中广核 CGN Natural Energy Powering Nature

Design, Applications and Siting Requirements of CGN ACPR50(S)

China General Nuclear Power Corporation (CGN)

China Nuclear Power Technology Research Institute (CNPRI)

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CONTENTS

1 Introduction

2 LNPP with SMR ACPR50

3 FNPP with SMR ACPR50S

4 International Sea Transportation of FNPP with SMR ACPR50S

5 Summary

01

Introduction

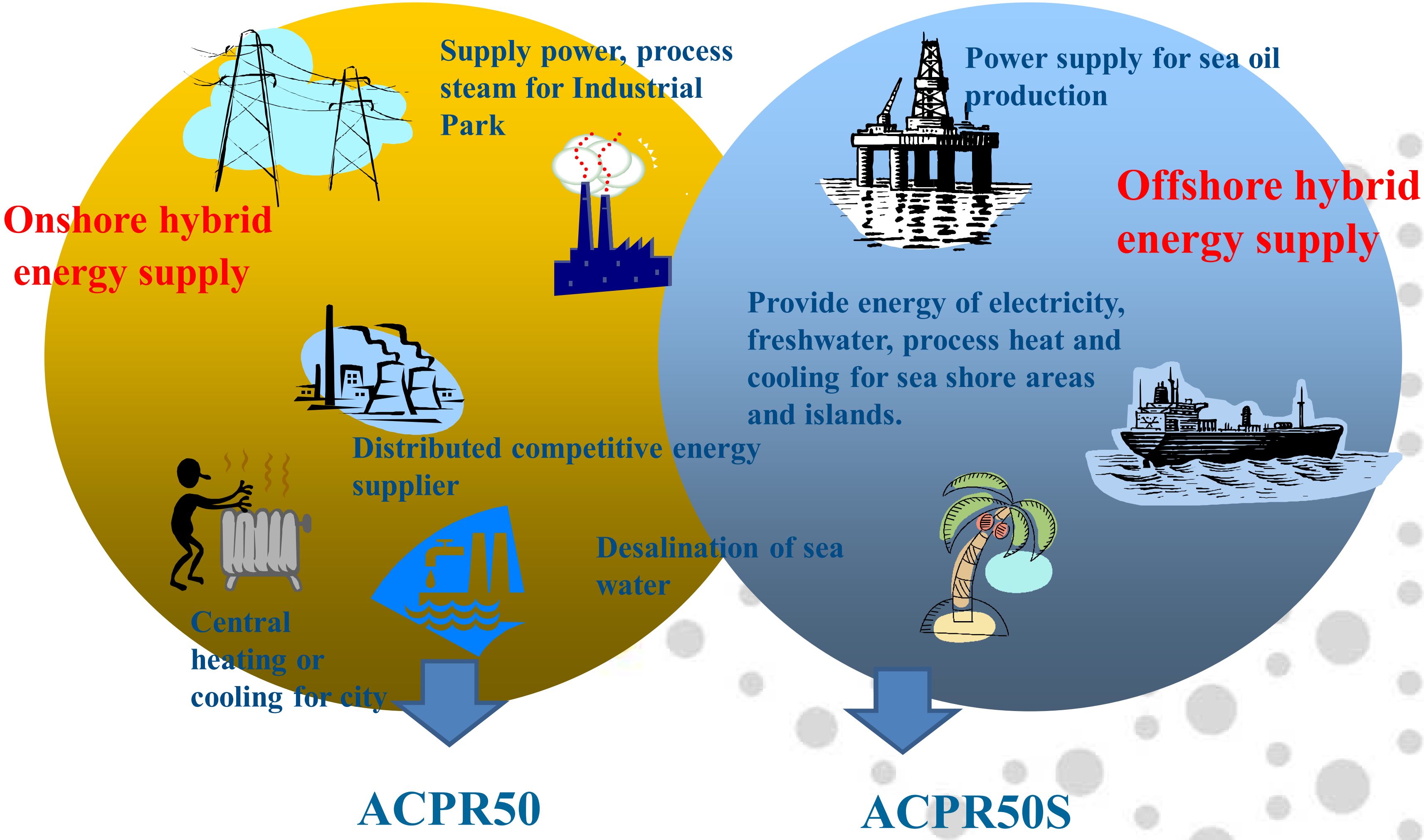
1.1 ACPR SMR Technology

ACPR：Advanced Customer-friendly Practicable Reliable

ACPR50: 60MWe compact SMR NPP. Applied to onshore, mainly utilized for power generation, heating and desalination of sea water.

ACPR50S: 50MWe compact SMR FNPP. Applied to offshore, carried by fixed or floating platform utilized for power generation, heating and desalination of sea water.

1.2 ACPR SMR Applications



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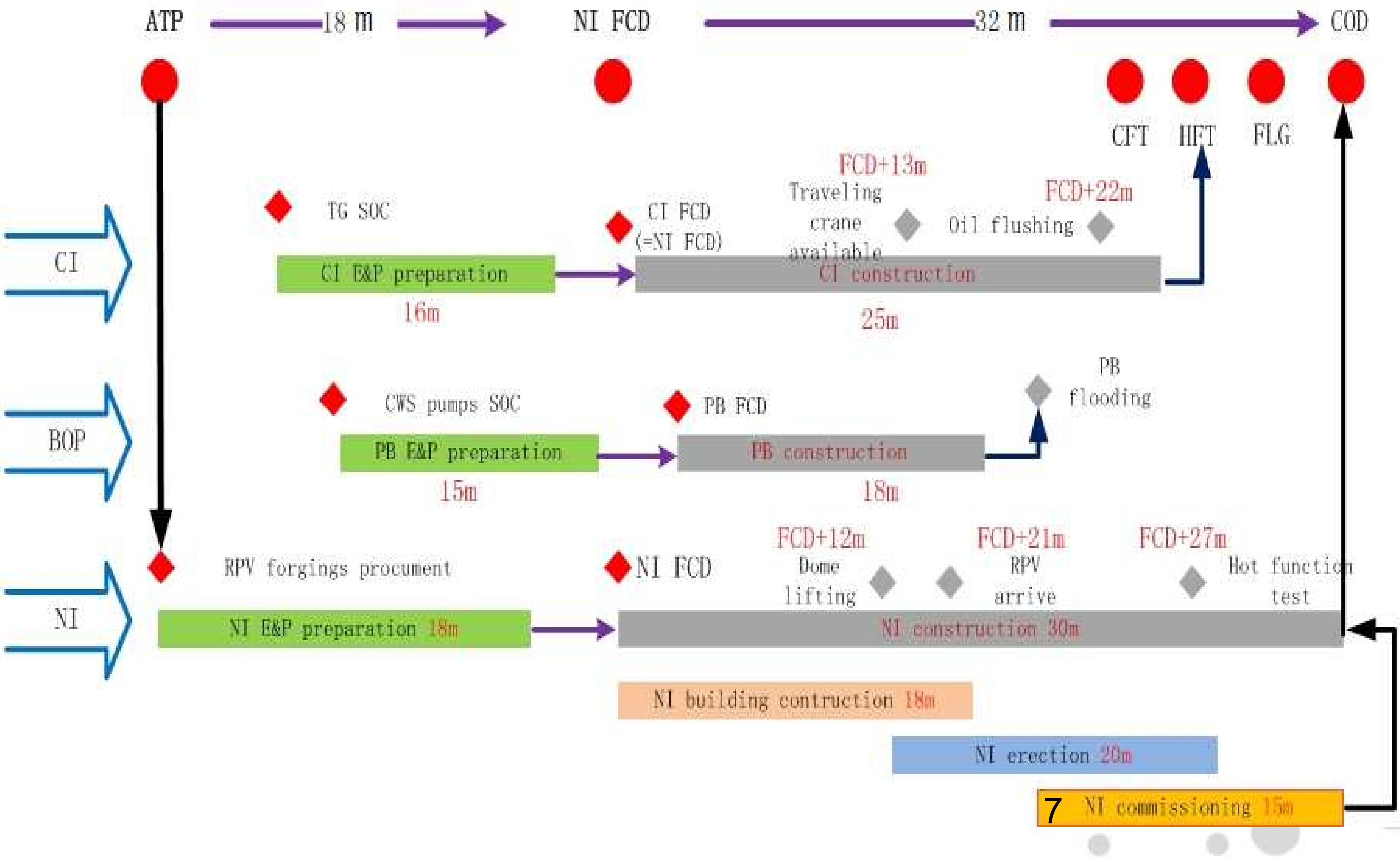
LNPP with SMR ACPR50

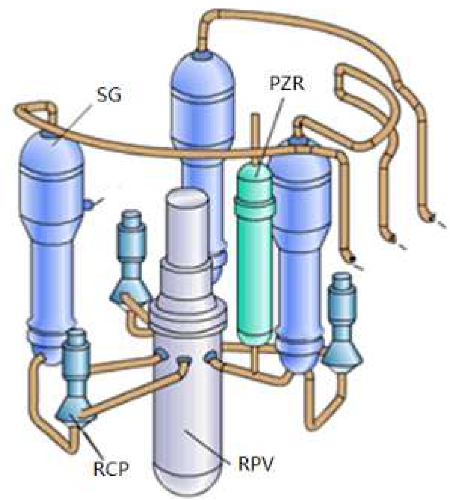
1.1 Project duration



1.2 Design features (1/5): Mature

Based on design experience and mature industrial supply chain of large PWR:

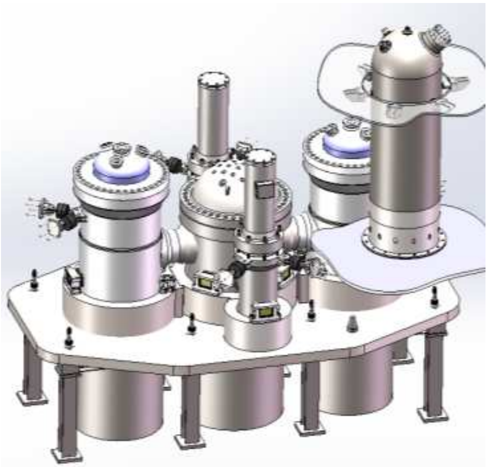
- Take mature large commercial PWR nuclear power plant as reference, "from large to small, from single application of power generation to hybrid applications";
- Using compact layout reactor module and mature reliable technology and equipment in order to meet the requirements of regulations and standards;
- Mature nuclear power equipment manufacturing chain.



Large PWR NPP

SMR

1.2 Design features (2/5): Compact

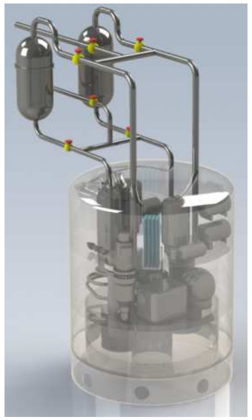


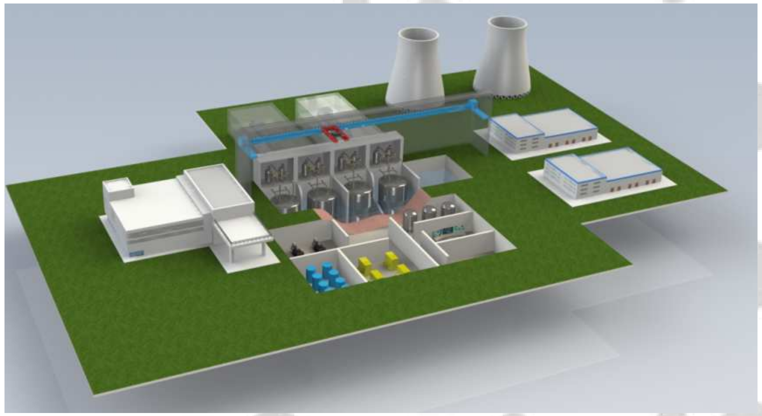
- Main components（RPV, SG, Pumps） are connected with pipe in pipe casing.
- Advantages:
  - Eliminating the large LOCA
  - Reducing the reactor module height
  - Benefiting for maintenance
  - Reducing containment volume

1.2 Design features (3/5) : Modularity

Flexible to meet user's power requirements; shortening the construction period.

- **Single module :** NSSS, including reactor coolant system, safety system, main nuclear auxiliary and containment;
- Power generation unit: Two reactor modules with one steam turbine;
- Independent safety module: Multiple modules are in safety injection system, but they are not affect each other ;
- Modular installation: Shorten the construction period .





1.2 Design features (4/5): Safety

High level Safety

- **Design Safety**
- **Passive Safety**
- **Inherent Safety**
- **Multiple Reactivity Barriers**
- **Very Low Reactivity Release Frequency**
- **No Off-site Emergency Measure**

Severe accident mitigation:
Containment flooded by water

5 barriers：Fuel pellet\Fuel canning\Primary loop \Containment\Water(Containment flooding)

Negative reactivity coefficient; Low linear power density;
Coolant natural circulation in accidents.

Residual heat removal depends on natural circulation.
Water(Containment flooding) and air is used as ultimate heat sink

SG joined to the RPV with pipe in pipe which largely reduces the frequency of LOCA.

1.2 Design features (5/5): Competitive costs

Integrated energy supplier, modularity, simplified systems and compact components.

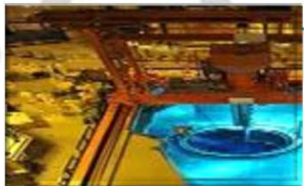
Project construction cost

Equipment procurement cost

Installation and commissioning costs

Other cost

Basic reserve cost



First nuclear fuel cost

1.3 Research & Development(1/4): Parameters

Thermal output (MWt)	200	Main steam pressure(MPa)	4.68
Electrical output (MWe)	~60	Inner diameter of RPV (m)	2.3
Primary loop pressure (MPa)	15.5	Generation efficiency	~30%
Fuel arrangement	17×17	RPV height (m)	7.2
Assembly number	37	Primary loop design pressure(MPa)	17.23
Burnable poison	Gd	Core coolant average temperature(℃)	310
CR material	Ag-In-Cd	Designed life (Year)	60
Fuel enrichment	<5%	Average reload burnup of fuel assembly (MWd/tU)	≥40000
CDF(One core per year)	$<1.0\times10^{-7}$	LRF(One core per year)	$<1.0\times10^{-8}$

1.3 Research & Development(2/4): Reactor and Fuel Design

Fuel assembly design

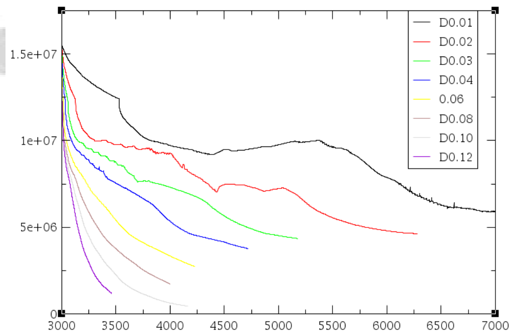
- Shorten active zone height,
- Maintain lateral dimension parameters,
- Design verification: maximum burn up, hold-down assembly verification, plenum spring design verification, internal pressure design verification, axial clearance verification, rod drop time, accident condition.

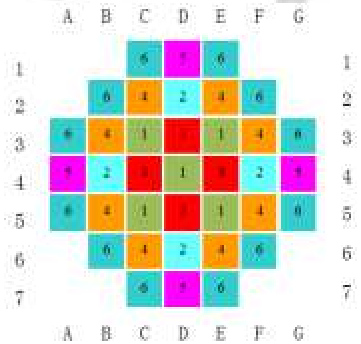
Fuel management

- 37 fuel assemblies in core, 16 control rod assemblies
- Gd_2O_3 as burnable poison,
- Reload burnup of fuel assembly ≧40000MWd/tU

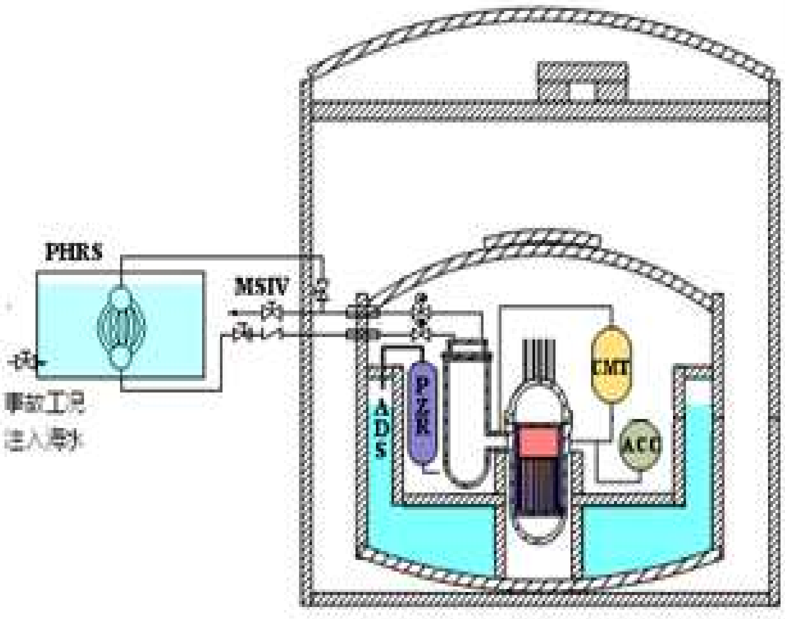
Thermal-hydraulic design

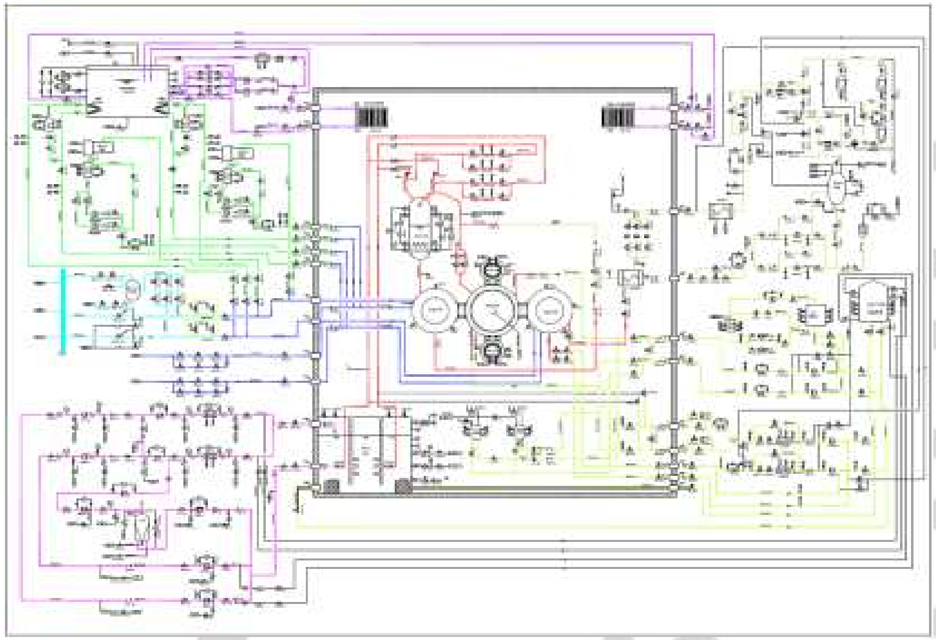
- WRB-1 correlation used to calculate DNBR
- DNBR margin>150%





1.3 Research & Development(3/4): System Design



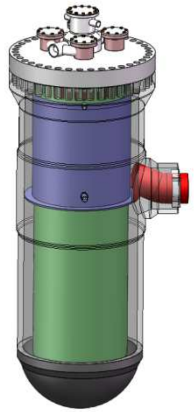


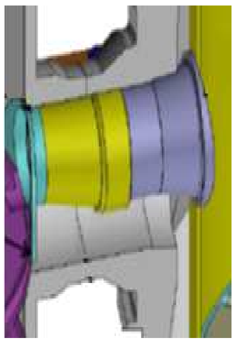
- Residual heat removal depends on passive device. Water(Containment flooding) and air is used as ultimate heat sink

- Reactor coolant system
- Engineered Safety System
- Main nuclear auxiliary system
- Containment system
- Fuel handling and storage system
- CI systems

1.3 Research & Development(4/4): Main components Design

Main component	Main pump	Canned-motor pump/Wet Winding Motor RCP
	OTSG	Helical-coiled tube OTSG
	CRDM	Electromagnetic stepping CRDM of PWR with Spring mechanism
	PRZ	Proven technology of PWR, optimal design, miniaturization
	RPV	Proven technology of PWR, optimal design, miniaturization
	Pipe in pipe	Pipe in pipe casing between main components
	RVI	Proven technology of PWR, optimal design, miniaturization

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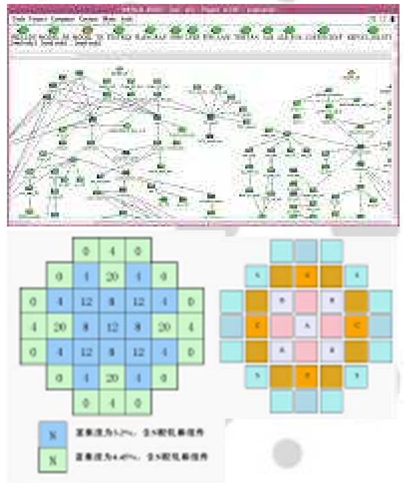
1.4 Verification test(1/4)

Thermal Hydraulic test and design platforms can satisfy the tests and design of ACPR50

- SMR safety test platform (6 test facilities)
- SMR equipment and key technology test platform (4 test facilities)
- SMR wave condition test platform (2 test facilities for FNPP)

Thermal-Hydraulic Test Lab. in Shenzhen



Design software

1.4 Verification test (2/4)

■ **The following tables shows some of the experimental plans.**

No.	Experiment
Reactor & equipment tests	
1	Reactor integrated hydraulic simulation test
2	Fuel assembly structural mechanics test
3	Fuel assembly hydraulics test
4	Fuel assembly CHF test
5	Once-through steam generator (OTSG) principle test
6	OTSG spiral tube heat transfer and resistance test
7	Spiral tube OTSG prototype test
8	Control rod driving system test
9	Pipe in pipe sealing & flow-induced vibration test
10	Main pump component test
11	Main pump two-phase characteristics test
12	……

No.	Experiment
Safety system tests	
1	Passive system test
2	Passive core direct vessel injection (DVI) test
3	In-vessel retention (IVR) engineering test
4	……
integral performance test	
1	Compact SMR integral performance test

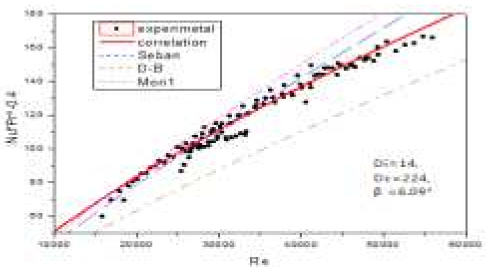
1.4 Verification test (3/4)

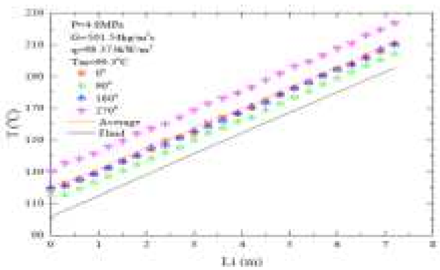
No.	Experiments compeleted
1	Once-through steam generator (OTSG) principle test
2	OTSG spiral tube heat transfer and resistance test
3	Passive safety system experiment
4	Natural circulation transient experiment
5	The principle experiment of the suppression pool

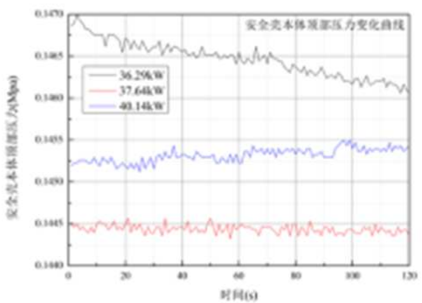


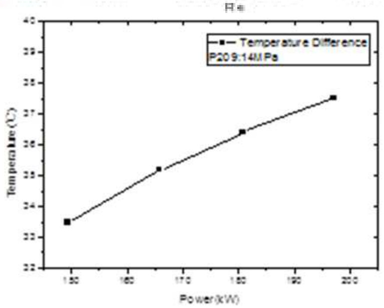


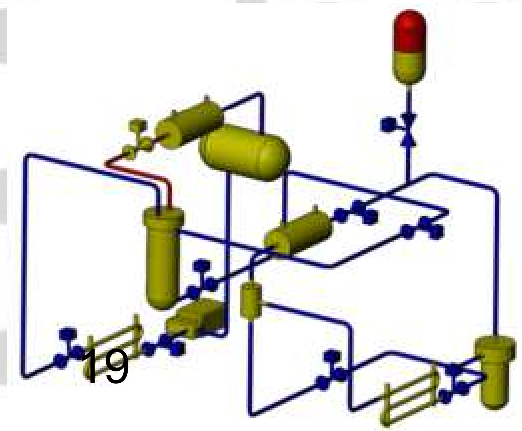








1.4 Verification test (4/4)

	On going experiments
1	Control rod driving system test
2	Overall performance of safety system test
3	Heat flux density of fuel critical test
4	Reactor integrated hydraulic simulation test
5	Reactor Vessel Internal flow-induced vibration test
6	Pipe in pipe seal test











1.5 Multi-Applications

Scenarios 1: Electricity &Water

Electricity is supplied to the local power grid, and heating is used for meds drinking water.

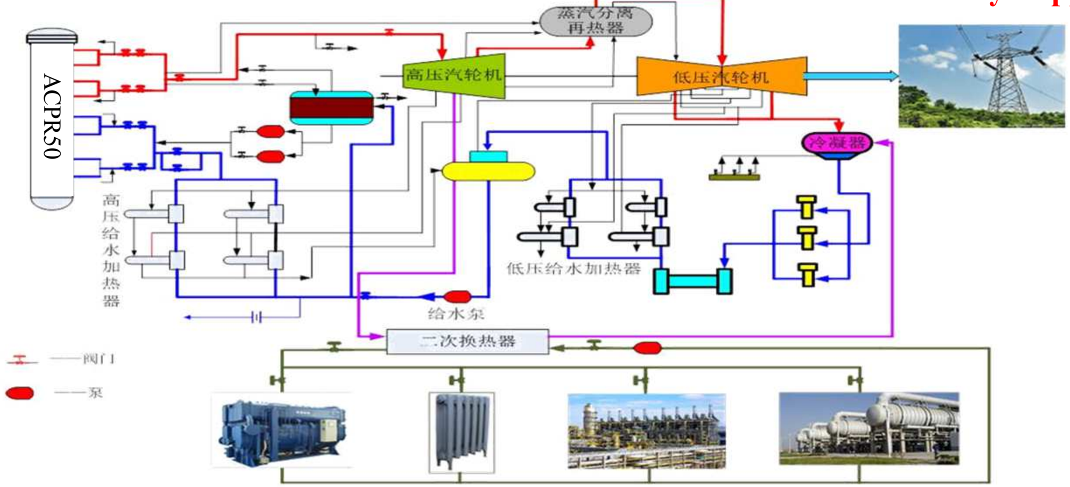
Scenarios 2: Fresh water

Used for the production of demand of households, and the heating is used for drinking water.

Scenarios 3: Electricity & Refrigeration

Electricity supply to the local grid, heating for lithium bromide absorption refrigeration and for ammonia absorption refrigeration.

Electricity Supply



Refrigeration

Process heating and steam supply

Desalination

1.5 Multi-Applications

			Scenario 1	Scenario 2	Scenario 3	
					①	②
output	Electricity		370 million KWh/year		270 million KWh/year	370 million KWh/year
	water	Drinking water	44,000 tons /day	44,000 tons / day		
		Domestic water		135,000 tons / day		
	Refrigeration	LiBr			117.3MW	
		Ammonia				53.9MW

1.5 Multi-Applications

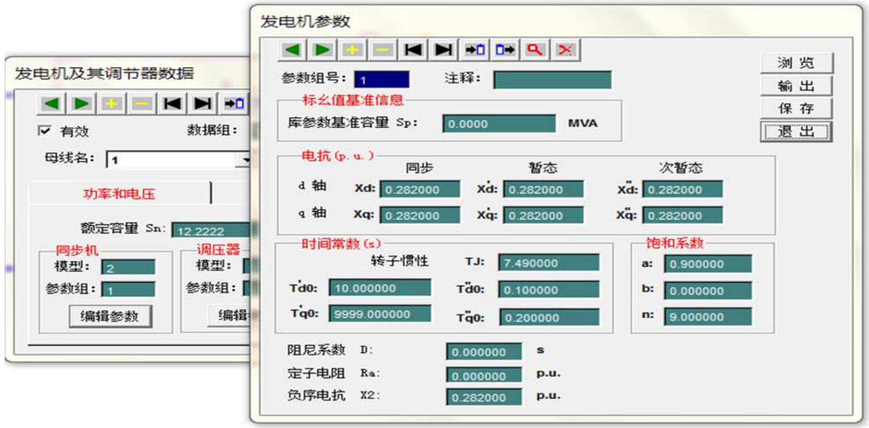
- **Electricity Supply**: generation and supply;
- **Thermal manufacture of fresh water:** Use MED to make water quality meet the drinking water requirements;
- **Reverse Osmosis manufacture of fresh water:** Use RO to make water quality meet domestic water requirements;
- **LiBr(lithium bromide) absorption refrigeration:** Refrigeration quality can meet the requirements of air conditioning refrigeration (above zero);
- **Ammonia absorption refrigeration:** Refrigeration quality can meet the requirements of industrial refrigeration (as low as -50°C).

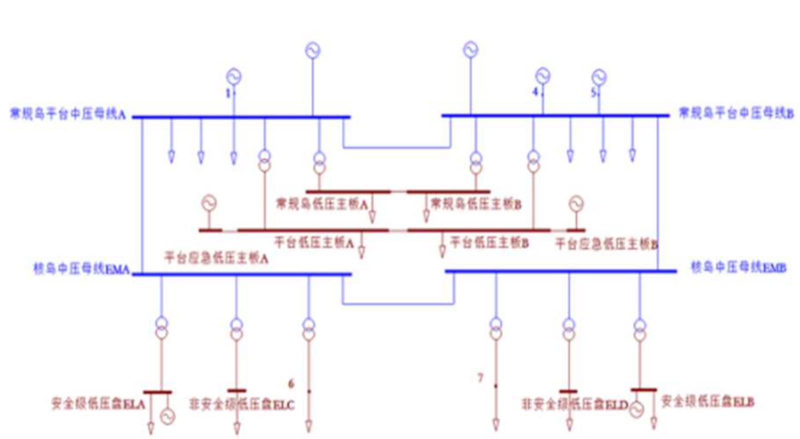
1.5 Multi-Applications

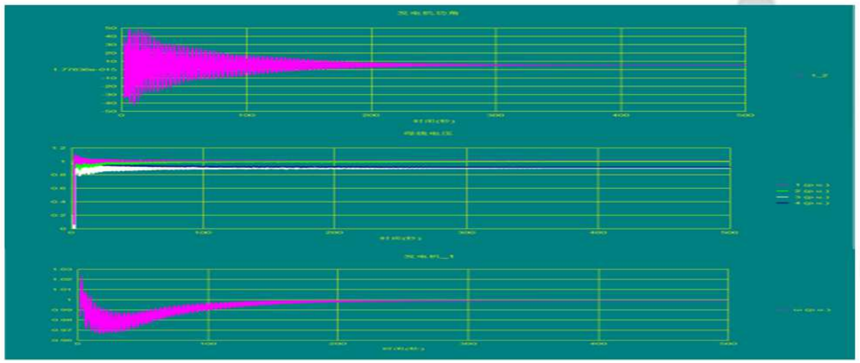
Small Isolated Grid Power Supply

Load and Supply Stability is the key issue for small isolated grid System.

Stability analysis is needed to evaluate whether the power system can maintain stability under various operating conditions, protection configurations and different faults.







1.6 Siting Requirements

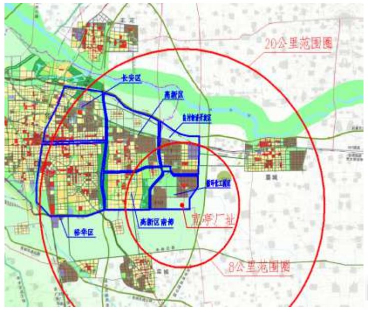
Siting principles of LNPP SMR ACPR50

- Construction necessity
- Safety reliability
- Economic rationality
- Technical feasibility
- Environmental compatibility

1.6 Siting Requirements

Main siting factors of LNPP SMR ACPR50

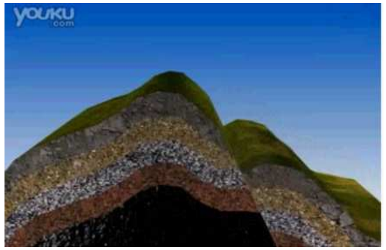
- **Earthquake:** Horizontal peak acceleration SL-2≤0.3g.
- **Transportation:** Highway transportation can meet the requirement of large and heavy equipment.
- **Site area:** Only 15hm2 for 2 units.
- **Water consumption:** Circulating cooling water can, based on the site condition, be used in arid water areas.
- **Radioactive waste water:** Zero discharge can be realized.



Market demand

Site area

Foundation



Capable fault

Natural events

Man induces events

1.6 Siting Requirements

The site selection in china is on the way.

- Two potential sites in Guangdong province: preliminary site feasibility research finished .
- One potential site in Guizhou Province: power supply for the regions of bad transportation condition.

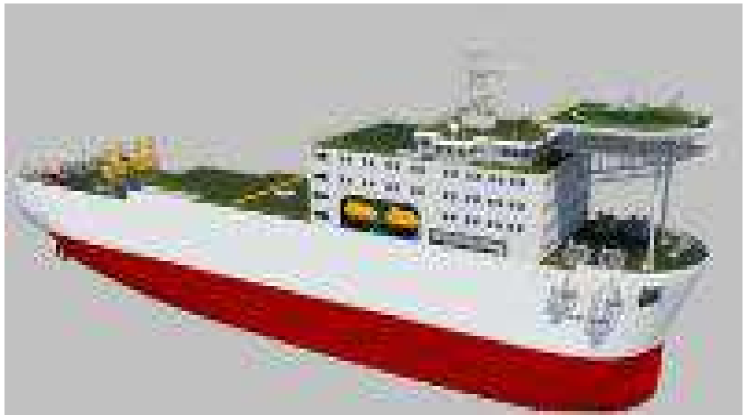
- Three potential sites in Hebei province for combined heat and power supply
- The preliminary site feasibility study finished.

03

FNPP with SMR ACPR50S

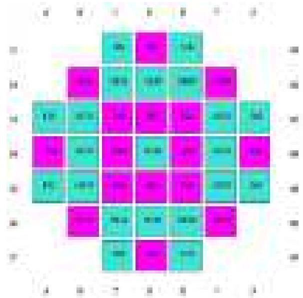
3.1 Status and schedule of ACPR50S project

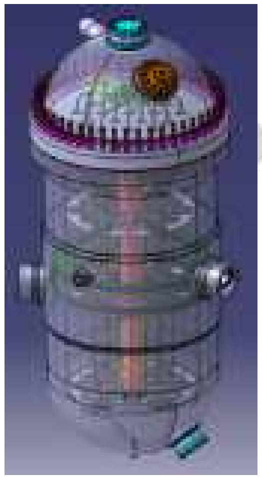
- Technical proposal of FNPP (2012)
- Key technology research (2013~2018)
- Preliminary conceptual design of ACPR50S (2013)
- Conceptual design of ACPR50S (2015)
- Preliminary design of ACPR50S (2016~2018)
- Earlier stage preparations of demonstration project approved by China government (2015)
- Demonstration project (2017~2022)

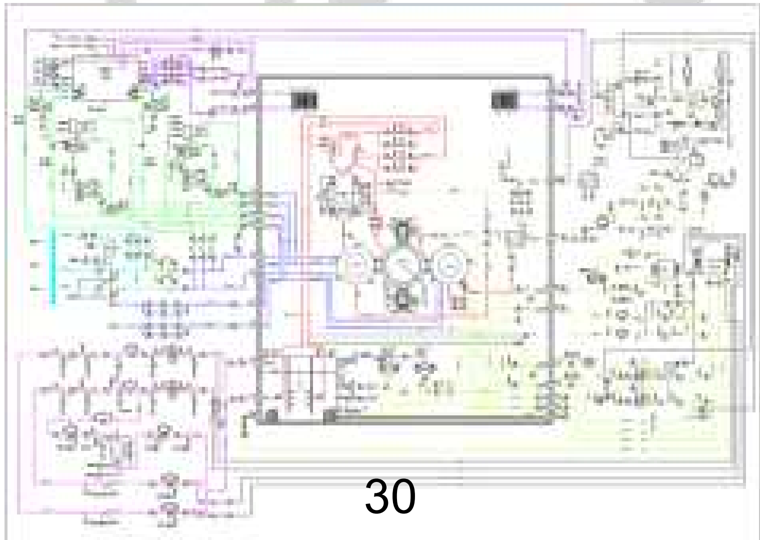


3.2 Design Progress(1/4): Research &Development

- Design of Fuel assembly
- Design of Reactor fuel management
- Design of Reactor core thermal-hydraulic design
- Design of DBA mitigation and severe accidents mitigation design
- Design of NSSS: Reactor coolant system, safety system and nuclear auxiliary systems
- Design of R&D of main RCS components
- Design of I&C system
- Design of electric power system
- Design of floating platform and overall layout







3.2 Design Progress(2/4): Construction and Commissioning

- Environment assessment, safety evaluation of construction site and feasibility study of construction site are ongoing.
- Construction and commissioning schemes study is on the way

Construction design

Ship block method → Module installation → Ship shaping → Equipment and cable installation → Launching

Commissioning design

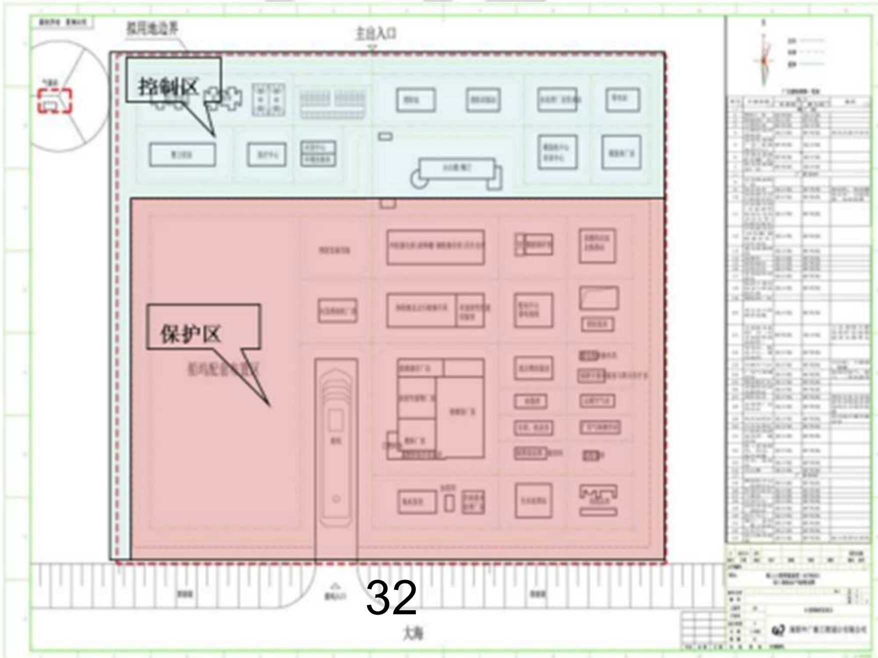
Commissioning of Main steam turbine → Fuelling → integrated commissioning → Marine experiment

3.2 Design Progress(3/4): Onshore Base

The onshore base of ACPR50S contains the fuel building, the radioactive waste treatment building, and other balance buildings of plant.

- Refueling and temporary storage of spent fuels
- Disposal of nuclear waste
- Maintenance

Completed conceptual design



3.2 Design Progress(4/4): Licensing

➢ Licensing Approaches

Apply for the license in 4 stages. Licensing stages, construction stage, fueling stage, operation stage etc.

➢ Licensing Experience

- NNSA and other regulators are aware of ACPR50S design features
- Making efforts to explore the new mode of regulation for FNPP
- Promoting communication of duty between NNSA and other regulators

➢ Licensing

- A set of design principles has been submitted to NNSA in July, which will benefit the review of PSAR.
- The first edition PSAR will be submitted to the NNSA by the end of 2017 and the Construction Permit will be applied at the same time.

➢ Review of maritime safety

- Through China Ship Research and Design Center (CSRDC), we are exchanging information with the maritime department about the design requirements on maritime safety..
- Conducting research of internal / external disasters of FNPP with Lloyd's Register

3.3 Procurement Progress

Procurement contract for all primary components shall be signed by the end of 2017, the selected supplier will be involved in R&D

3.4 Design Features(1/4)

ACPR 50S Design Philosophy and Technical Route

- ACPR50s is a combination of industry proven PWR and floating platform technology
- ➢ The ACPR50S realizes design simplification with less cost and lower investment risks in order to be competitive with conventional offshore energy sources.

SMR

+

Industry-proven sea floating platform technology

SMR FNPP

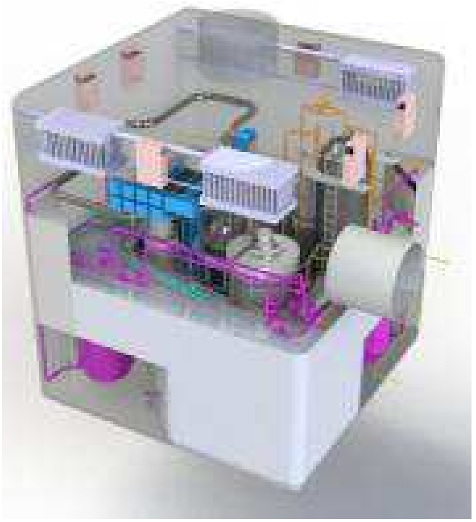
3.4 Design Features(2/4)

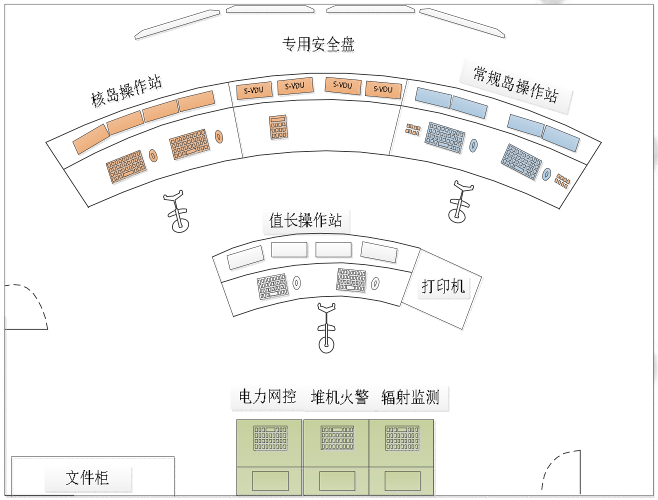
In addition to onshore NPP regulations, the vessel requirements and maritime conditions are comprehensively considered .

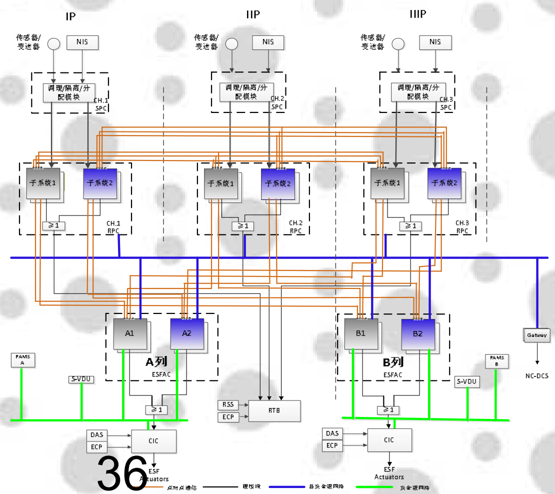
➢ Considering Ship conditions

The space and resources of the ship are valuable, the design needs to meet the following requirements:

- The reactor compartment is as small as possible
- The area of the main control room is limited





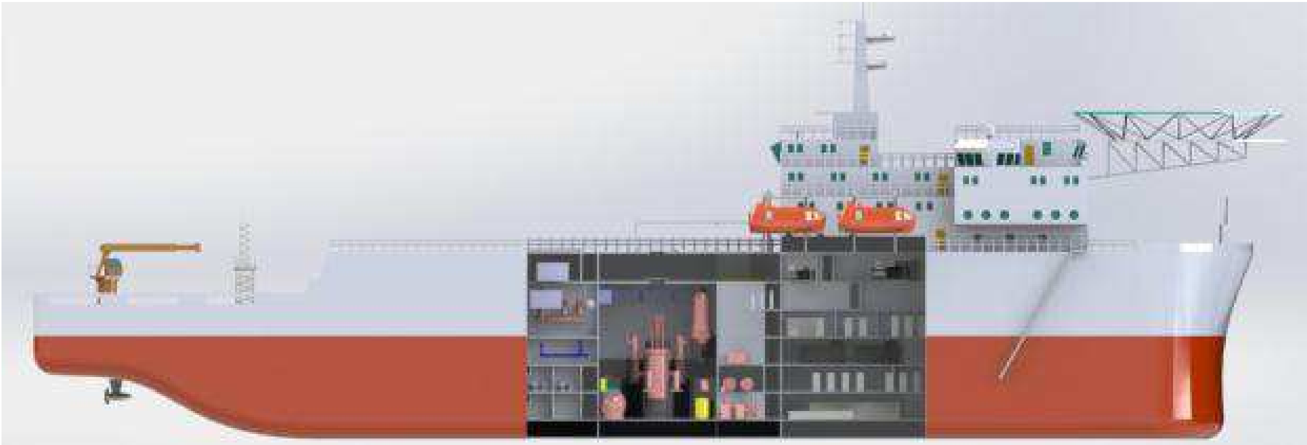


3.4 Design Features(3/4)

- **Considering ocean environmental conditions**

The control rods shall be well designed and tested in order to be inserted smoothly when tilted by 45° and to remain in reactor core to control the reactivity.

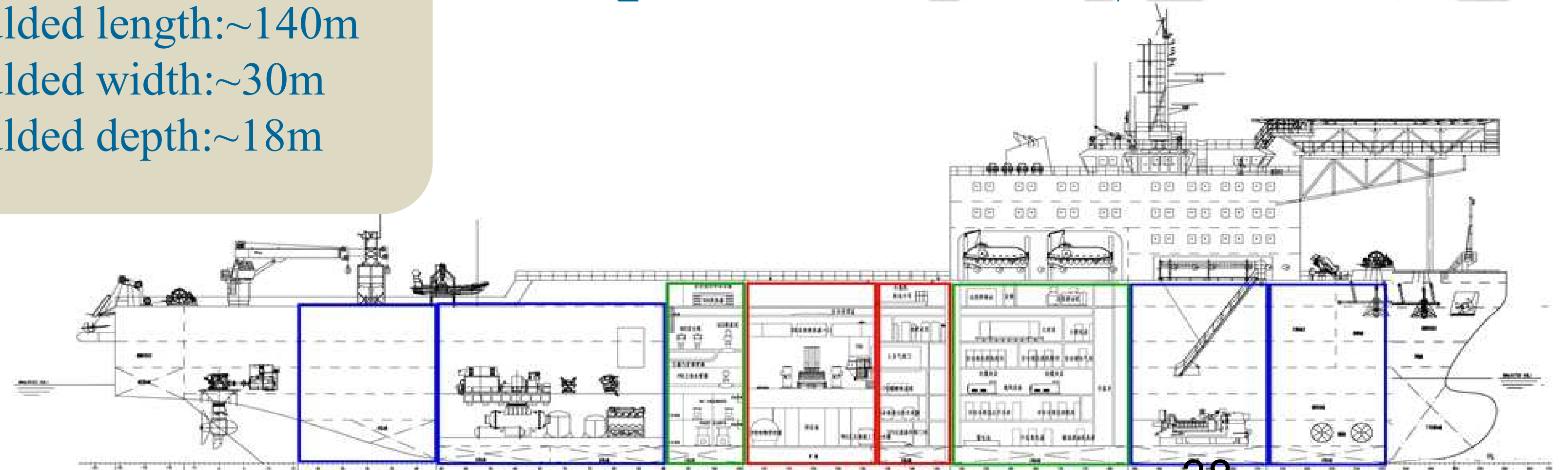
3.4 Design Features(4/4):



Offshore Platform: living area and process systems

8 cabins totally
moulded length:~140m
moulded width:~30m
moulded depth:~18m

Floating Platform Overall Layout



3.5 Verification test

In addition to the experiments carried out by ACPR50S, the ocean condition test and floating platforms experiments are implemented.

➢ **Ocean condition tests**

1	**Effect of ocean conditions on control rod driving system test**
2	**Effect of ocean conditions on passive system thermal-hydraulics performance test**
3	……

Through the experiment, the resistance curve of the platform, the natural period and the damping coefficient of the platform are obtained.Compared with the previous estimates, the result is in line with the design expectations.

➢ **Experiments related to floating platforms**

Hydrostatic damping test

Ship model resistance test

3.6 ACPR50S Multi-Applications

- **Power supply**

Offshore power supply;

- **Fresh water production**

Producing fresh water for living or for drinking combined with offshore desalination device or ship;

- **Refrigeration**

Air conditioning or industrial refrigeration combined with offshore refrigeration device.

3.6 ACPR50S Multiple Applications

Application scenarios

Scenarios 1: Power supply

Offshore power supply;

Scenarios 2: Electricity &Water

Offshore power supply, and product fresh water for drinking by MED;

Scenarios 3: Fresh water production

Product fresh water for living by RO;

Scenarios 4: Electricity & Refrigeration

Electricity supply to the local grid, heating for lithium bromide absorption refrigeration and for ammonia absorption refrigeration.

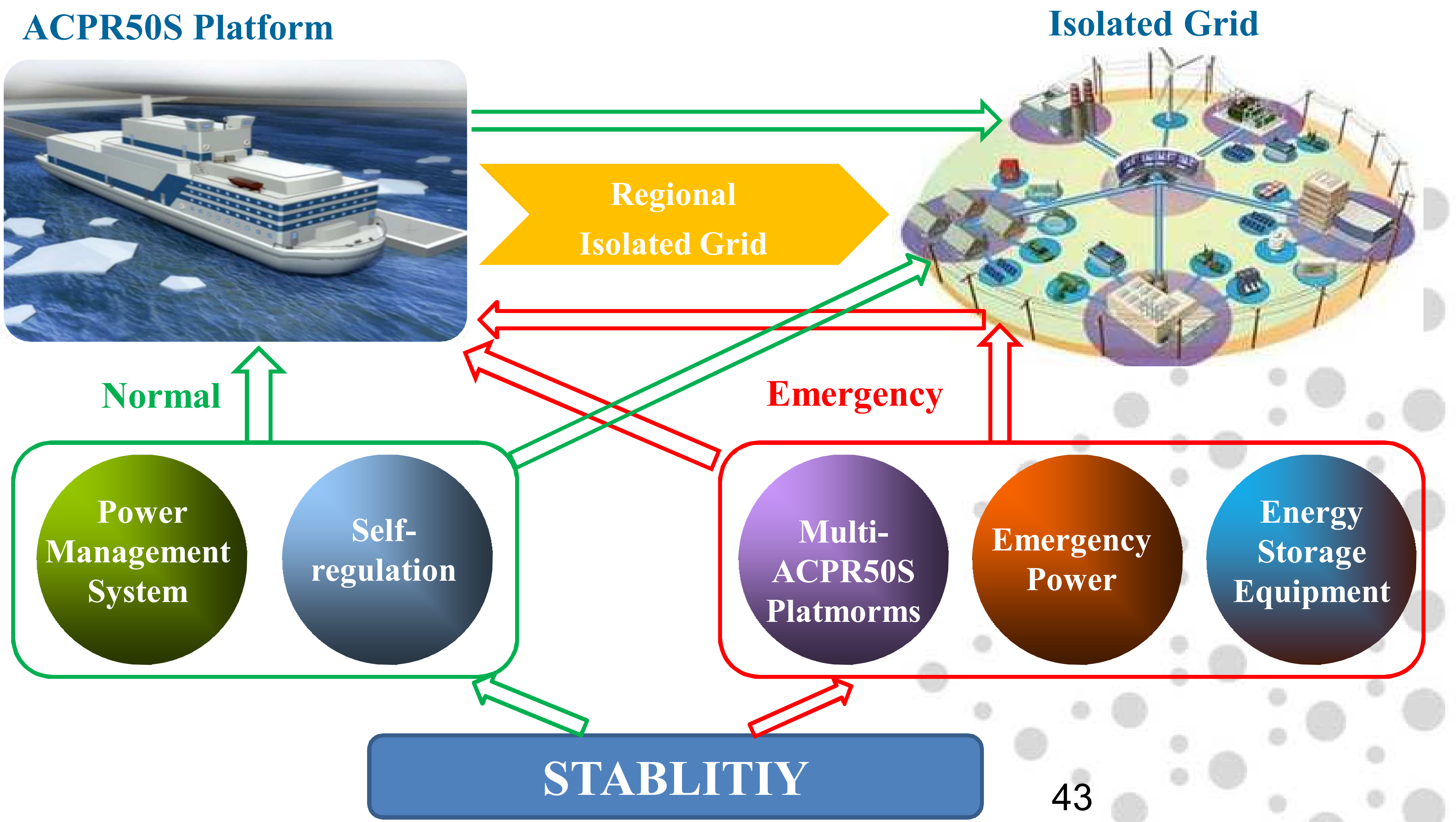
3.6 ACPR50 Multi-Applications

Application scenarios

			Scenario 1	Scenario 2	Scenario 3	Scenario 4 ①	Scenario 4 ②
Output	Electricity		440 million KWh/year	420 million KWh/year		420 million KWh/year	370 million KWh/year
	water	Drinking water		22000 tons per day	22000 tons per day		
		Domestic water			153,000 tons per day		
	Refrigeration	LiBr					52.1MW
		Ammonia				24.8MW	

3.6 Multiple Applications

◆Stability is the key issue for small isolated grid



3.6 Multiple Applications

➢ Oil Production

Strategy for Emergency：Emergency Power Plant, Associated Gas Turbines …

➢ Isolated Island

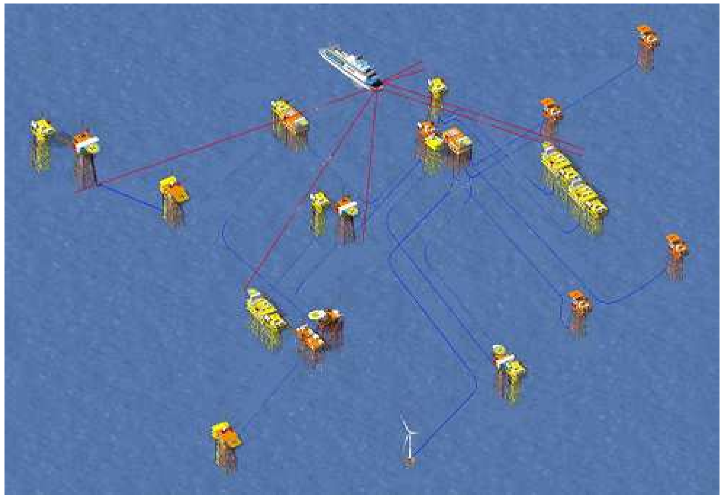
Strategy for Emergency：Emergency Diesel Engine, Energy Storage

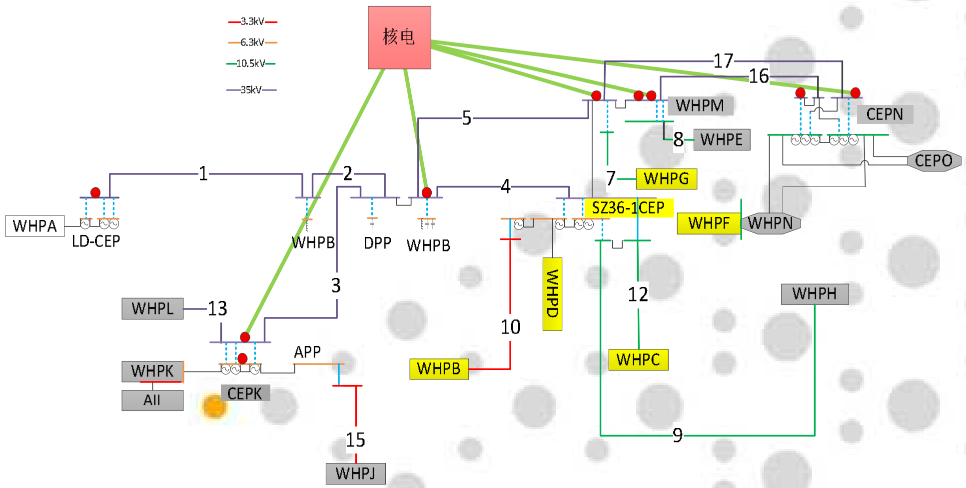
3.6 Multi-Applications

Application Scenarios

Bohai Sea

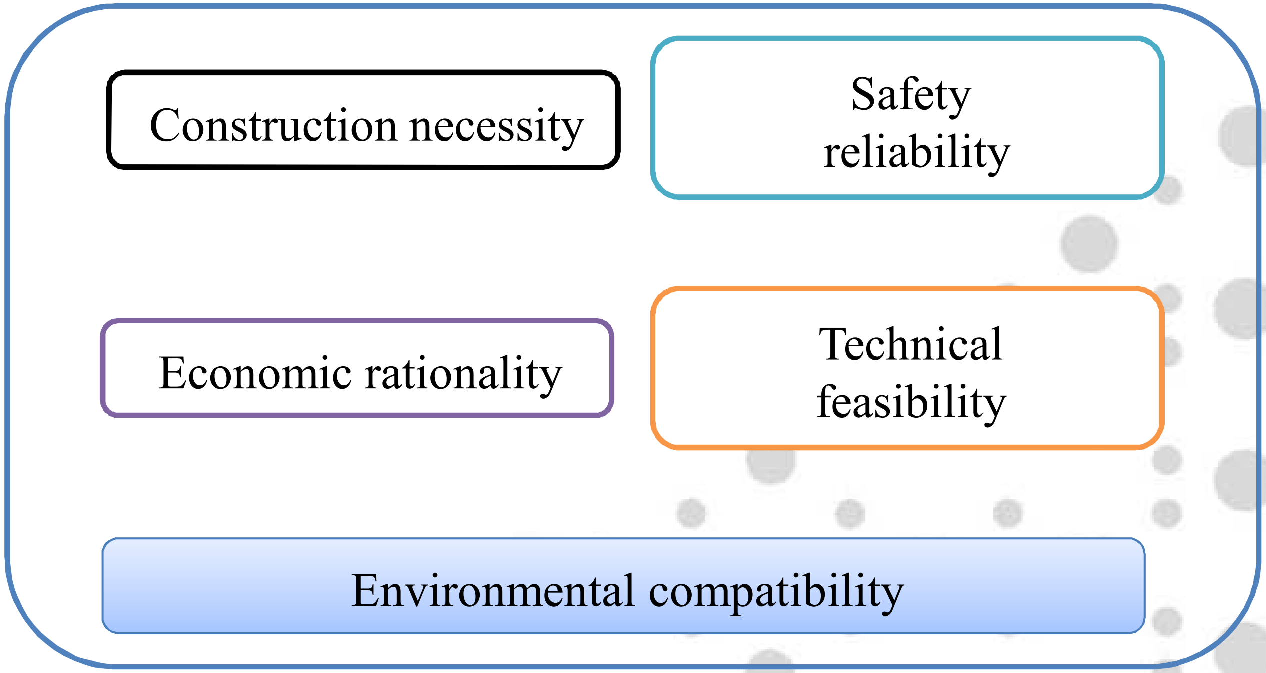
- FNPP is expected to replace the current power sources of gas turbine generators in sea oil production isolated benthoal grid.
- Analysis and calculation shows that the FNNP with multiple auxiliary devices and systems can adapt different emergency and keep stability.





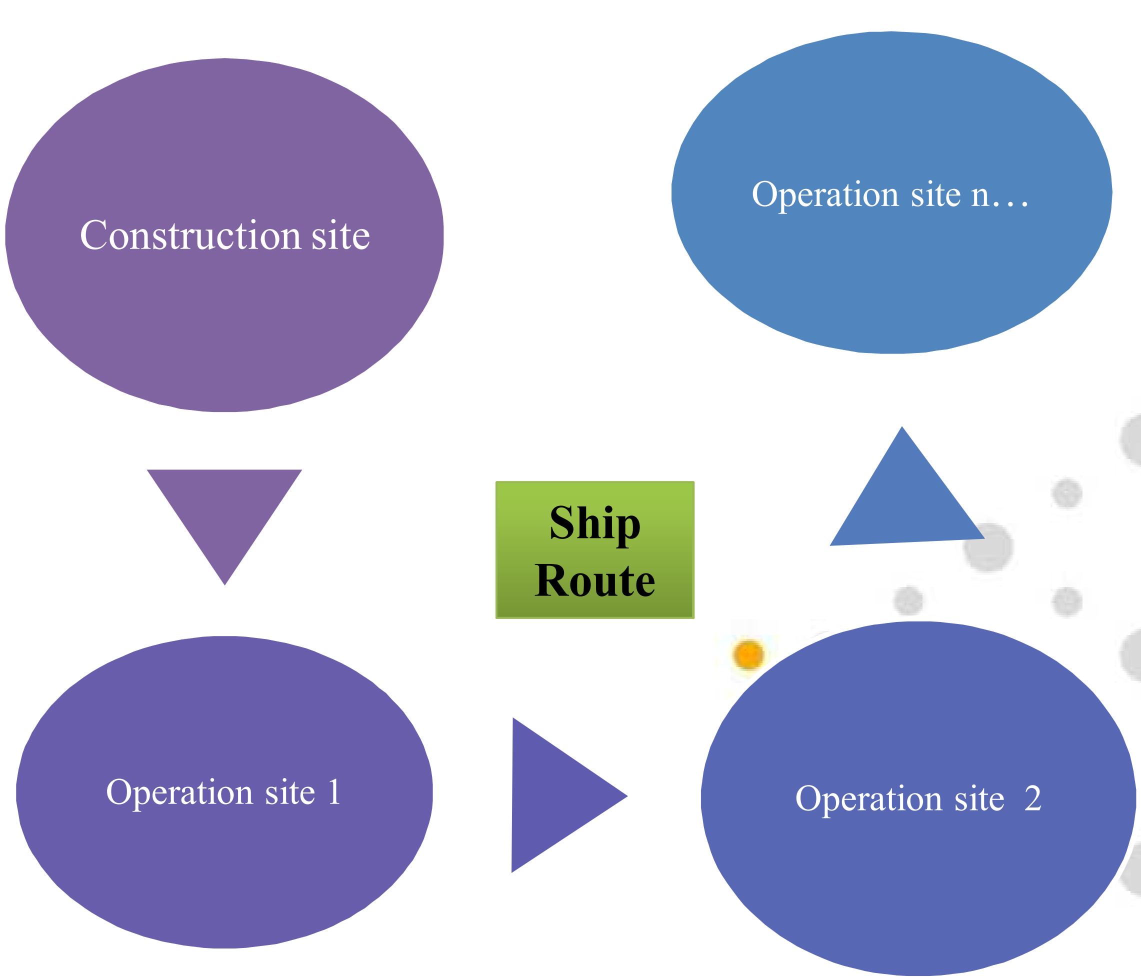
3.7 Siting Requirements

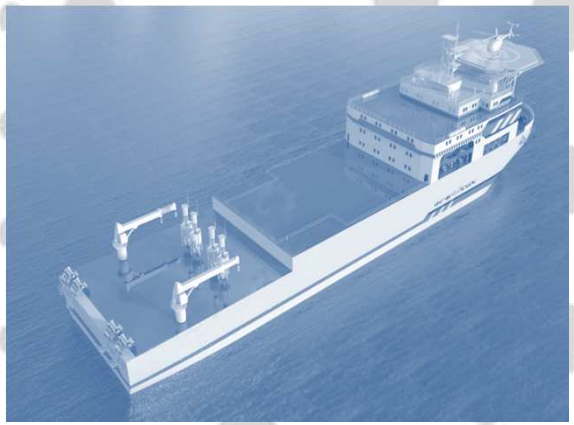
The same as the LNPP SMR, siting of ACPR50S should follow the following principles:



3.7 Siting Requirements

Unlike LNPPs, there are more than one site for FNPP SMR ACPR50s:





3.7 Siting Requirements

The difference between Small FNPP and Small LNPP in siting requirements:

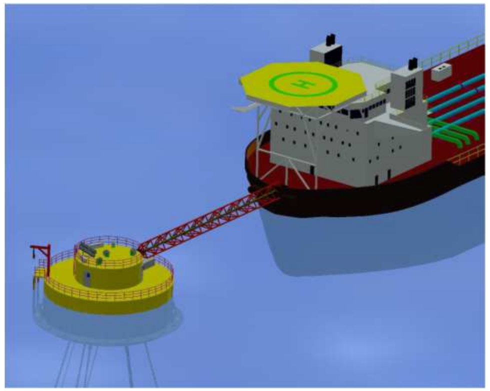
Site factors	Small LNPP	Small FNPP			
		Construction site	Operation site	maintenance base	Ship route
hydrology, weather	√	√	√	√	√
Rock-soil, earthquake	√	√	×	√	×
Submerged rock, shoal	×	√	√	√	√
Water intake and outlet	√	√	×	√	×
Sea-route	×	√	√	√	√
Transportation	√	√	√	√	√
Population	√	√	√	√	×
External man induced event	√	√	√	√	√
Environmental impact and emergency	√	√	√	√	√

3.7 Siting Requirements

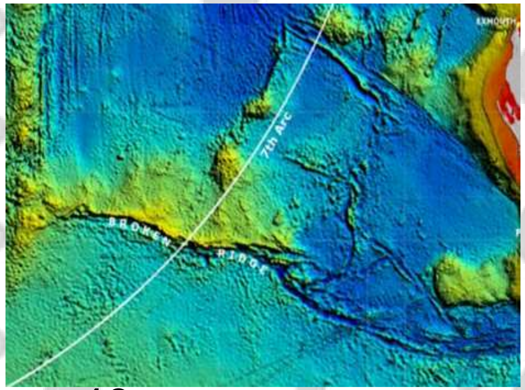
Main siting factors of FNPP with ACPR50s:

- Earthquake: No need to consider in floating state.
- Sea route: Need to consider the safety of navigation. Avoid running aground and stranding.
- Severe sea condition: when typhoon and other bad condition, ACPR50s can sail to the safe area.
- Mooring system: Need to select the appropriate mooring system according to operation site conditions.

Severe sea condition



Mooring system



Submarine topography

04

International Sea Transportation of FNPP with SMR ACPR50S

4.1 Background

- In 2013, IAEA published "Legal and Institutional Issues of Transportable Nuclear Power Plants: A Preliminary Study".
- ACPR50S is a floating NPP which need to take international ocean transportation into account in some cases.
- The two aspects below are being studied.

✓ Legal issues

✓ Safe, secure, efficient and reliable transportation: Safety, Security, Emergency

4.2 Legal issues

As a participant, CNPRI is studying the case of Transportation of FNPP.

Country A
(Country of origin)

FNPP is designed and constructed in Country A. Country A is in charge of the transportation of FNPP.

↓

Country B:
(Transit country)

The transportation of FNPP passes Country B's territorial waters.

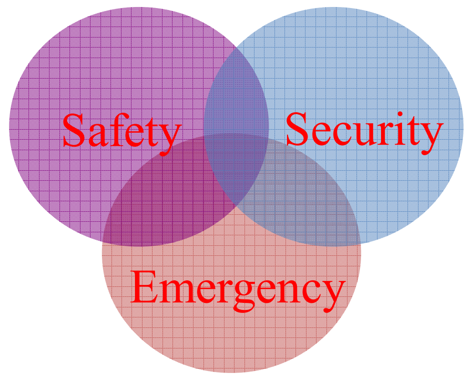
↓

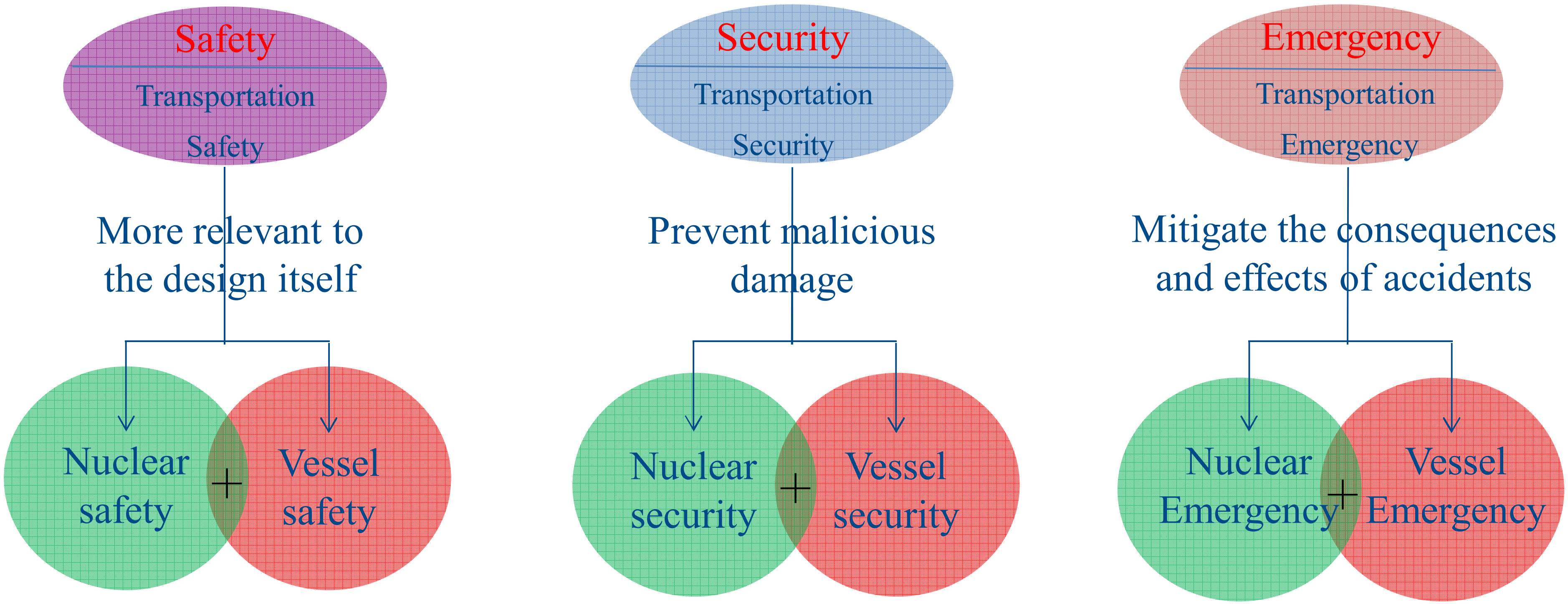
Country C:
(Receipt country)

Rental and use the FNNP.

Safety, Security, Emergency.

The three countries are independent and interrelated





05
Summary

Summary

- CGN is developing compact SMR(ACPR 50 and ACPR50S) which are modular designed with high level safety, industry-proven and reliable NPP and sea facility technology which makes ACPR50(S) good economics.
- ACPR50(S) is multiple applications and the site selection of ACPR50(S) is more flexible which makes ACPR50(S) having broad market prospects.
- CGN will continue to carry out FNPP transportation research, and actively exchange results with IAEA and other countries.

中广核 CGN

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Thank You For Your Attention