

INTRODUCTION of CAP1400

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Assistant Director, Sep 2015

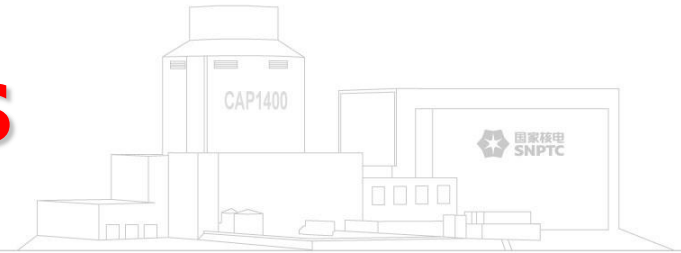


国家核电
SNPTC

**Shanghai Nuclear Engineering
Research & Design Institute (SNERDI)**

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III. Summary



I. SNERDI Introduction

1. SNERDI Introduction

□ ShangHai

- Area: 6340 square kilometers
- Population: 24 million
- Gross value of production: 380 billion US \$



1. SNERDI Introduction



Qinshan NPP



Chashma NPP in PAK



Qinshan III (PHWR)



1970-2007 Independently researched, developed and exported CNP300 (Gen 2/2+)



Sanmen NPP (AP1000)



Lufeng NPP (CAP1000)



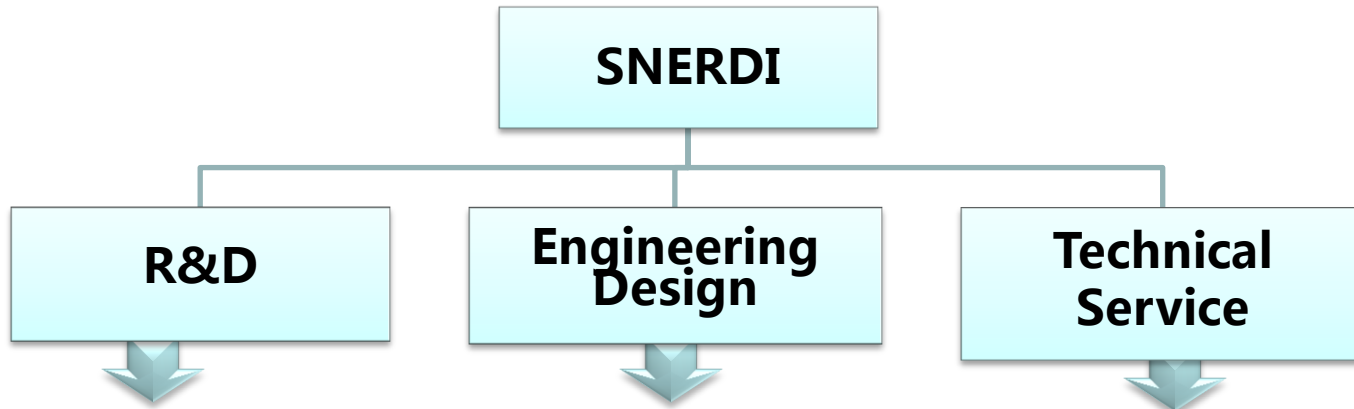
ShiDaoBay NPP (CAP1400)



2007-now Introduced AP1000 (Gen 3), digested, absorbed and re-innovated CAP1400 (Gen 3)



1. SNERDI Introduction



National key projects

NI key design tech

NI key equipment design tech

PRE research of Serial model

Localization & Standardization

Important experimental task

Prophase

Engineering design

Equipment design

License Application

Tech service in plant

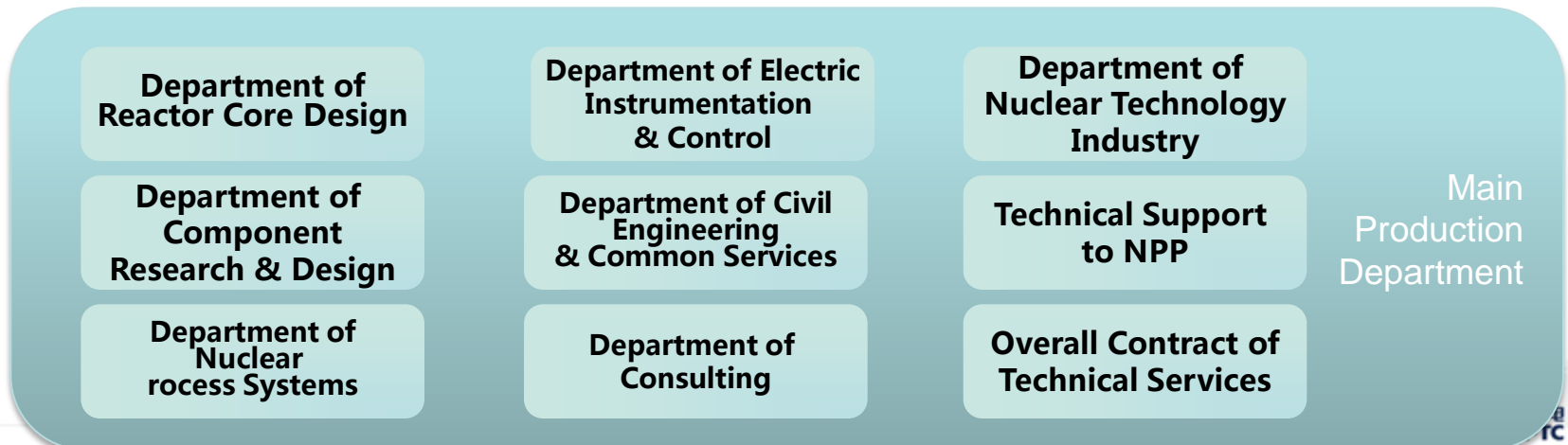
construction

Safety evaluation of plant in service

Ageing management

Safety technology design & transformation

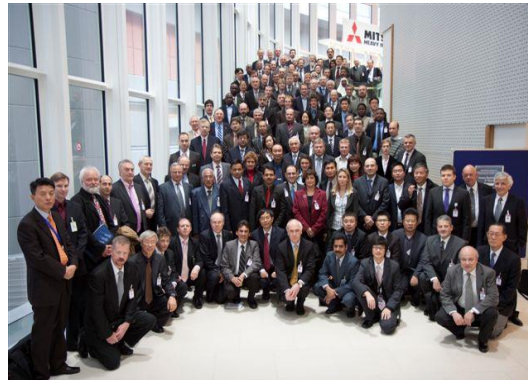
Refule support and fuel cycle



1. SNERDI Introduction

□ International Cooperation

- Cooperation Organization: IAEA,
- Cooperation Association: ASME, IEEE, ANS.....
- Cooperation Enterprise/Institute/University: EPRI, Westinghouse, GRS, UMich.....



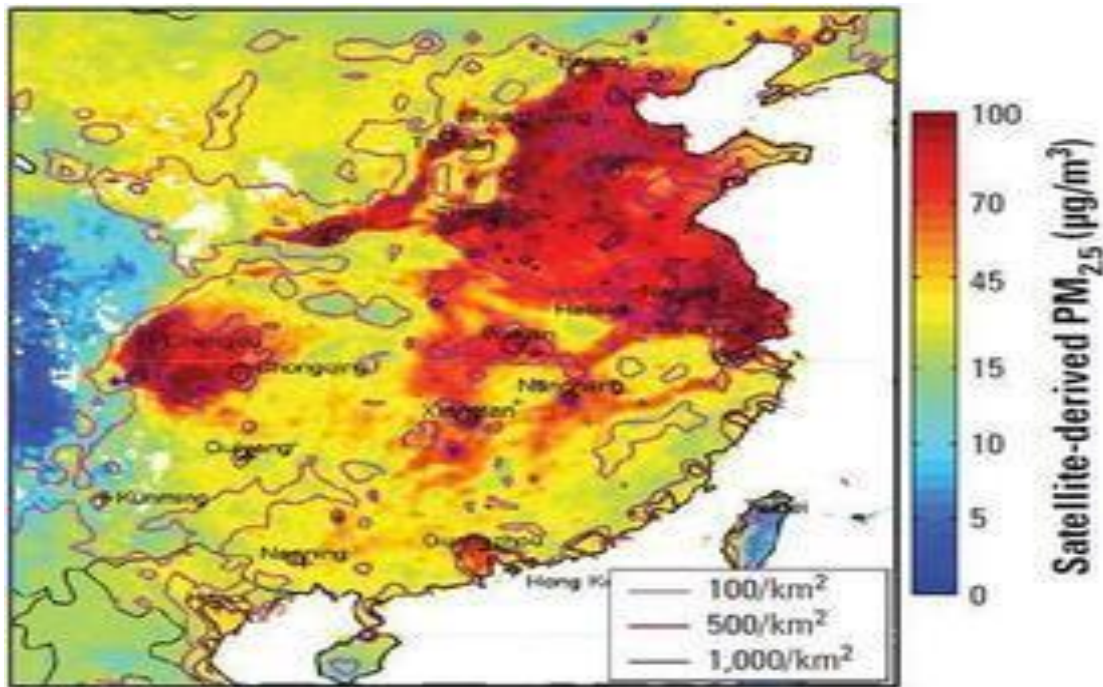


II. CAP1400 Overview

1. Background

□ Facing the pressure on

- Energy saving and sustainable development
- SO₂ & CO₂ discharge reduction
- Environment protection challenges (acid rain, fog and haze)



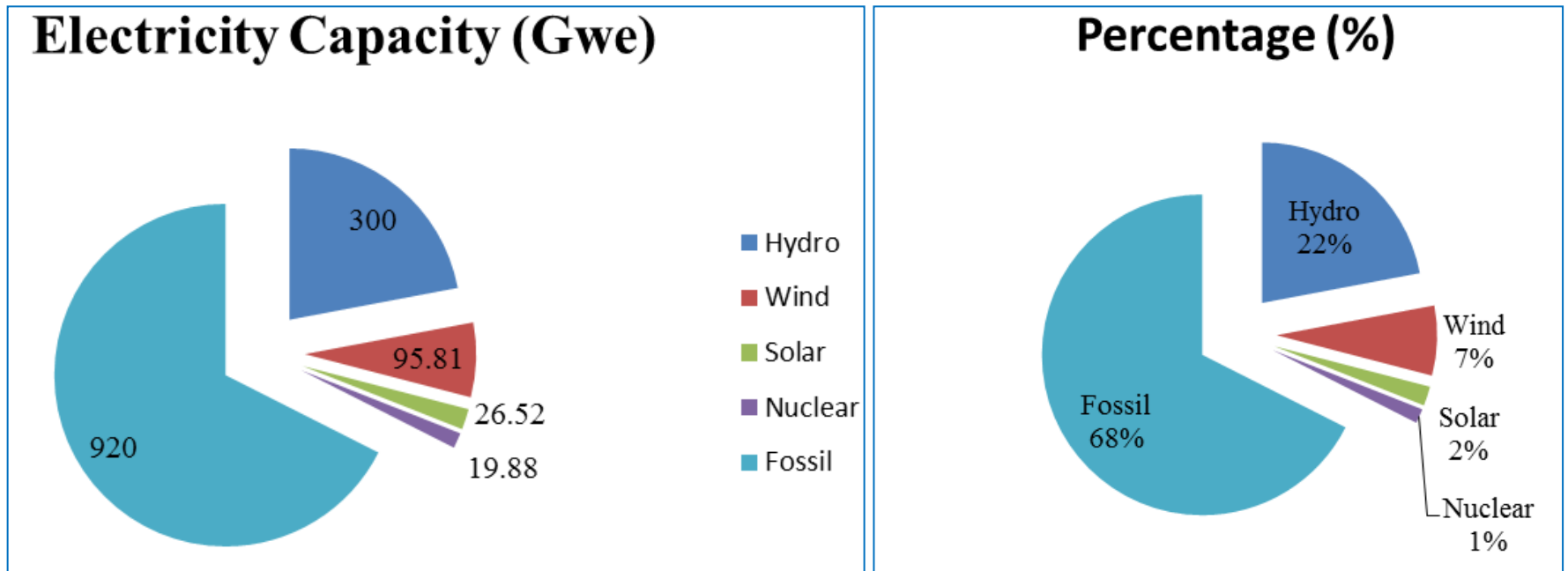
PM_{2.5} distribution



Haze call for energy structure revolution

1. Background

- Facing the pressure on energy structure
 - 1360 GWe Electricity Capacity of China last year (2014), and will reach to 1460 GWe at the end of 2015
 - The ratio for non-fossil fuel will increase up to 35% in 2015, besides is 33.3% in 2014

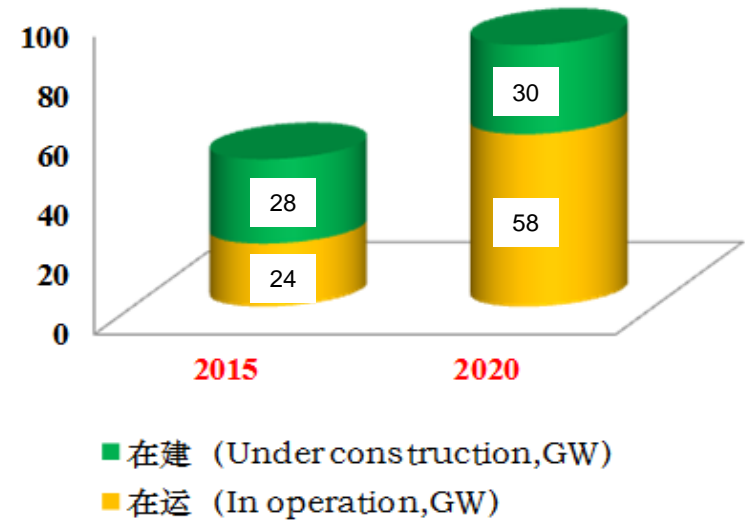


26 units in operation, 25 units under construction
(Data from China Electricity Council)



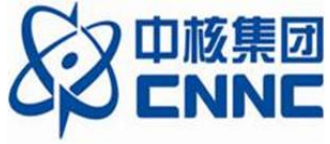
1. Background

- Nuclear is an effective solution
- **Government Strategy**, “Mid to Long Term Nuclear Development Plan (2011-2020)” issued On Oct.24,2012 by **NEA** (**National **Energy **A**dmistration), :
to 2020: **58GW in operation, and 30GW under construction**
(from 2.39% in 2015 to ~4% in 2020)****



1. Background

Utility , Vender and Technology in China



Tech: CNP300, CNP600, ACP1000, CANDU, VVER
Vender + Utility, 12 units, 9.67GWe operation and
10 units, 10.14GWe construction



Tech: M310, CPR1000, EPR
Vender + Utility, 14 units, 14.74GWe operation and
10 units, 12.04GWe construction



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SNPTC

Tech: CNP300, CNP1000, (C)AP1000, CAP1400
Vender, 2 units, 3GWe for CAP1400 will get
permission in the second half of 2015



Tech: AP1000
Utility, 2 units, 2.5GWe for AP1000
construction

Hua Long 1#



SPIC
CAP1400



2. CAP1400 overview

□ What is CAP1400?

- **Passive safety features** (Passive core cooling system, passive containment cooling system, passive main control room habitability system, etc.)
- 2 loops symmetrical arrangement, one loop with 1 SG and 2 MCPs
- With high electricity output about **1500MWe** in gross
- Design life 60 years, and the design annual availability **> 93%**
- Non-intervention time after accident for operators **~72 hours**
- Refueling interval **18 month**, and has the ability to operation with half of core MOX fuel loading
- Design safety goals for CDF and LRF $<1.0 \times 10^{-6}$ /reactor year and $<1.0 \times 10^{-7}$ /reactor year, respectively, the actual value for CDF and LRF is **4.02×10^{-7}** and **5.21×10^{-8}**
- Design construction duration for first CAP1400 is 56 month, the goals are to be controlled in 48 month
- A passive **G-III NPP with independent IPR**

2. CAP1400 overview

□ What is the basis of CAP1400?

- AP1000 TT from WEC, and subsequently assimilation, absorption and innovation
- Government support and invest on R&D, total 11.9 Billion RMB (about **2 Billion US\$**) for research, design, test and pre-manufacture
- Domestic nuclear power experience, including **40+ years** PWR R&D, engineering, manufacture, construction; **20+ years** safe operation
- The **very good industry system** for NPP equipment manufacture and adequate capacity
- Broad cooperation and **joint efforts** from domestic & abroad nuclear industry, beyond 100 company, factory, institute and university involved and make contribution

2. CAP1400 overview

Global Participation



Westinghouse(US) provides design consultation;



L&M (US) participates in PMS development;



OSUs (US) participates in test verification;



EMD(US) and KSB (Germany) participate in the development of Reactor Coolant Pump;



GRS (Germany) participates in engineering verification;



Laboratories of OECD provide large amounts of test data;



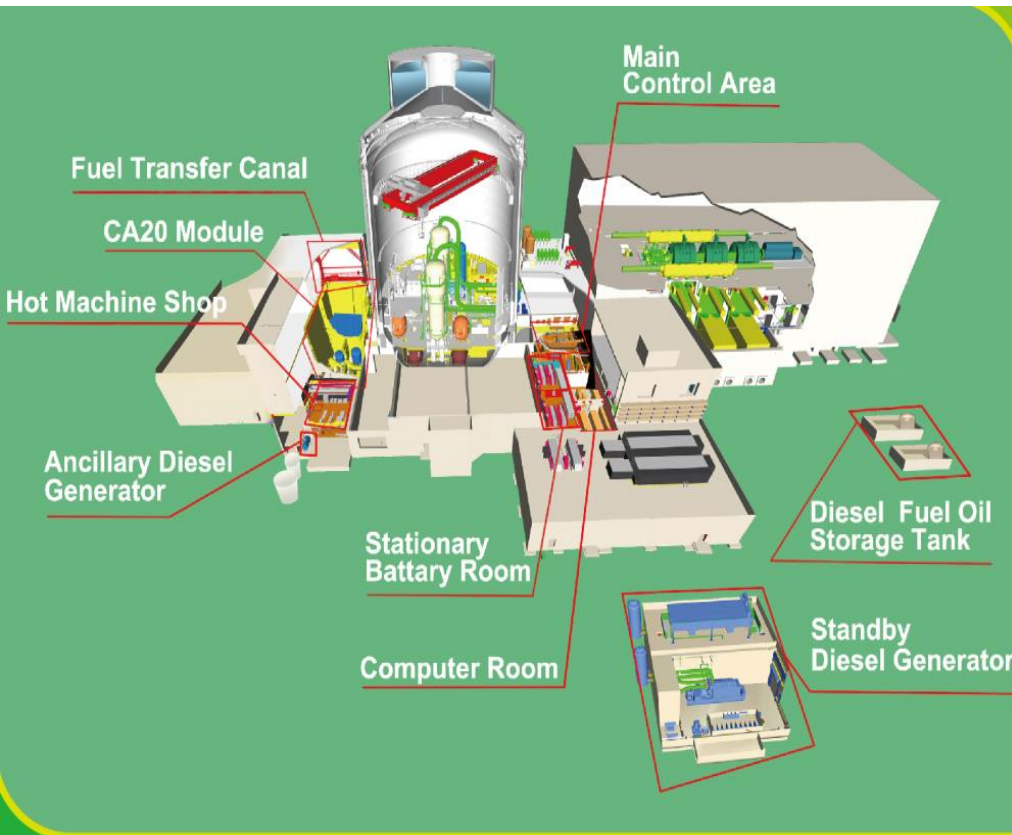
Corporate from US, Canada and Japan participate in equipment material research and test verification;

2. CAP1400 overview

- Design Principle/criteria & application
 - **Meet the newest rules/regulation/standards** (the newest Chinese law/regulations/applicable national standards, IAEA' s safety guides, NRC' s regulations, URD' s requirements)
 - **More safety** (Passive concept, DID, PSA, enhanced accident resistance, core damage prevention and mitigation)
 - **More Economic** (High capacity, modularization, high availability, Simplification/Localization/Standardization)
 - **More friendly** (Better neighbor through Radiation protection & Radwaste minimization)
 - **Localization of materials and equipment**
 - **Digital control system and advanced main control room**
 - **Standard design with enveloped site parameters**
 - **Modular design and construction**
 - **Address Lessons learned from Fukushima event**

2. CAP1400 overview

□ NPP General Arrangement of CAP1400



2. CAP1400 overview

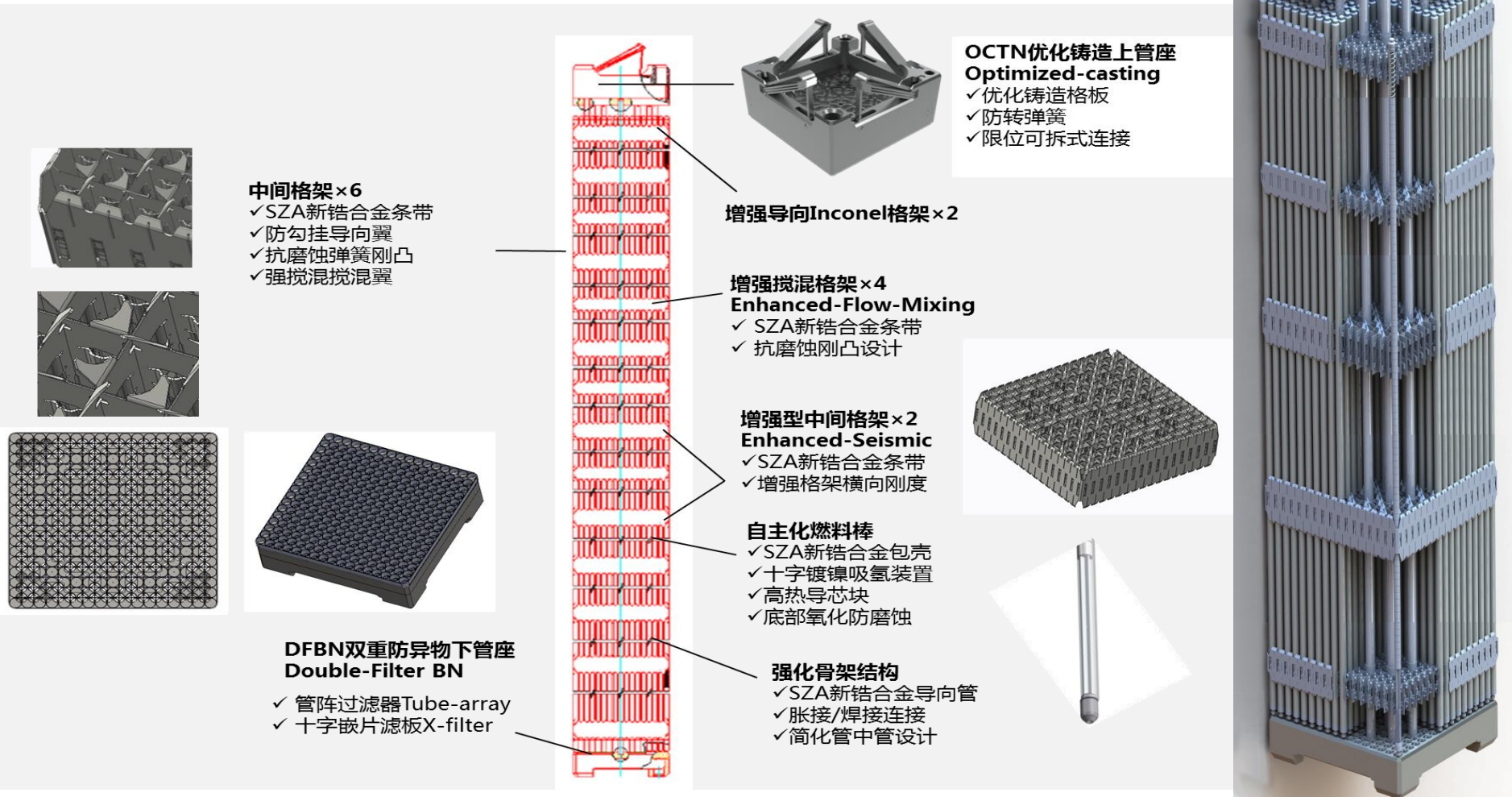
□ Design Features

Parameters	AP1000	CAP1400
Reactor core output , MWt	3400	4040
Electrical output , MWe	~1250	~ 1500
Reactor type	2-loop	2-loop
Averaged reactor T , °C	300.9	304
Fuel assembly No.	157	193
Averaged linear power , W/cm	187	181
MCP flowrate , m ³ /h	17886	21642
SG exit P , MPa(a)	5.61	6.0
Steam flowrate(Per SG) , kg/s	944	1122
DNBR margin	>15%	>15%

2. CAP1400 overview

High performance fuel assemblies for CAP1400

- 14 feet high, 55000MWD/tU
- the calculation codes, materials, test has been carried out

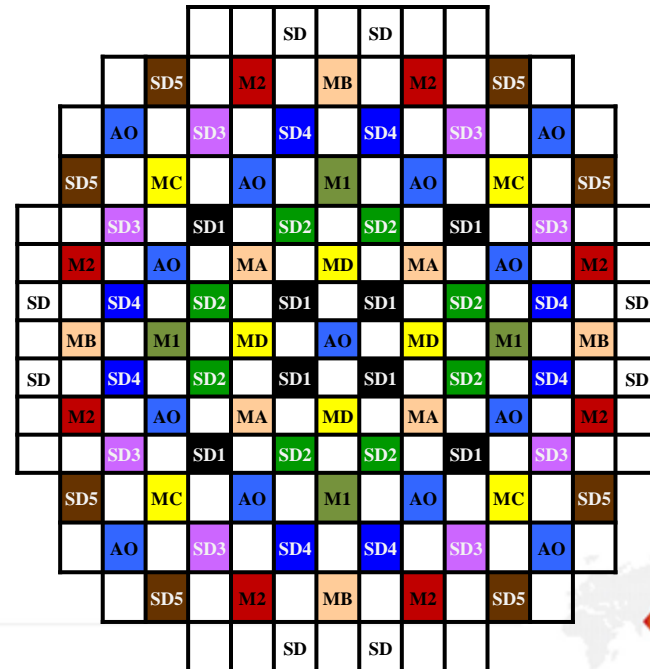


2. CAP1400 overview

□ Core Design

- 17*17 fuel assemblies, DNBR margin is $\geq 15\%$
- low-leakage core pattern, Mechanical SHIM control strategy
- Difference from AP1000:
 - ✓ 193 fuel assemblies
 - ✓ High average burnup (5% higher, $\sim 53000\text{MWd/tU}$)
 - ✓ MOX fuel loading capability

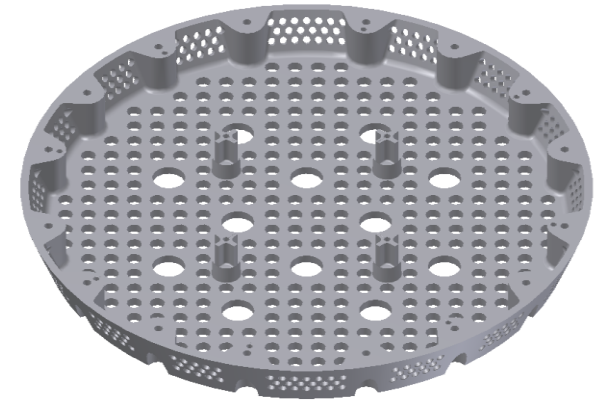
	H	G	F	E	D	C	B	A
08	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED E1_124	FEED A1_000
09	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_068_12	FEED C1_000
10	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED E1_124	FEED A1_000
11	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED E1_136	FEED C1_000
12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED E1_156	FEED C1_000	
13	FEED D1_088_12	FEED B1_000	FEED D1_088_12	FEED B1_000	FEED E1_156	FEED B1_000	FEED C1_000	
14	FEED E1_124	FEED D1_068_12	FEED E1_124	FEED E1_136	FEED C1_000	FEED C1_000		
15	FEED A1_000	FEED C1_000	FEED A1_000	FEED C1_000				



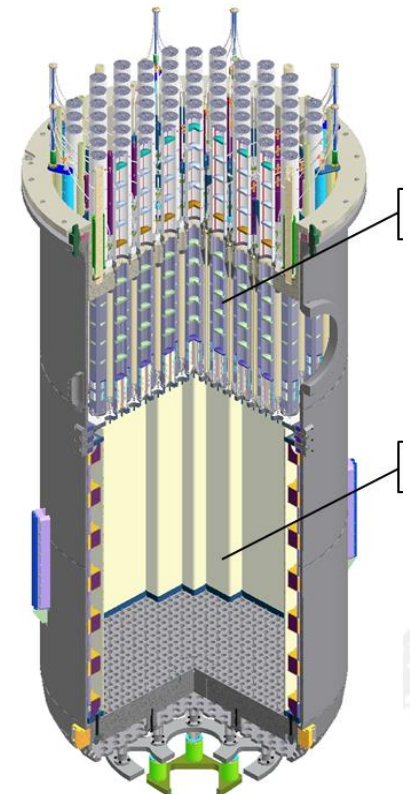
2. CAP1400 overview

□ CAP1400 Main Equipment—RV&RVI

- Active core region of RV is forged
- Without neutron shield pad in RV, can reduce the risk of loose components
- Reactor internals weight increased to facilitate the implementation of IVR and is beneficial for anti-FIV
- Even-flow distributor replaces flow skirt to optimize the distribution of the flow into reactor



Even-flow distributor



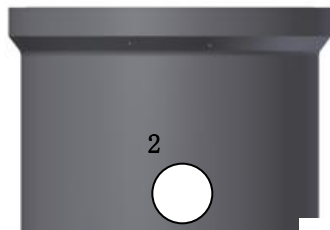
Category	Test Cases
Flow Simulation	76
FIV	12

2. CAP1400 overview

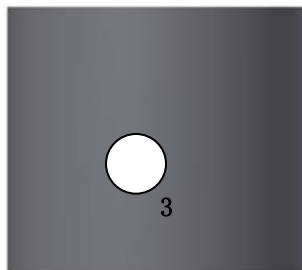
RPV--CFHI



(1) IHP



(2) Nozzle



(3) Core tube



(4) Bottom head

2. CAP1400 overview

□ CAP1400 Main Equipment—SGs

- New design of SGs, SNP140 type
- 12606 U-Tubes, and 27% heat transfer area increased comparison with □125 SGs of AP1000
- The integrated performance of SG, and the capability of moisture separator and steam dryer have been verified by approximately 300 test cases.

Category	Test Issues	Test Cases
SG Test	Moisture separator test	220
	Flow distribution of secondary side	50
	Sound vibration and FIV test	5
	Flow resistance test on coolant side	5
	Dynamic characteristics test for U-Tube	3



2. CAP1400 overview

SG-DEC



Elliptic Head



A & B supporting block



Cone

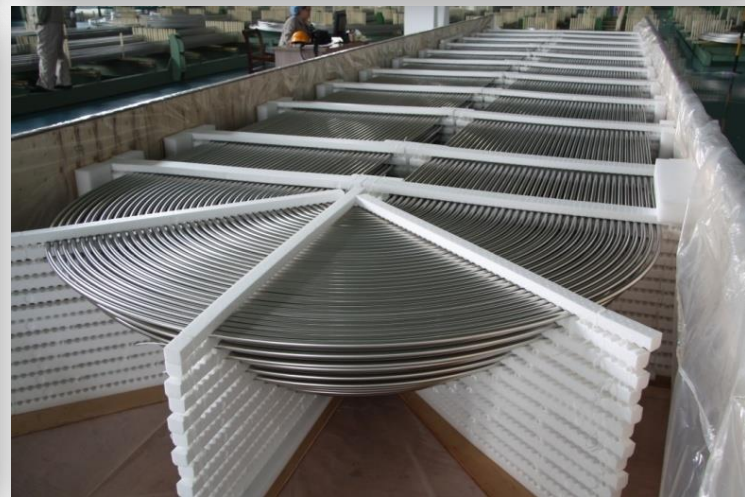


Tube sheet

2. CAP1400 overview

690 Alloy u shape tube for SG

The first batch U type tube was delivered to customer on April 26, 2014.



2. CAP1400 overview

- CAP1400 Main Equipment—MCPs
 - Two different technique routings, canned pump , wet winding motor pump
 - The canned pump manufactured in Shen Yang, Liaoning province, the prototype pump will be tested this year
 - The wet winding motor pump manufacture in Shanghai KSB, the prototype pump is being tested on facility
 - The design flow increased to 121% of AP1000



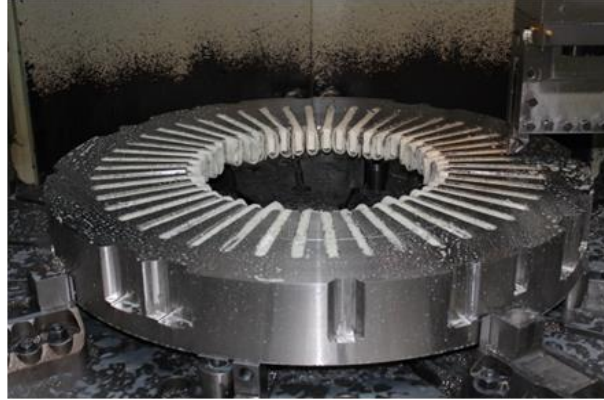
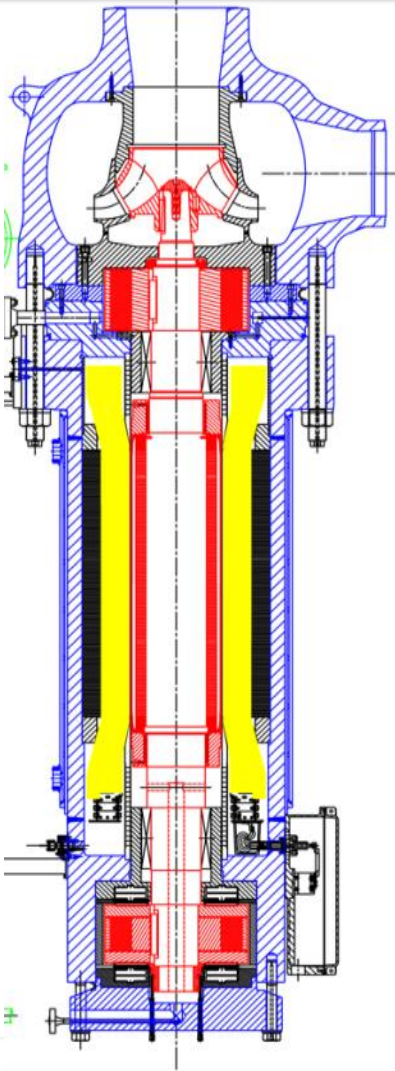
Canned MCP rotor



Wet MCP erected for test

2. CAP1400 overview

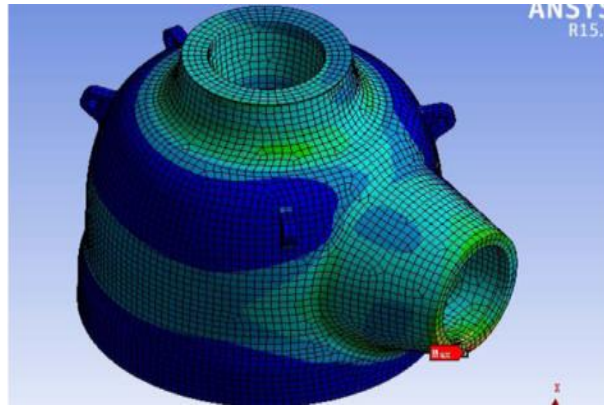
RCP-CANNED PUMP-SBN/HEC



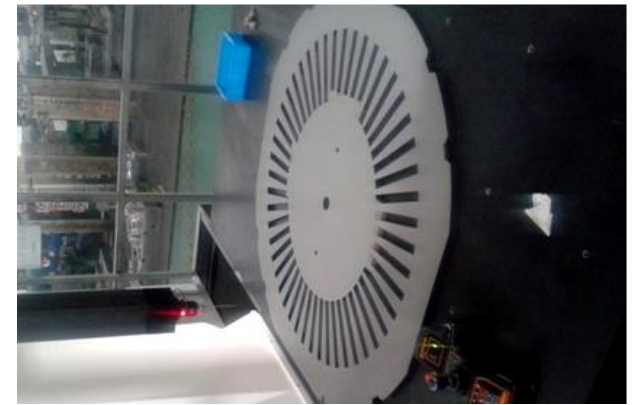
Fingerplate



Stator Winding Mockup



Pump Shell 3D Design



Punching

2. CAP1400 overview

RCP-RUV PUMP-SEC/KSB



Test loop



Prototpye



Stator



Rotator



2. CAP1400 overview

Squib valves (DN200, 250, 350, 450)

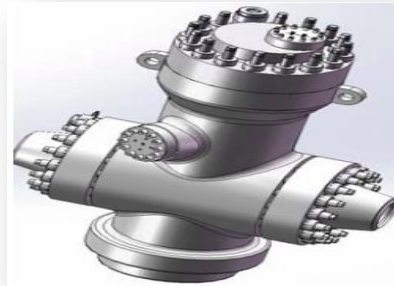
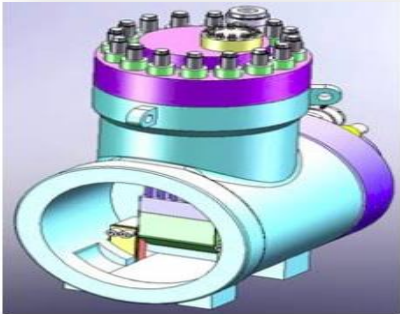
- ❑ April 17, 2014, the prototype(DN450) has been successful tested.
- ❑ Prototype DN450 squib valve will be available in 2015.
- ❑ DN350, DN200 prototype trial blasted.



DN450



DN350



DN200

2. CAP1400 overview

□ CAP1400 Main Equipment—Passive Systems Capacity

- The relevant equipment capacity have been redesigned and analyzed
- All the thermal hydraulic phenomena has been verified on PXS Test Facility (ACME) and PCS Test Facility (CERT)

Component	CAP1400	AP1000	Increased by
CMT	85m ³	70.8m ³	+21%
ACC	78.6m ³	56.6m ³	+39%
Water	66.4m ³	48.1m ³	+38%
IRWST	2780m ³	2070m ³	+34%
DVI	10in	8in	+25%
PCCWST	3700m ³	3008m ³	+23%
ADS4	DN450	DN350	+60% (capability)

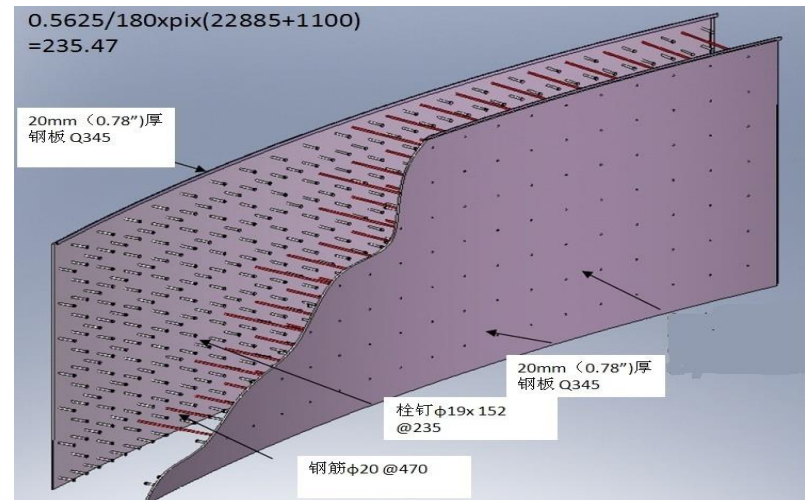
2. CAP1400 overview

□ CAP1400 Main Equipment—CV and Shield Building

- Steel containment is designed to get a high margin, more free volume and higher design pressure
- Size of CV, Internal diameter 43m, height 73.6m
- **SC structure (1.1m thick) for shield building to resist large commercial airplane crash**



CV Bottom Head

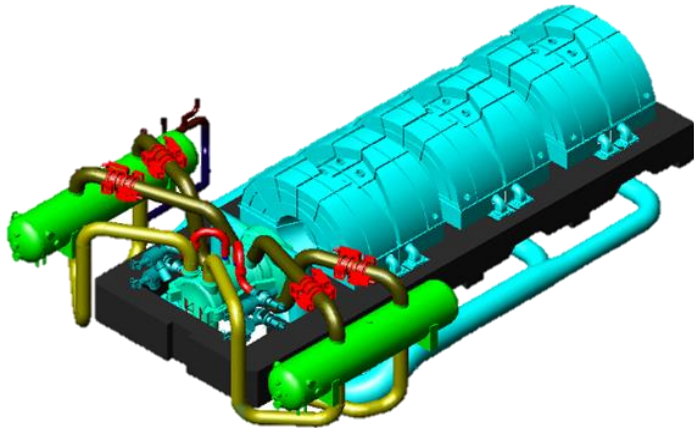


	CAP1400
Design P	0.443MPa
P maximum(Level C)	0.946MPa

2. CAP1400 overview

□ CAP1400 Main Equipment— Turbine

- 1500 rpm, Tandem combined HP-IP cylinder, 3 LPs with 6 exhaust.
- Last blade length: 1828 mm



2. CAP1400 overview

CAP1400 T-G



Generator rotator



HP upper casting



LP2 rotator



HP rotator forging



MP under casting

2. CAP1400 overview

□ Localization of materials and equipment

- ✓ Gen III qualified supplier chain were basically formed.
- ✓ 88 Chinese companies were qualified.
- ✓ Over 85% of equipment and materials localized
- ✓ Other will be localized in the coming 3-5 years



RCP test loop



RCP motor



RCP Heat shield
guide vane



CMT



Squib
valves



RV



SG



PRZ



RCS Pipe



PRH

2. CAP1400 overview

□ Design Verification

- 887 test conditions performed for the 6 key tests on the 12 new test facilities and 10 modified test facilities.
- As one of the National Key Projects, the critical test conditions witnessed by NEA and NNSA respectively.
- The test results verify the design and supporting safety reviews.



Facility for hydro-simulation



Facility for SG steam-water separation test



ACME complex



CERT facility



IVR test facility

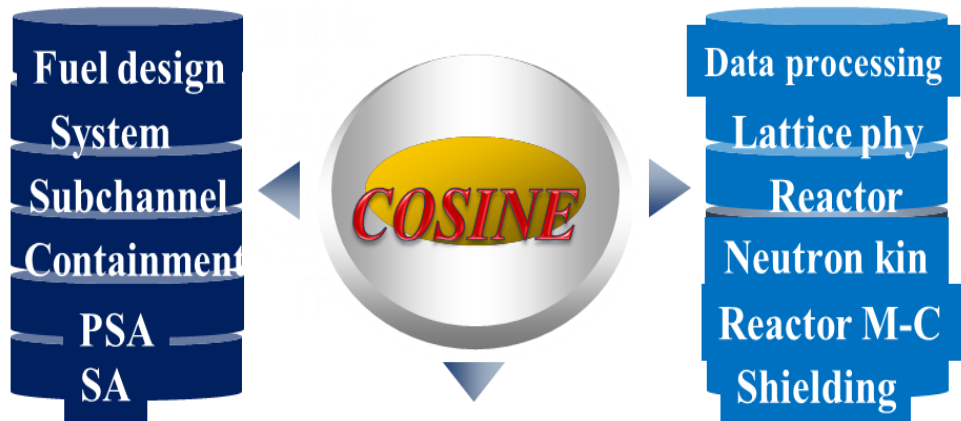


Facility for FIV test

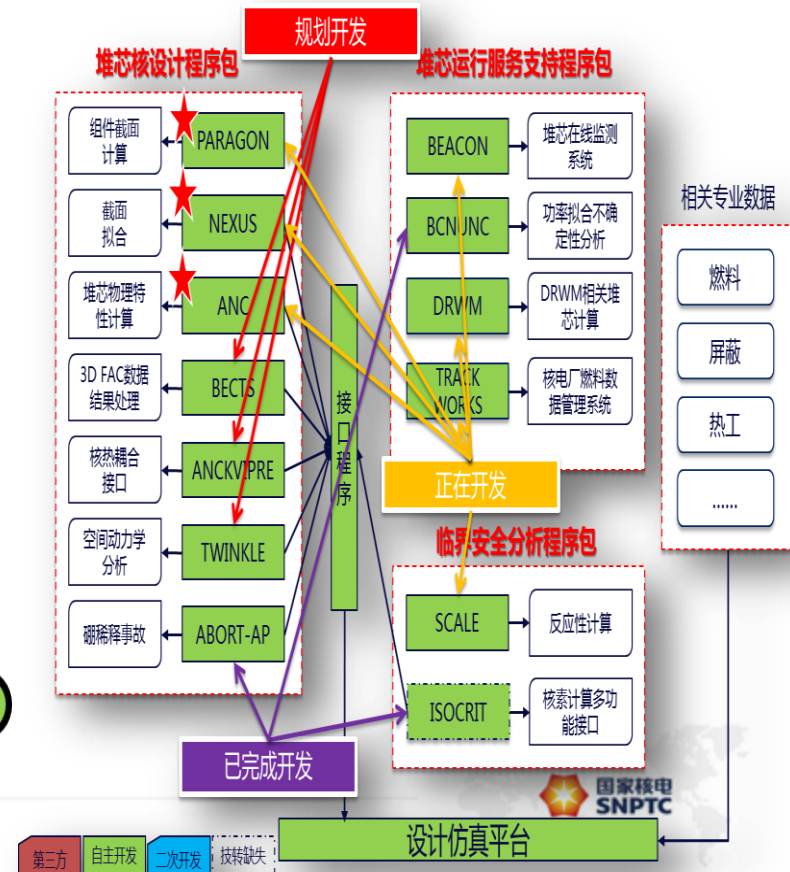
2. CAP1400 overview

Codes development for design of CAP1400

- Two independent codes under development, one is being developed in SNERDI, the other is being developed in SNPTC research institute (Core & System Integrated Engine for design and analysis (COSINE))



Integrated comprehensive analysis platform



2. CAP1400 overview

- Standard design with enveloped site parameters

Standard site parameter	Design Value
Atmosphere Temperature	-40~46°C
Wind Speed	Extreme wind speed: 65m/s Tornado: 134m/s
Seismic	SSE=0.3g (applicable for the high seismic area)
Design base flood level	Lower than plant elevation (dry site)
Ground Water level	-0.6m Lower than plant elevation
Rain	525.8mm (1hr)
Snow / Ice	3.6 kPa
Site exclusion area	≥800m

2. CAP1400 overview

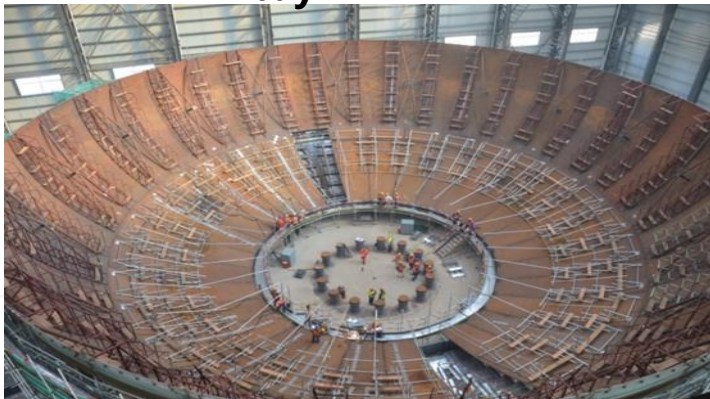
□ Site preparation



1# Nuclear Island



1st bay



- SNPTC&HUANENG established SNPDP in Sep,2009.
- Strategic agreement signed to construct CAP1400 demonstration plant Dec 2013.
- Be ready for FCD.



2. CAP1400 overview

□ CAP1400 Lessons learned from Fukushima Accident

- Seismic capability enhanced : SSE(Safety Shutdown Earthquake) 0.3g
- Automatic seismic trip system (Seismic class I) installed to enhance the seismic responding
- “Dry” site design philosophy, movable flashboard installed in auxiliary building and compartment of IE class battery with higher elevated ground level to protect the plant from external flooding
- Water source & power supply for emergency enhanced
- Hydrogen control capability enhanced
- SAMG optimized
- Post accident monitoring enhanced

2. CAP1400 overview

□ CAP1400 response to the Fukushima event

- Due to the passive safety feature and the fail-safe design for PRHR and PCS, the SNERDI-Westinghouse joint assessment of AP1000 response to the Fukushima event showed that the plant would have the following results with limited operator actions
 - No fuel damage occurs in the reactor core or in the spent fuel pool.
 - Containment integrity is maintained.
 - No unacceptable radiological releases occur.
 - No offsite assistance is required for 72 hours.

2. CAP1400 overview

□ CAP1400 response to the Fukushima event

- Since CAP1400 followed the "passive safety" feature, and made several further improvement for safety systems, it could be concluded that CAP1400 has **same or better mitigation capability** under similar accident.
- The Safe Shutdown Earthquake **Peak Ground Acceleration level of 0.3g** was applied in CAP1400 design, which could cover most of the site condition. In addition, the Seismic Margin Assessment showed the **HCLPFs for safety class SSCs were not less than 0.5g**.
- According to current codes and standards, CAP1400 was a "dry site" design with proper margin. The **nuclear safety equipments would not be affected by flooding**.

2. CAP1400 overview

□ CAP1400 response to the Fukushima event

- CAP1400 had **diverse power supply systems**, including onsite and offsite AC and DC power sources, which could maintain the plant safety for 72 hours. In addition, the ancillary diesel generators could provide power to post-72 hour facilities.
- Based on the passive safety systems, **CAP1400 could maintain the plant safety within 72 hours without AC power**. After 72 hours, the non safety DID facilities could provide another 4 days cooling. After 7 days, only limited offsite support was required, and the relative interfaces were already considered in the CAP1400 design.

2. CAP1400 overview

□ Design Review

- **Three-tier Review performed**

- ✓ **1st tier Internal Design Review:** Inner independent design review and utility design review are performed for confirming design match the demand of engineering construction.
- ✓ **2nd tier Safety Review:** Safety review are performed for licensing by National Nuclear Safety Administrator (NNSA), as the safety supervision authority.
- ✓ **3rd tier Design Review:** As one of national Key Projects, CAP1400 need to be reviewed by National Energy Administration(NEA), as the representative of nation.

2. CAP1400 overview

□ Internal Design Review

- **Internal independent design review:** It is performed by the experts, not participate in design, from SNERDI and CI design institute.
- **Utility design review:** Peer view is organized by utility.
- **Enough documents & drawings for 12 months construction after FCD.**

2. CAP1400 overview

□ Safety Review by NNSA

- Unprecedented Safety Review: Most Wide/Deep in History

- ✓ **PSAR Review**

- ✓ **6 special topics review:** code and experimental facility applicability analysis , safety analysis of containment and shield building , safety analysis of major components, severe accident analysis, seismic margin analysis or seismic PSA, I&C

- ✓ **Independent calculation and analysis** by NNSA

- ✓ **Critical experiments** witnessed and independent experiments

- ✓ **Independent design validation** by utility

Over **5300 questions** replied through 3 rounds of dialogue during 18 months with **200 NNSA staffs** involved up to 2014.09.



PASR kickoff meeting



Site review Expert consulting meeting



PSAR review end meeting

2. CAP1400 overview

□ Design Review by NEA

- **Conceptual Design Review** : CAP1400 concept design content is comprehensive, technical scheme is reasonable and feasible, can carry out preliminary design work
- **Basic Design Review** : Content integrity, advanced technology, feasible in general



January 9, 2014 , CAP1400 pass basic design review (more than one year)



III. Summary

1. Summary

□ An advanced large passive PWR

- Independent development and optimization based on AP1000 technology.
- Reliable system design, increased safety margin, and comprehensively considered severe accident prevention and mitigation.
- Standard design approaches wide site suitability.
- The Largest Passive PWR, simplified systems and module design to improve economy.

□ Comprehensive Design verification

- Test verification for passive safety system and key equipment.
- Multi-tiers design review for engineering performability.

1. Summary

- ❑ Independent Design and Localization of Key equipment
 - Independent design of key equipment and materials
 - High localization rate of key equipment and materials: 85% for 1st unit

- ❑ Follow the Newest regulations/codes/standards
 - Follow the newest domestic regulations/codes/standards, especially for the post-Fukushima technical policies.
 - Refer to international regulations/codes/standards, including the corresponding IAEA guides and NRC regulations.
 - The updated & effective codes/standards, such as ASME, is applied.

1. Summary

□ Safety Enhancement with Fukushima Feedback

- Based on the inherent passive safety system, CAP1400 have high capability against extreme external event.
- Further enhancement of CAP1400 improve the survivability of plant beyond design basis external hazards.
- CAP1400 meet the safety requirements including the Post-Fukushima Requirements.



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