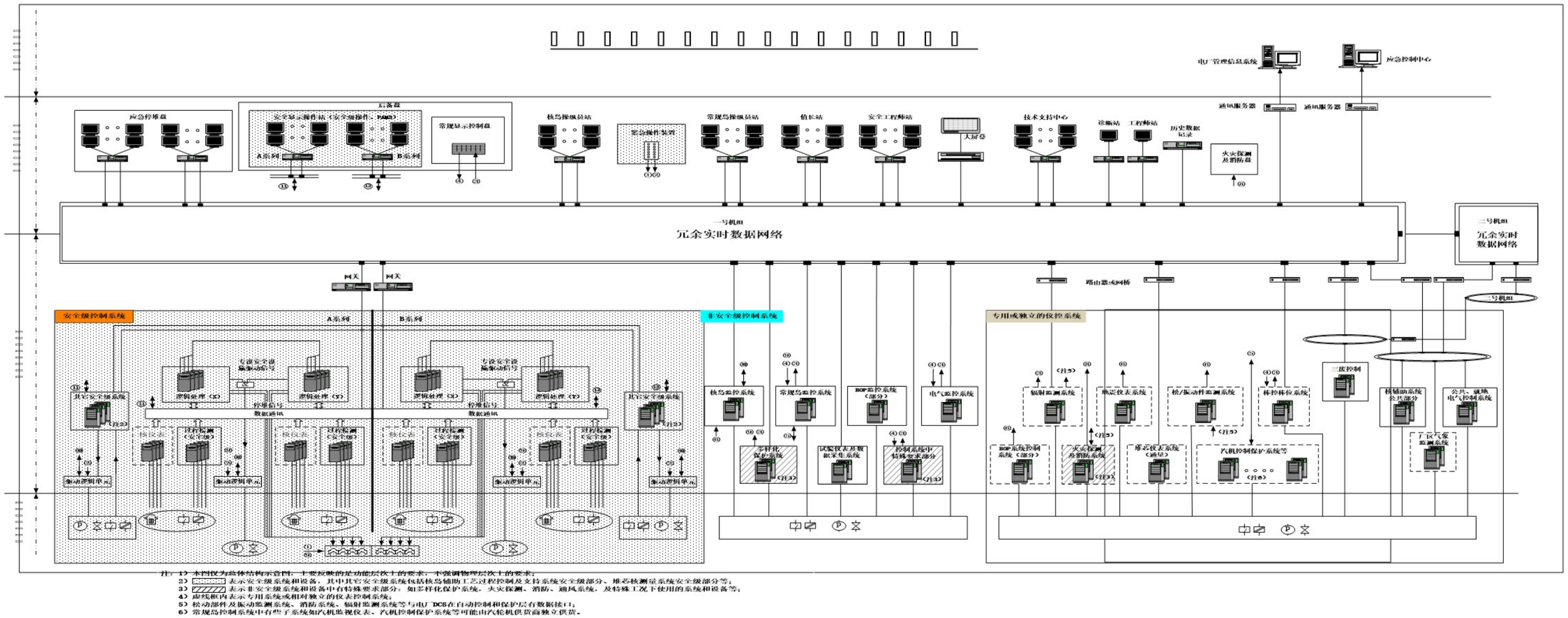
- (7) I&C system
- Functionally divided into 4 layers ：

  0. Interface layer

  1. Auto control and covering layer

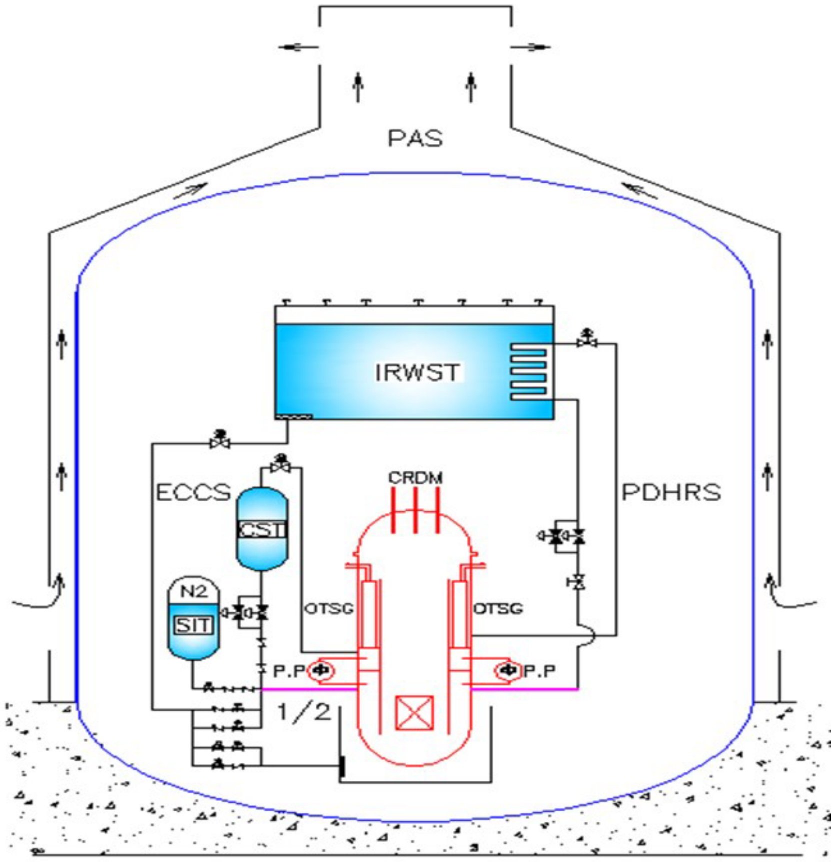
  2. Operation and management information layer

  3. Plant technical management layer



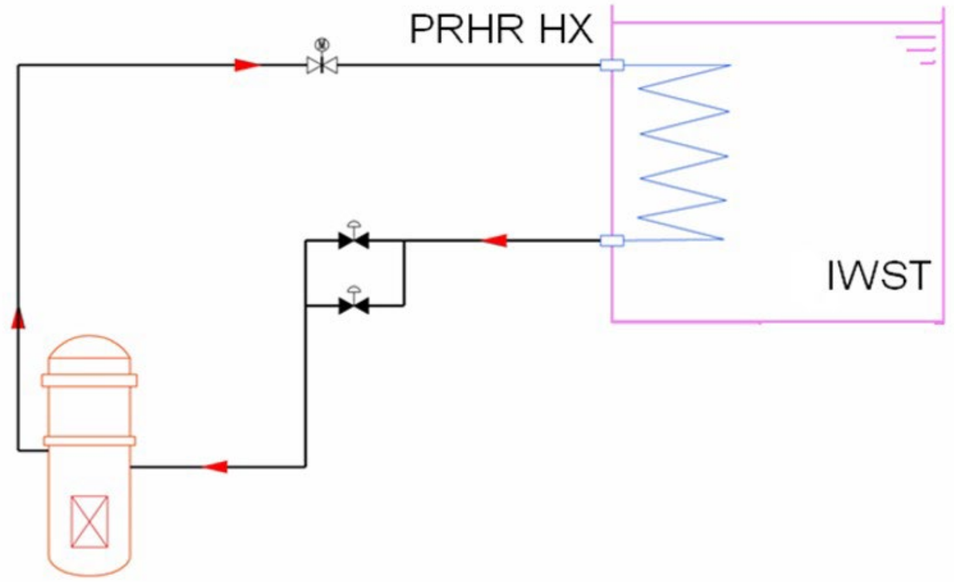
Technical Aspects

- (8) Fully passive safety system
- ACP100 adopts a fully passive safety system, which is illustrated in the figure:
  - passive core cooling system,
  - passive residual heat removal system
  - passive containment heat removal system
  - passive inhabitation system,
  - automatic depressurization system
  - passive hydrogen control system



Technical Aspects

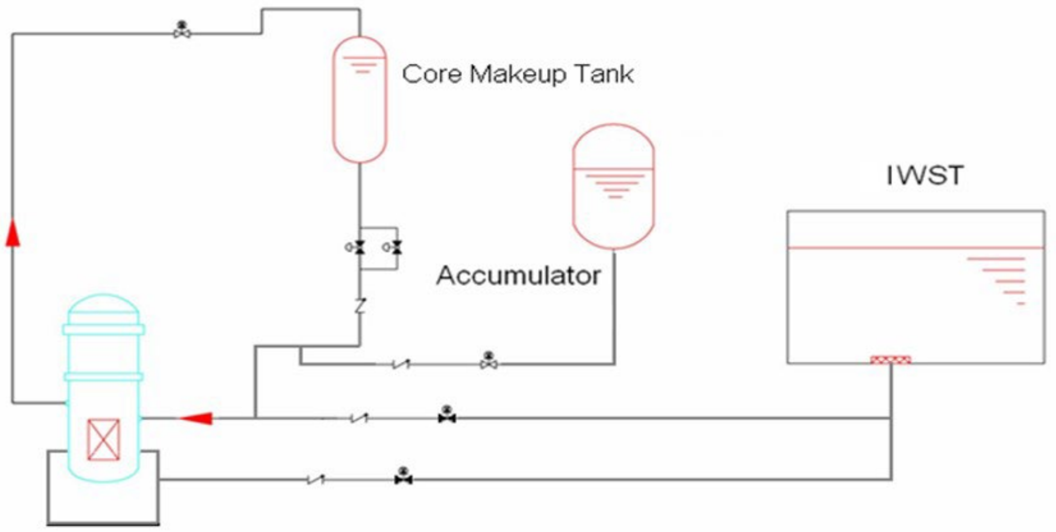
- (9) Passive residual heat removal system
  - The heat exchanger is mounted in the IWST. HX is usually filled with coolant.
  - Natural Circulation or if the RCPs are running, forced flow through the HX.
  - Flow through the HX-tubes from the RCS transfers heat to the IWST contents.



Passive Residual Heat Removal system

Technical Aspects

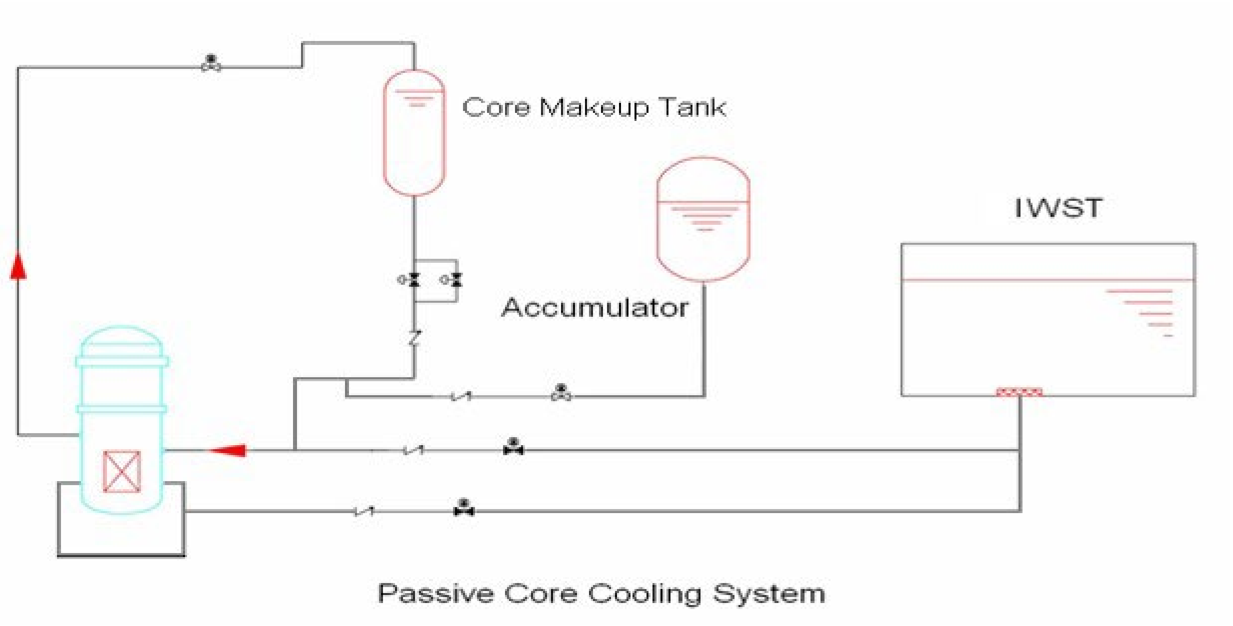
- (10) Passive core cooling system
  - Provides the Reactor coolant system emergency makeup.
  - Safety injection: Provide adequate core cooling for the SBLOCA (i.e., SGTR) by:
    - CMTs
    - Accumulators
    - IWST
  - After CMTs, Accumulators, & IWST have injected, containment is flooded sufficiently to provide recirculation flow.



Passive Core Cooling System

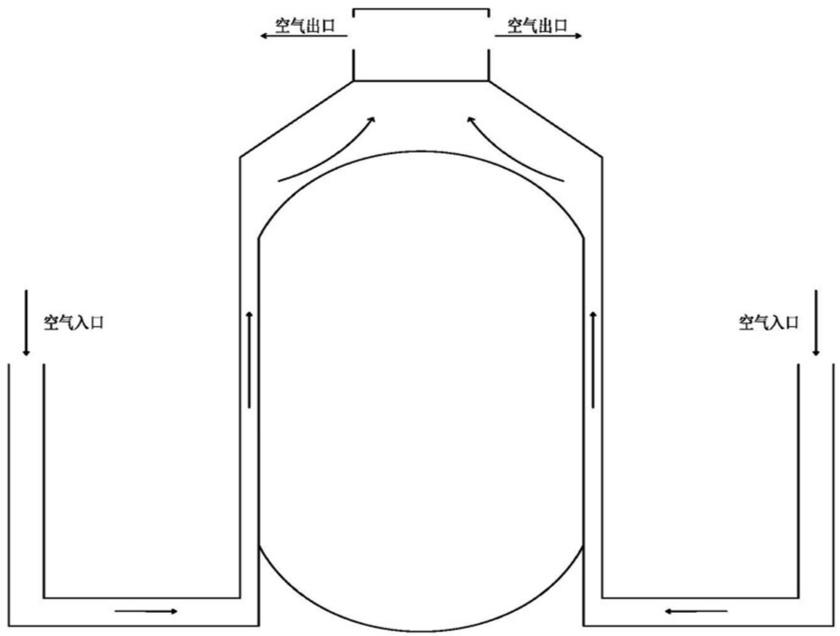
Technical Aspects

- (11) Passive Reactor Cavity Flooding System
  - Provides a means of external reactor vessel cooling under assumed severe accident condition.
  - Prevents the core from melting



Technical Aspects

- (12) Passive containment cooling system
  - Provides long-term heat removal from the containment in the case of any DBA & BDBA, including those associated with blackout and spray system failure; Steam condenses on containment HX.
  - Condensate collects in IWST/Sump via gutter arrangement.
  - Core heat is ultimately transferred through the containment HX into the surrounding atmosphere by natural circulation.



Technical Aspects

- (13) Other safety systems
  - Provide automatic depressurization (ADS) in the event of a SBLOCA
  - Passive combustible gas control in containment

Safety and licensing strategy

- Codes and Standards applied by ACP100
  - Level 1, Laws - Issued by the Congress (mandatory).
  - Level 2, Codes and Regulations - Issued by the State Council (mandatory). Setting up administrative scope, principles, organizations and its functions etc；
  - Level 3, Departmental Rules - Issued by governmental organizations (mandatory). Defining the implemental methods based on the Regulations. Setting up nuclear safety objectives and basic requirements；（NNSA)
  - Level 4, the Guides - Issued by the Governmental organizations (recommended). Recommending the methods or procedures to satisfy the safety requirements；
  - Level 5, Technical documents - Issued by the Governmental organizations (referential).

Safety and licensing strategy

Codes and Standards applied by ACP100

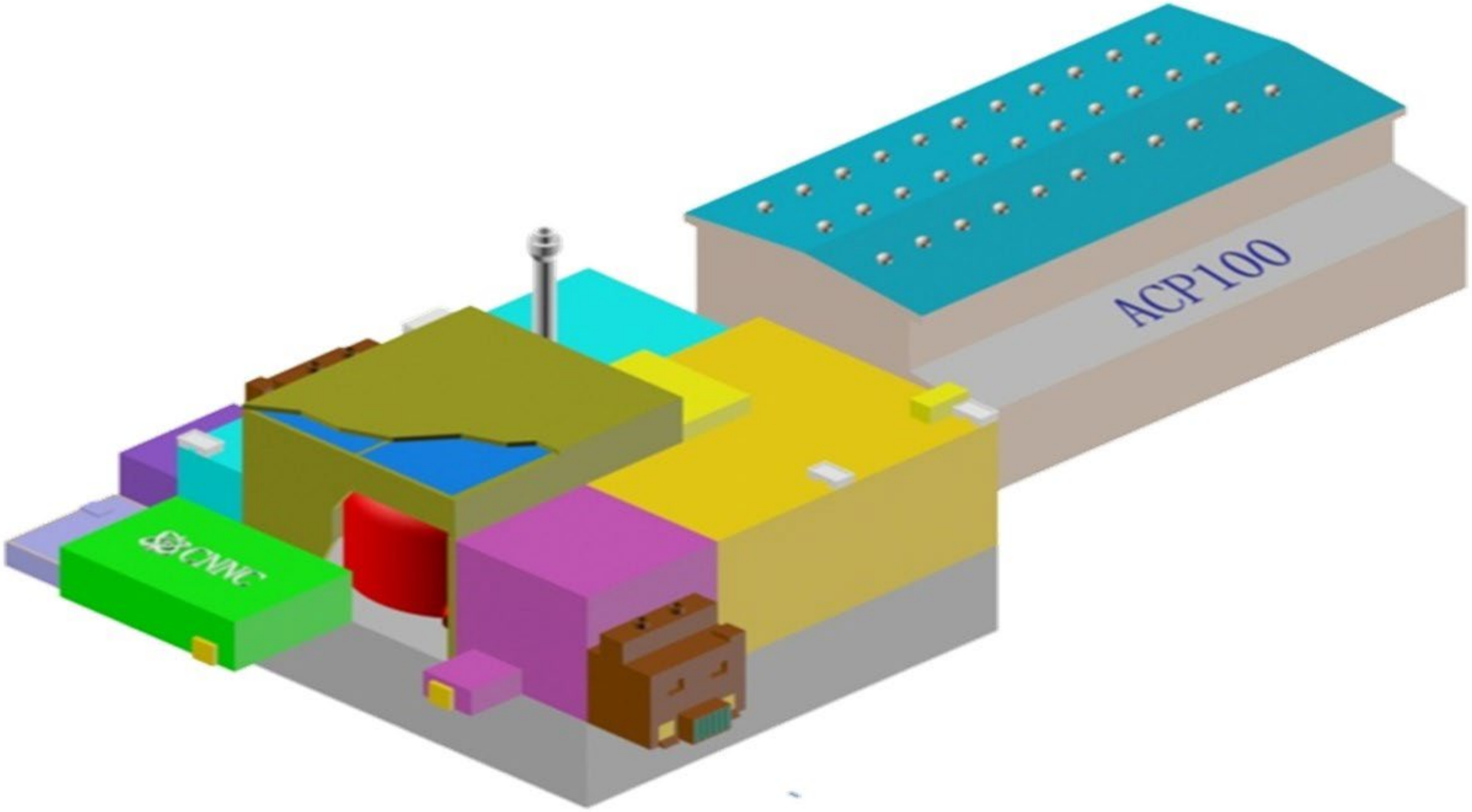
Safety and licensing strategy

- ACP100 Safety design conception
  - No active Emergency Core Cooling System
  - No active containment spray and recirculation system.
  - No need for operator intervention after accident for 72 hours.
  - No safety-related emergency AC power.
  - NSSS integral design minimizes both the probability and impact of design basic accident (DBA).
  - Mitigate DBA without non-safety system. Emergency planning zone is limited inside the site boundary.

Safety and licensing strategy

Safety design in defense-in-depth

- Defense in depth (DiD) is critical element of safety principles and has been incorporated into all the safety related activities to guarantee that those activities are protected under overlapped safety measures. 5 layers DiD measures are incorporated into ACP100 design



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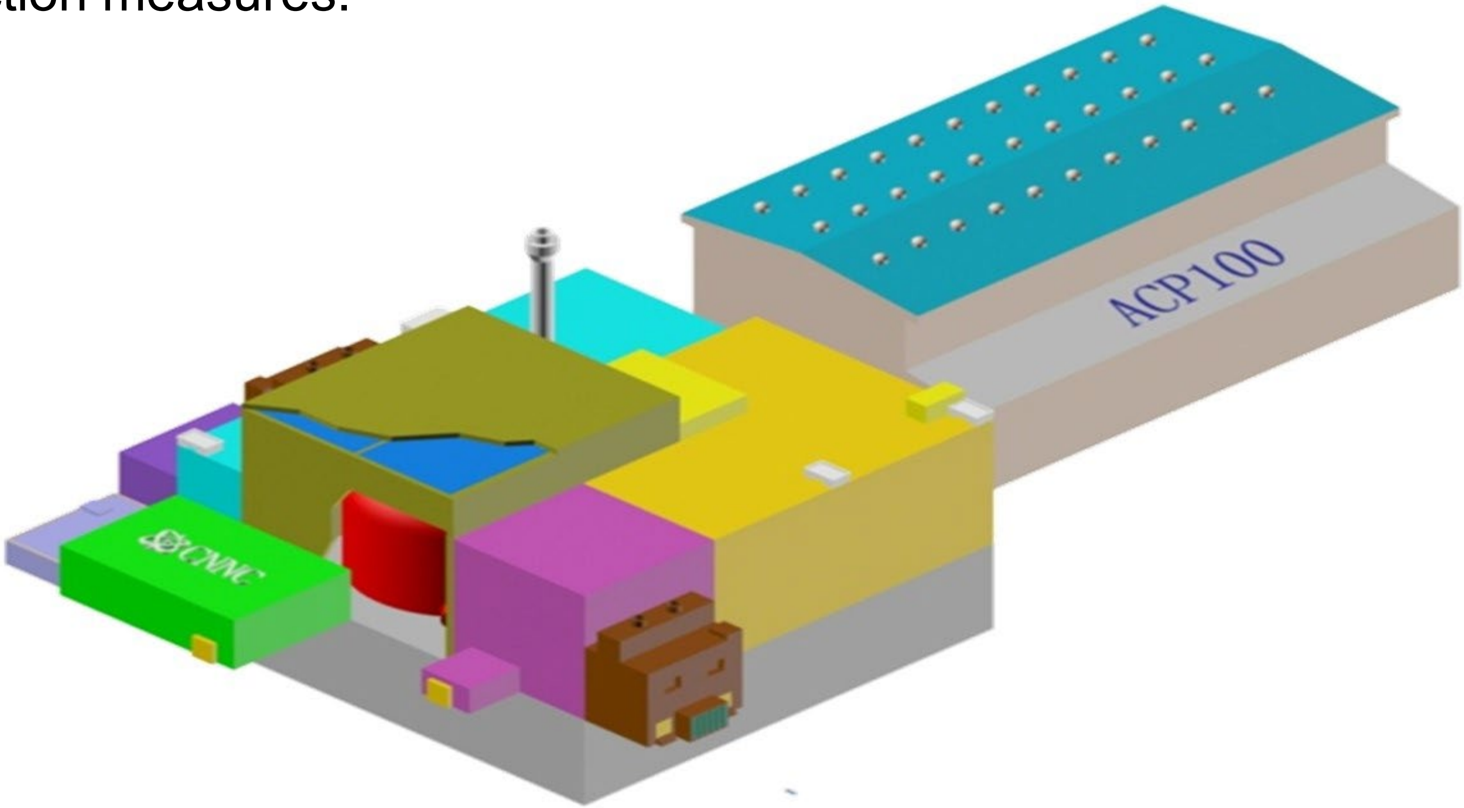
Safety and licensing strategy

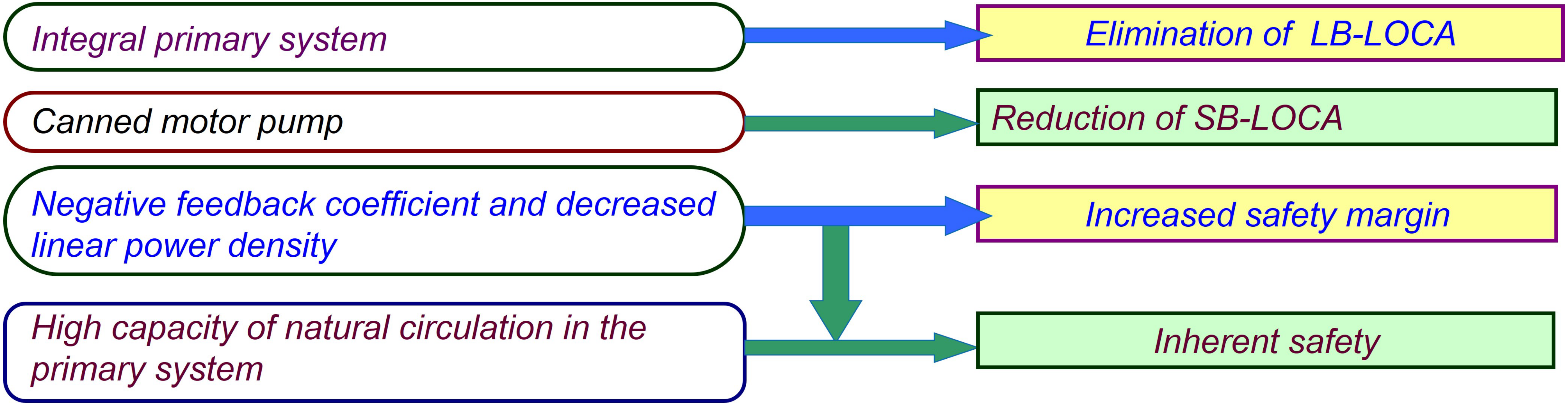
Safety design in defense-in-depth

- ACP100 has robust multiple physical barriers to prevent radioactive materials release. Those barriers are composed of fuel matrix, cladding, reactor coolant system barrier, containment and aircraft protective containment. ACP100 designs guarantee the effectiveness of every barrier and provide protection measures.



Safety and licensing strategy

Special design aspects



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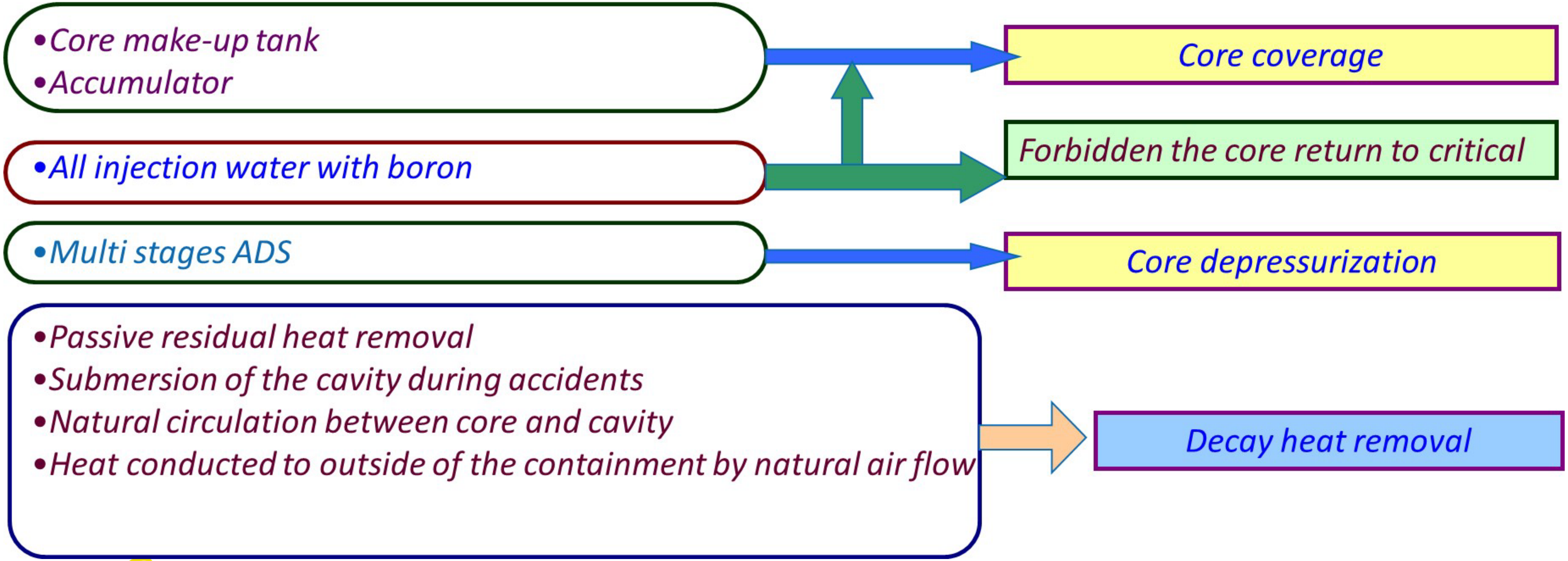
Safety and licensing strategy

Passive safety system



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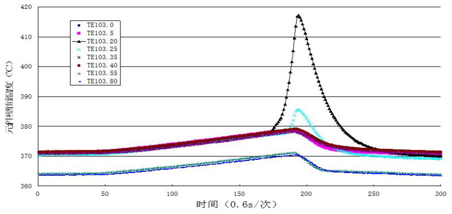
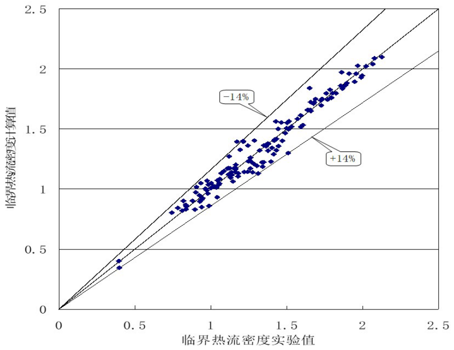
Safety and licensing strategy

Deterministic and Possibility Safety analysis

Deterministic Safety analysis

- *7 categories including 50 kinds of incidents and accidents*
- *15% of thermal margin achieved*

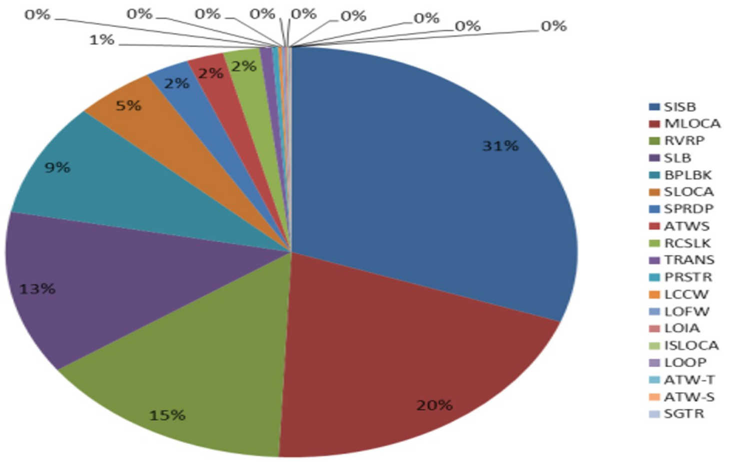




Possibility Safety Analysis (PSA)

CDF： 1.91×10^{-7}

LRF: 10^{-8} level



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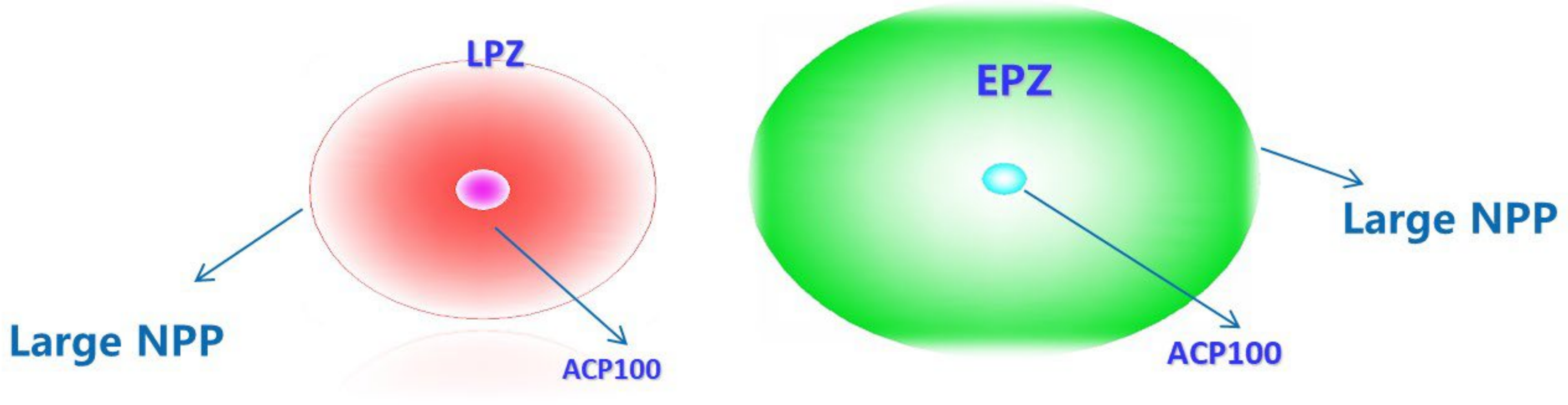
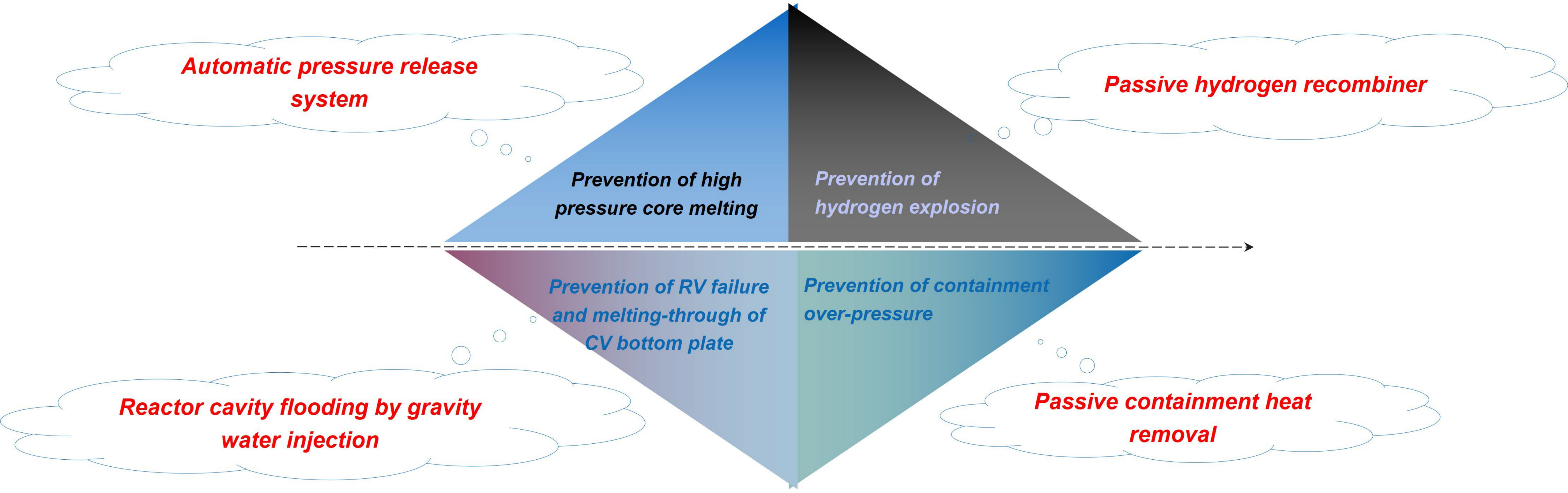
Safety and licensing strategy

- Non-residential Area and Planned Restricted Zone Study
  - Non-residential area (EAB): Less than 300 m; (for large reactor 500m)
  - Planned restricted zone (LPZ): Less than 500 m; (for large reactor 5km)
  - Emergency plan zone (EPZ): Internal zone Less than 500 m; (for large reactor 3~5 km) External zone Less than 600 m. (for large reactor 7~10 km)



Safety and licensing strategy

Severe accident prevention and Mitigation measures



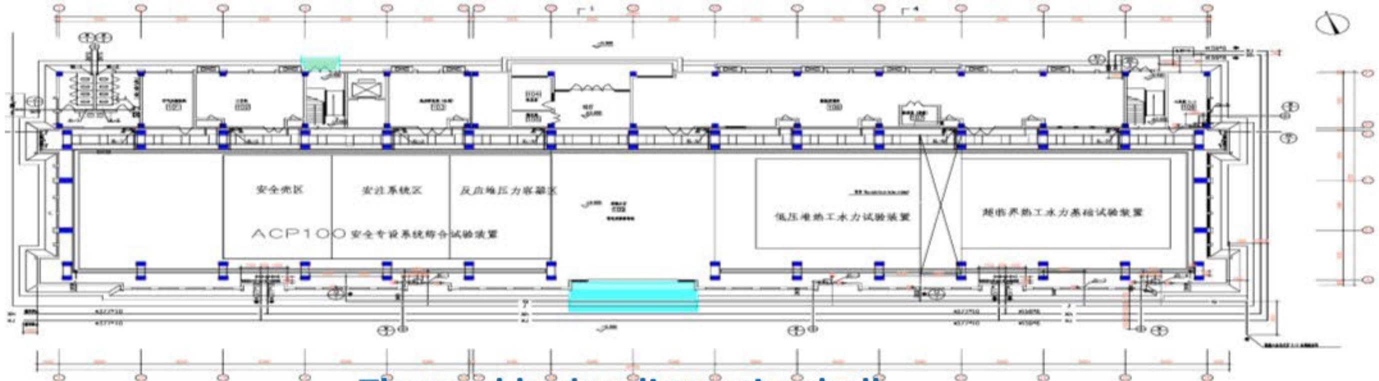
Safety and licensing strategy

- Third party verification
  - IAEA gave the review comments on ACP100 Generic Reactor Safety Review GRSR report on April 22, 2016, the 1st SMR completion of GRSR in the world.

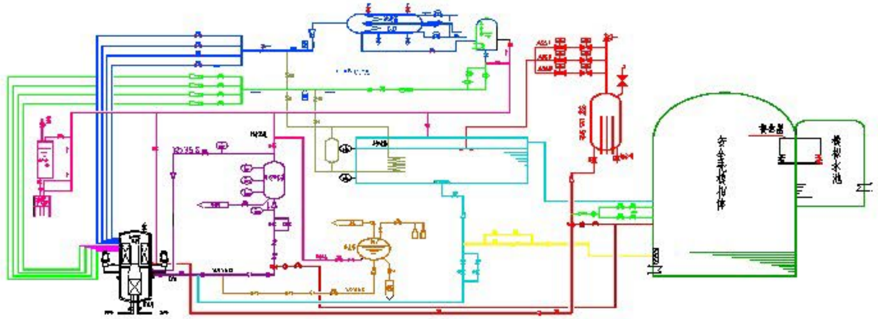
"According to the safety documentation, the ACP100 plant is an innovative design that belongs to the SMR class of NPPs and deploys passive safety features. It can be expected from new designs that they are capable of dealing with extreme environmental conditions and multiple failures to assure that early or large radioactive releases are practically eliminated. "

Testing & Verification

- Seven test research
  - Control rod drive line cold and hot test
  - Control rod drive line anti-earthquake test
  - Internals vibration test research
  - Fuel assembly critical heat flux test research
  - Passive emergency core cooling system integration test
  - CMT and passive residual heat removal system test research
  - Passive containment heat removal testing



Thermal hydraulic testing hall



Passive emergency core cooling system

Testing & Verification

- Seven test research
  - Control rod drive line cold and hot test
  - Control rod drive line anti-earthquake test

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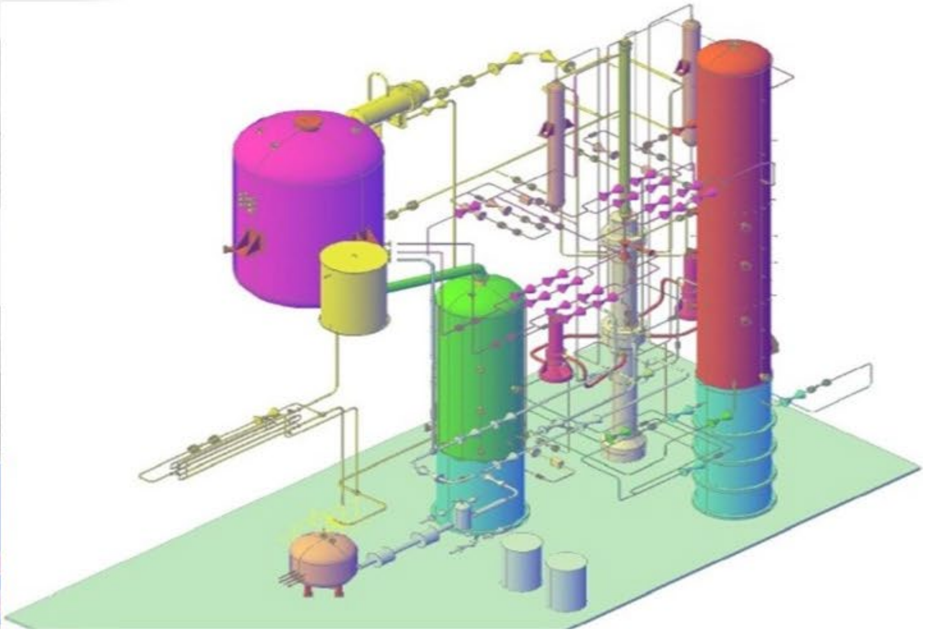
Testing & Verification

- Seven test research
  - Passive emergency core cooling system integration test
  - Over 3 years, CNNC has constructed the most comprehensive passive engineering safety system testing facility. Core cooling system integration testing, Passive residual heat removal system testing had finished on this facility



Testing & Verification

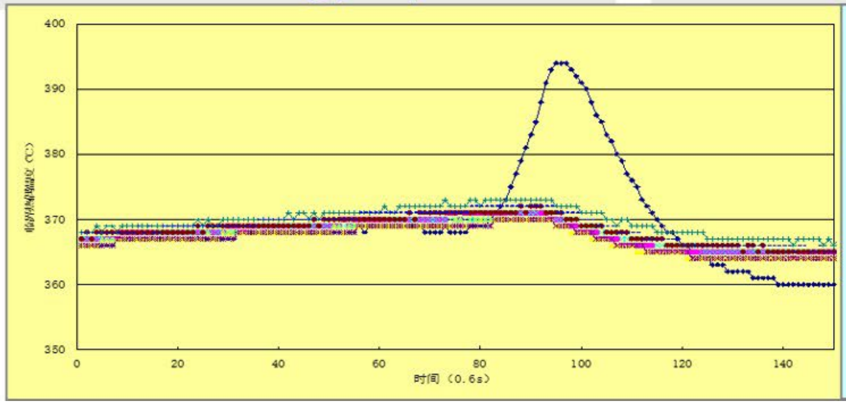
Seven test research

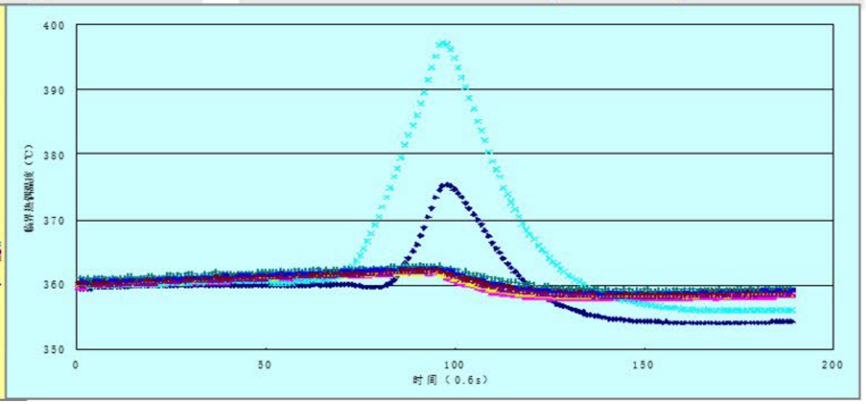
– Fuel assembly critical heat flux test research

CHF testing facility

CHF testing tube

CHF heating assembly





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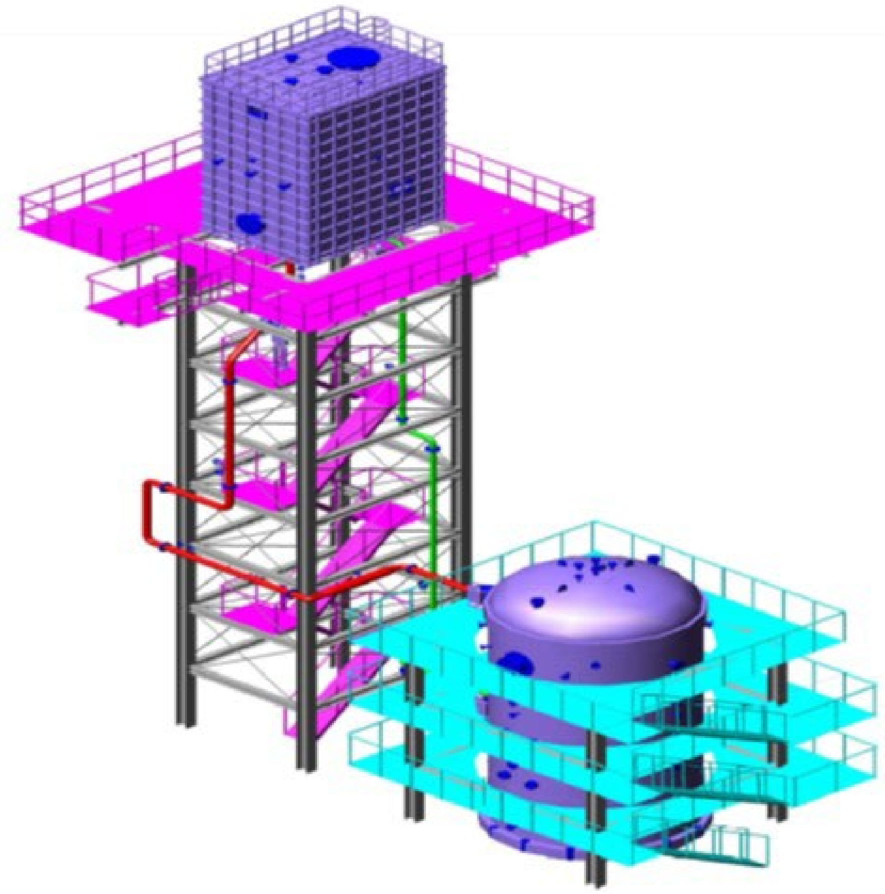
Testing & Verification

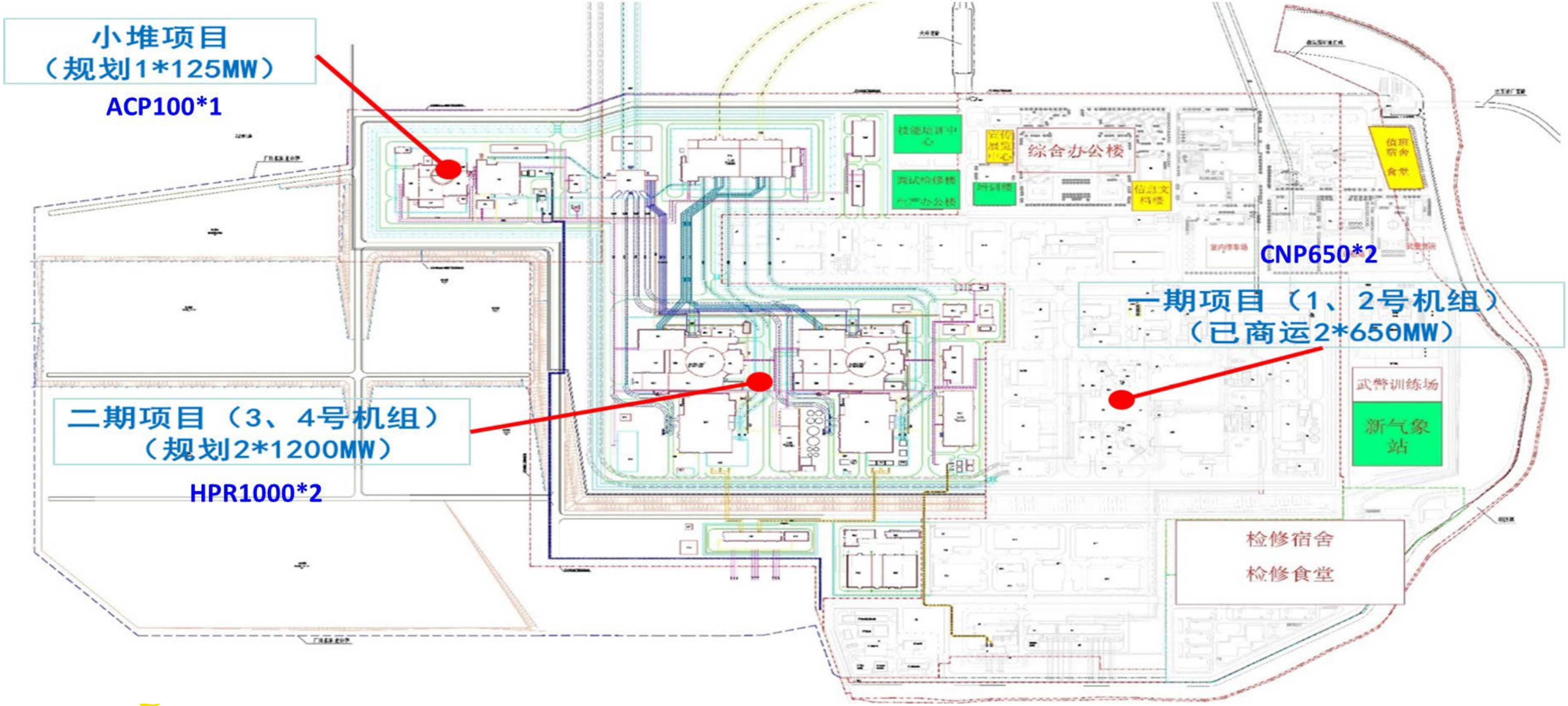
- Seven test research
- Passive containment heat removal testing
  - The results of the testing indicate the passive containment heat removal system is sufficient to conduct the heat to the ultimate heat sink



Demonstration project of ACP100

- Changjiang nuclear power site, Hainan, China, as illustrated in Figure, was chosen to build the first of a kind (FOAK) ACP100 demonstration project.
- FCD in July, 2021.
- Construction period of FOAK 55 months, target commercial operation in 2026

Demonstration project of ACP100



Demonstration project of ACP100

- Major equipment, such as the Reactor Pressure Vessel, steam generator and turbine generator are already in the manufacturing stage.

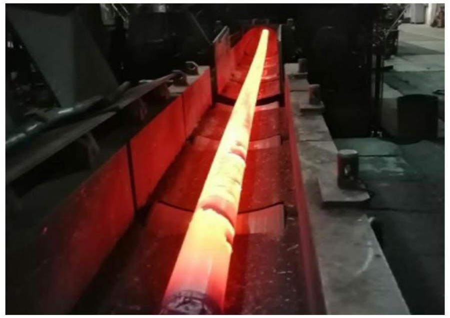

RPV主泵接管锻件


RPV支承段筒体堆焊


RPV容器法兰堆焊


RPV主泵接管待堆焊


主泵试验回路


SG钛管热轧


主泵电机组装

Demonstration project of ACP100

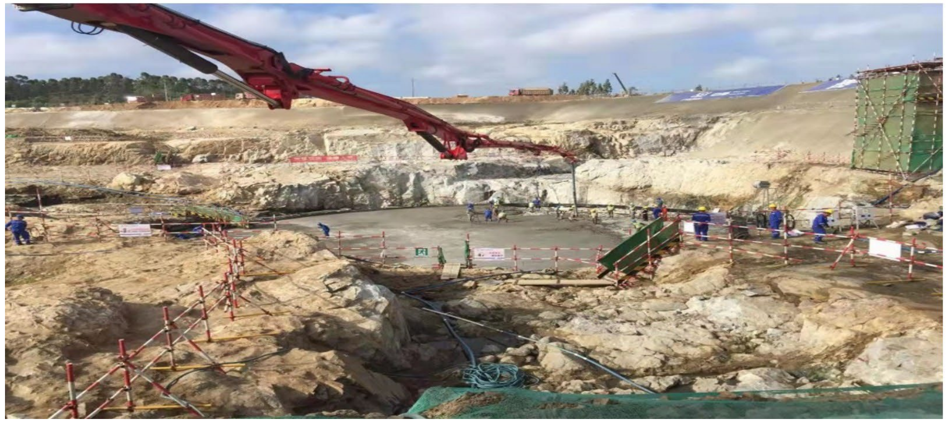
- Site preparation on 18 July 2019

小堆施工现场

Demonstration project of ACP100

- Site preparation on 31 December 2019






Demonstration project of ACP100

- Site preparation on 30 June 2020

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Demonstration project of ACP100

- Site preparation on 26 February 2021

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Demonstration project of ACP100

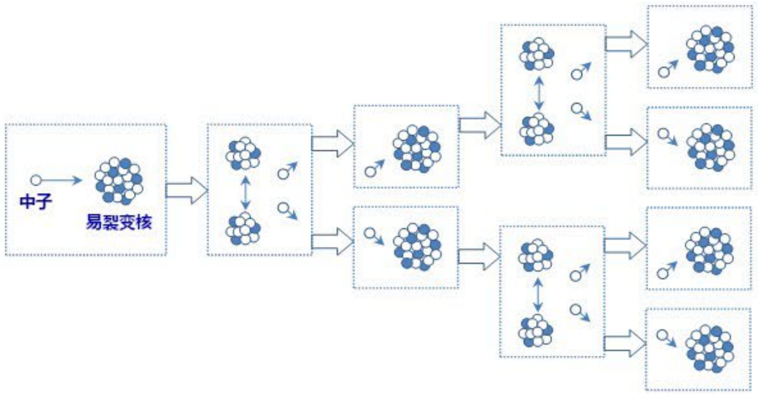
- FCD on 13 July 2021

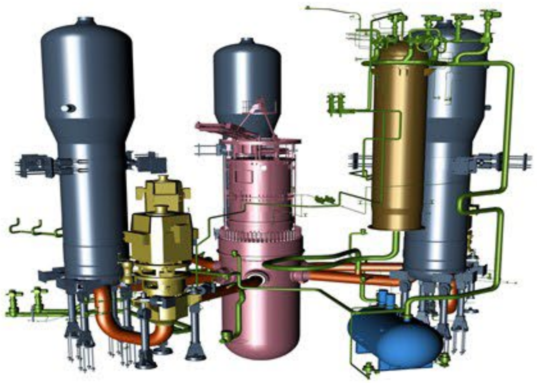
Multiple applications of ACP100

- Merit of nuclear energy：
  - Higher density, lower carbon emission
  - Stable operation, no fluctuation

1kgU235=2700 Ton Coal

1000MWe NPP de-carbonize 3 million Ton Coal per year





Reactor

Multiple applications of ACP100

- 80% end user of energy is used for electricity, heating and transportation
- In year 2019, energy consumption of China (electricity 23.9%, heating 45% Industry 24%, civil 21%), transportation 11%)

ENERGY	Electricity	Heating		Transportation	Others
		Industry	Civil		
	23.9%	24%	21%	11%	--

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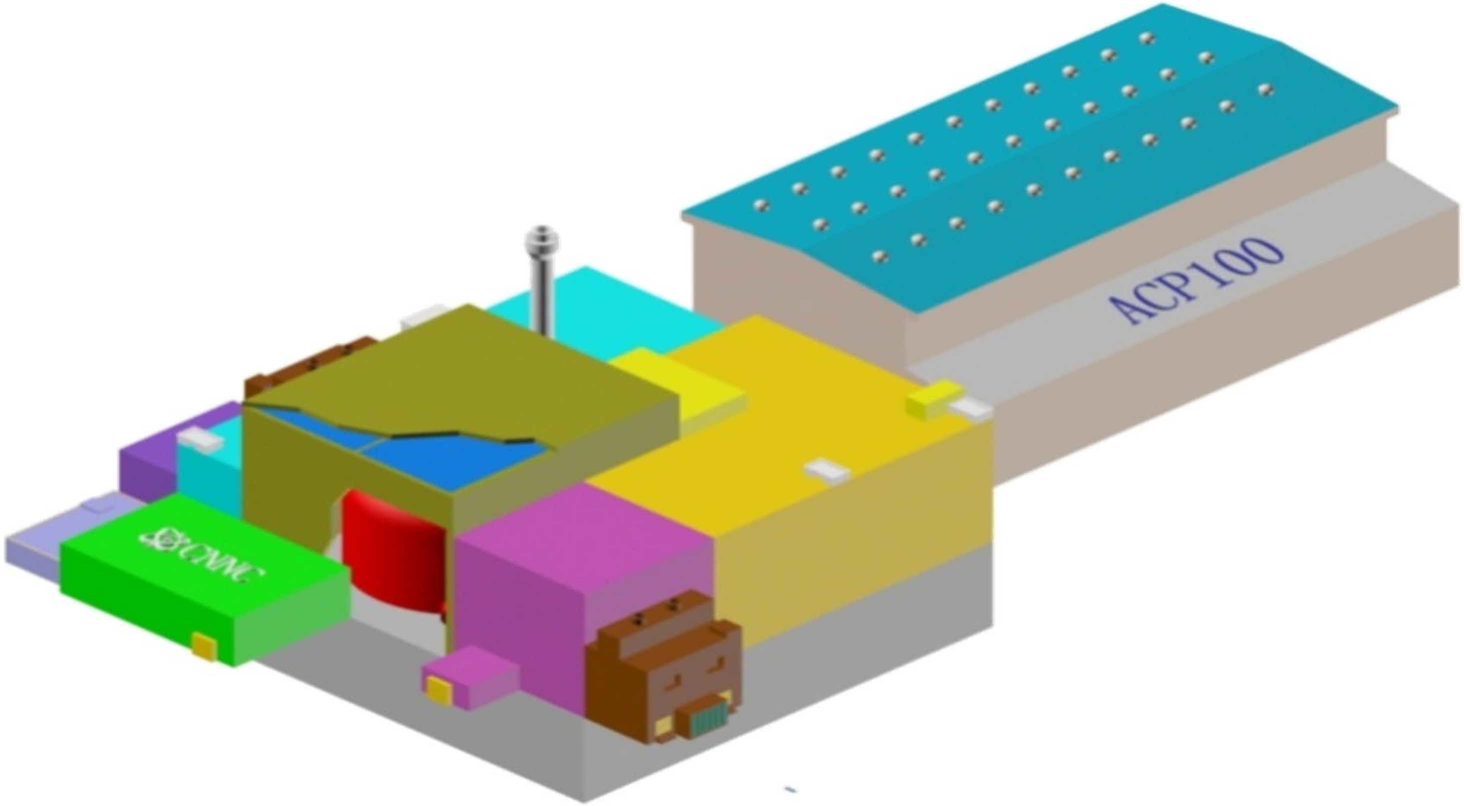
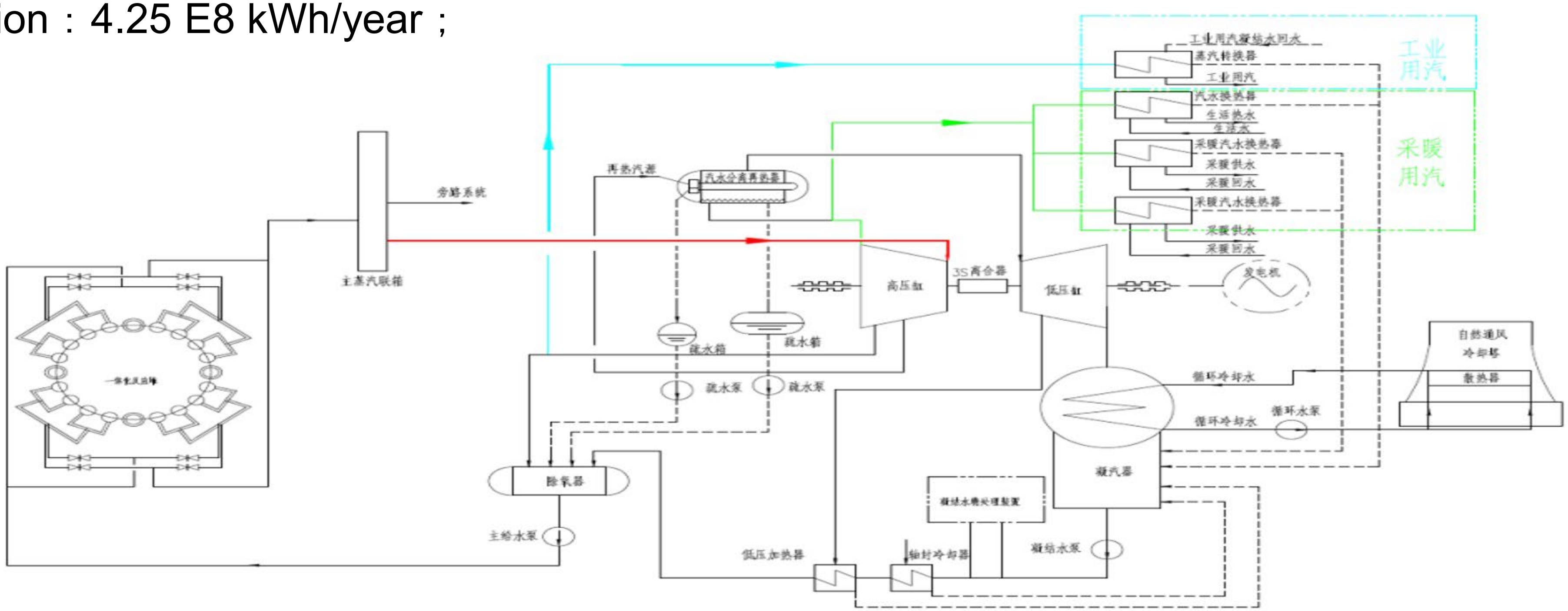
Multiple applications of ACP100

- In the fields of Electricity Generation
  - Hainan Changjiag Project (under construction) :
  - Electrical Power 126.5Mwe, Refueling period 24 months. Electrical generation 109 Kwh/year, Satisfy for half million families.



Multiple applications of ACP100

- In the fields of District heating & Electricity Generation
- Gansu project (feasibility study)
  - Thermal generation：6.55 million GJ/year；
  - Electrical power：80 MWe；
  - Electrical generation：4.25 E8 kWh/year；



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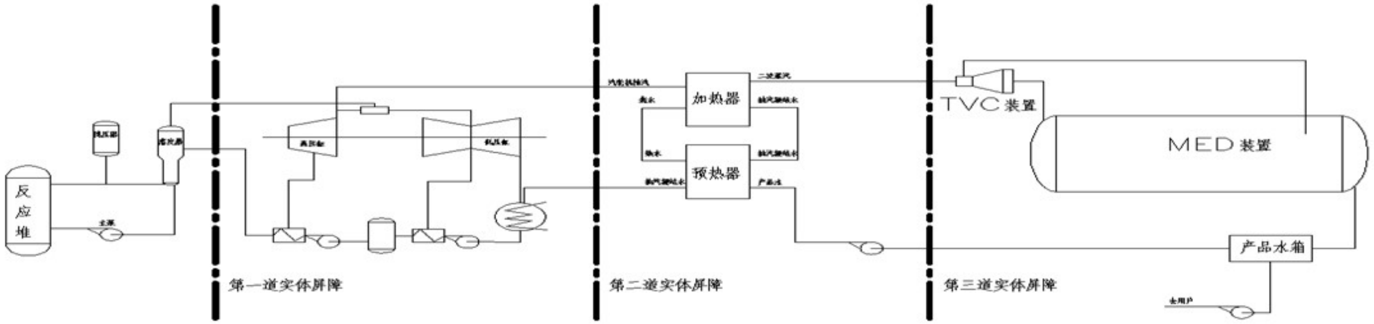
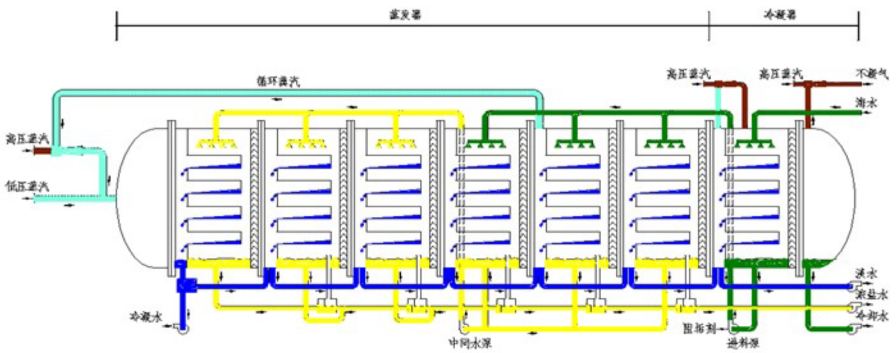
Multiple applications of ACP100

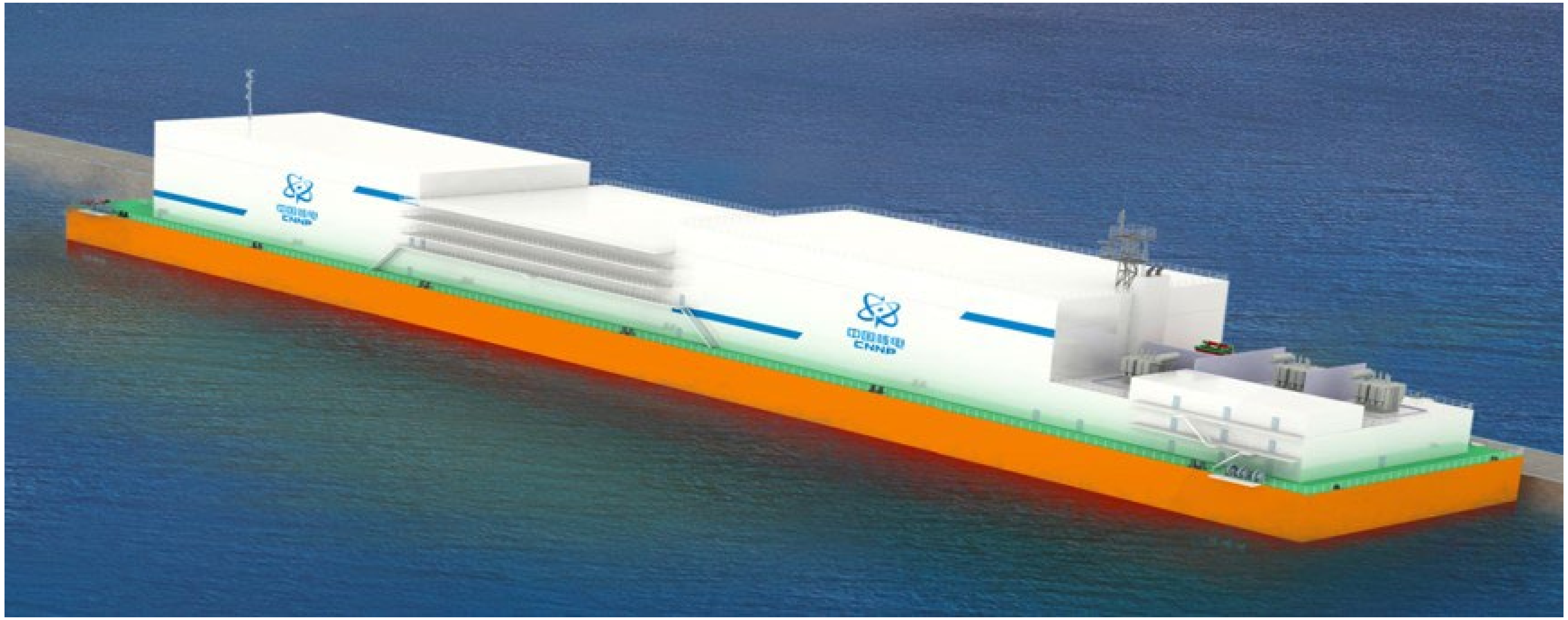
- In the fields of Seawater Desalination & Electricity Generation
  - Fujian Putian project (feasibility study)
  - （Low Temperature Multi-effect Sea Water Desalination Facility):
    - Fresh water generation： 48,000 m3/day
    - Electrical generation：75 MWe





Multiple applications of ACP100

- In the fields of Floating Nuclear Power Plant
  - Shandong   Yantai project (feasibility study)
  - Two ACP100 reactor on the floating platform
  - Electrical generation：250 MWe



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Thanks and Questions

Upcoming Webinars

Date	Title	Presenter
28 September 2022	Development of In-Service Inspection Rules for Sodium-Cooled Fast Reactors Using the System Based Code Concept	Dr. Shigeru Takaya, JAEA, Japan
26 October 2022	Sodium Integral Effect Test Loop for Safety Simulation and Assessment (STELLA)	Dr. Jewhan LEE , KAERI, Republic of Korea
28 November 2022	Visualization Tool for Comparing Energy Options	Dr. Mark Deinert, Colorado School of Mines, USA

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