华龙国际核电技术有限公司
Hualong Pressurized Water Reactor Technology Corporation, Ltd.

An Advanced Active & Passive PWR
能动与非能动技术相结合的先进压水堆

HPR1000 presentation

”华龙一号”介绍

Hualong Pressurized water Reactor Technology Corporation, Ltd.

华龙国际核电技术有限公司

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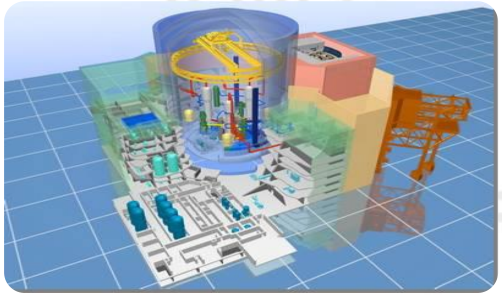
1. Overview （1/2）
概述

1.1 HPR1000 Overview
华龙一号

- An evolutionary advanced PWR nuclear power technology developed according to HAF, IAEA SSR, EUR, URD and the post-Fukushima safety requirements
- Taking advantages of proven technology, considering experience feedback from PWR NPPs in operation and under construction all over the world, keeping in line with the state laws and regulations
- Improved safety, reliability and economic efficiency of the HPR1000



- 作为渐进改进式先进压水堆技术，满足HAF/IAEA SSR/EUR/URD，以及福岛事故后新的安全要求；
- 华龙一号采用成熟技术，充分考虑了全球在建/在运压水堆的经验反馈；
- 华龙一号系统性地提升了安全性、可靠性和经济性。

1. Overview （2/2）

概述

1.2 Roadmap of PWR Domestically-development & Oversea-introduction 研发历程

ACP1000 (CNNC) and ACPR1000+（CGN） are developed based on over 30 years NPP experience in R&D, Manufacture, Construction and Operation experience. HPR1000 is evolved from ACP1000 and ACPR1000+.

Independent design of CNP300
自主建造秦山一期
(CNP300)

Independent design of CNP600
自主建造秦山二期
(CNP600)

Independent construction of CNP1000/CPR1000
自主建造CNP1000/
CPR1000

Independent R&D of CP1000/ACPR1000
研发具有自主知识产权
的CP1000/ACPR1000

Independent R&D of ACP1000/ACPR1000+
ACP1000
ACPR1000+
三代核电技术
HPR100

"华龙一号"是由华龙国际公司在 ACP1000 和 ACPR1000+ 技术的基础上进一步优化形成的三代核电技术。

Introduction of M310 (Daya Bay NPP)

引进大亚湾核电站技术

Cooperative construction of LingAo Phase I
合作建设岭澳一期

Introduction of VVER

引进VVER核电站技术

Introduction of EPR

引进EPR核电站技术

Introduction of AP1000

引进AP1000核电站技术

02

Plant Design

技术方案

2.1 Technical Characteristics

技术特征

2.2 General Parameters

主参数

2.3 Design feature

设计方案

2.4 Feedback from Fukushima accident

福岛事故反馈

2. Design feature
技术方案

2.1 Technical Characteristics (1/2)
技术特征

- 177 12-feet advanced fuel assemblies
- Active + Passive safety measures
- Reactor Core thermal power 3180MWt ,
- Nominal Power ≥1200 MWe
- CDF<1×10^{-6}/reactor • year

  LRF<1×10^{-7}/reactor • year
- Safety margin ≥15%
- Single-unit layout
- SSE: 0.3g
- Double shell containment

- 177个12英尺燃料组件的反应堆；
- 能动与非能动相结合的安全措施；
- 堆芯热功率3180 MWt，机组额定功率不小于1200MWe；
- 概率安全目标：CDF<1×10^{-6}/堆•年、LRF<1×10^{-7}/堆•年；
- 堆芯热工裕量≥15%；
- 单堆布置；
- 安全停堆地震0.3g；
- 大自由容积双层安全壳

2. Design feature
技术方案

2.1 Technical Characteristics (2/2)
技术特征

- Protection against Large Commercial Aircraft Crash
- Design lifetime of 60 years
- Refueling cycle of 18~24 months
- Average plant availability ≥90%
- Minimum 30min nonintervention
- Design features for Design Extension Conditions
- DCS and advanced MCR
- Improved in-core instrumentation inserted from upper head
- IRWST
- LBB
- Solid Rad-waste Volume < 50 m^3/reactor · year
- Collective dose of occupational exposure < 0.6 person · Sv/reactor · year

- 抗大型商用飞机撞击
- 60年设计寿命
- 18~24个月换料周期
- 电厂平均可利用率≥90%
- 操纵员不干预时间不低于30分钟
- 完善的设计扩展工况应对措施
- 全数字化仪控系统
- 堆芯测量从堆顶引入，取消反应堆压力容器下封头贯穿件
- 安全壳内置换料水箱
- 破前漏技术
- 放射性废物离堆处理，待处置固体废物年产生量小于50m^3/堆•年
- 职业照射集体剂量小于0.6人•Sv/堆•年

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2.2 General Parameters (1/2)
主参数

Core rated power 堆芯额定功率	3180 MW
Nominal power 机组额定功率	1200 MW
RCS Operation pressure 一回路运行压力	15.5MPa (abs)
RCS Design pressure 一回路设计压力	17.23 MPa (abs)
RCS Average temperature 一回路平均温度	310℃
RCS Design temperature 一回路设计温度	343℃
Nominal primary flow-rate (Best Estimated) 反应堆冷却剂系统最佳估算流量	~25000 m^3/h/loop
Active length of fuel 堆芯活性段高度	12 ft
Number of fuel assemblies 燃料组件数	177
Average linear power density 平均线功率密度(冷态)	181.2 W/cm
Number of control rod assemblies 控制棒组件数	69

2.2 General Parameters （2/2）
主参数

Heat transfer area of SG SG换热面积	~6500 m^2
Secondary side design Temperature SG二次侧设计温度	316 ℃
Design pressure of primary containment 安全壳内壳设计压力	0.52MPa (abs)
Design temperature of primary containment 安全壳内壳设计温度	145℃
Containment Free Volume 安全壳自由容积	＞73000 m^3
Turbine Rotating speed 汽轮机转速	1500 r/min
Voltage of auxiliary power 厂用电电压等级	10 kV

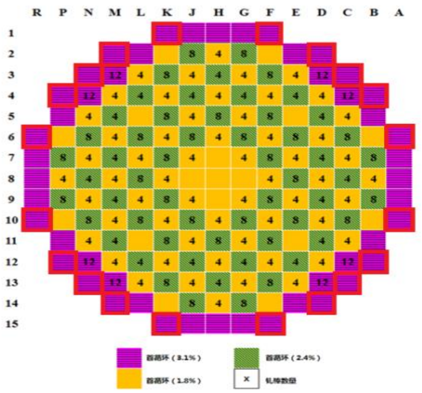
2. Design feature
技术方案

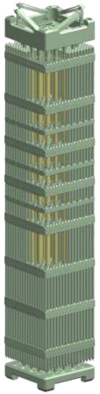
2.3 Design feature
设计方案

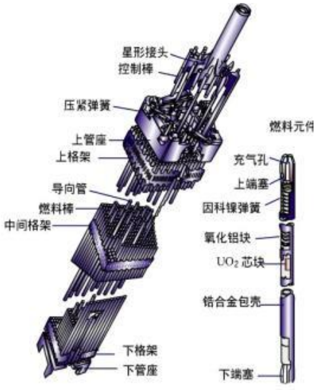
- **Core Design 堆芯设计**

  - 177 fuel assemblies with 12 feet active length
  - Low leakage fuel loading pattern， refueling cycle of 18~24 months
  - Fuel assembly average discharge burn-up ≥45 GWd/tU
  - Load follow ability and Low-power operation ability
  - Capability of fuel cycle with MOX fuel

    - 177组12英尺燃料组件
    - 低泄漏换料堆芯装载模式，换料周期为18~24个月
    - 组件的平均卸料燃料≥ 45 GWd/tU
    - 具备负荷跟踪和低功率运行能力
    - 具备使用MOX燃料的能力







2. Design feature
技术方案

2.3 Design feature
设计方案

- **Core Design 堆芯设计**

■ 69 RCCAs

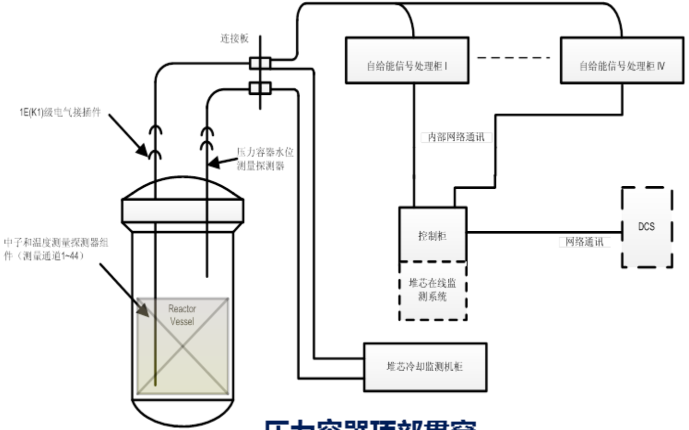
■ In-core neutron measurement system with SPND detector

■ In-core instrumentation top mounted, no penetration in the RPV bottom head

■ 69组控制棒组件设计

■ 采用SPND技术的堆芯测量系统

■ 堆内仪表采用从堆顶插入堆芯的方式



压力容器顶部贯穿

2.3 Design feature
设计方案

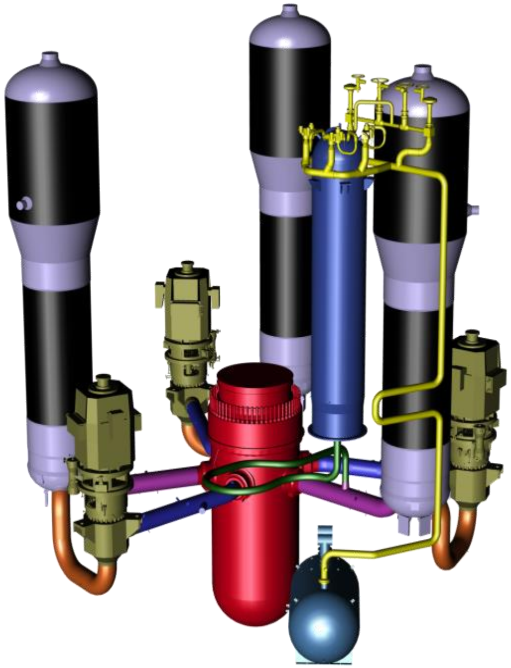
- **Reactor Coolant System 反应堆冷却剂系统**

The RCS of HPR1000 is design with 3 loops, each of which includes a SG and a RCP. The pressurizer with electric heater is connected to one of the loops.

- Three-loop configuration
- Pressurizer equipped with safety valves, Fast Depressurization valves
- Vertical U inverted tube SG
- Shaft seal reactor coolant pump
- Forged reactor coolant pipe

华龙一号的RCS采用三环路设计，每个环路包含一个SG和一个反应堆冷却剂泵。采用电加热器的稳压器连接在其中一个环路上。

- 三环路
- 稳压器设有安全阀和严重事故卸压阀
- 轴封型主泵
- 立式倒U型蒸汽发生器
- 锻造的冷却剂管道



2.3 Design feature
设计方案

● **Reactor Structure 反应堆结构**

Reactor pressure vessel 压力容器

- RPV design life of 60 years, the forged main components without longitudinal welds
- Top mounted integrated in-core measurement assemblies without penetrations at bottom of RPV
- 69 control rod assemblies
- High point vent of RPV

- RPV设计寿命60年，压力容器主要部件整体锻造，无纵焊缝；
- 一体化堆内测量组件从RPV顶盖引入，RPV底部无贯穿件；
- 反应堆本体结构包括69组控制棒组件
- 高位排气。

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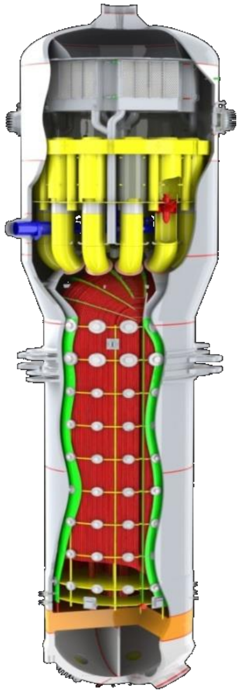
2.3 Design feature
设计方案

- **Reactor Coolant System　　反应堆冷却剂系统**

  Steam Generator　蒸汽发生器

  - Vertical inverted U-tube natural circulation SG
  - Large liquid inventory and steam volume of SG secondary side
  - Two stage Moisture Separator
  - Design life of 60 years

    - 立式倒U形管自然循环蒸汽发生器
    - 大的二次侧汽空间和水空间
    - 两级汽水分离装置
    - 设计寿命60年。

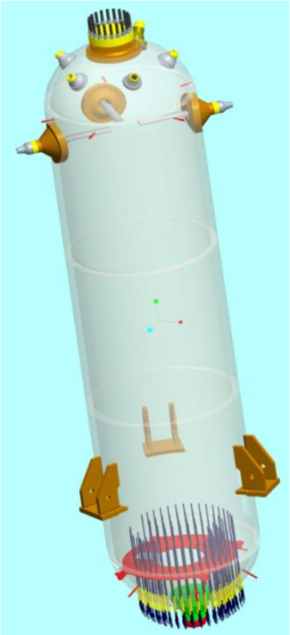


2. Design feature
技术方案

2.3 Design feature
设计方案

- **Reactor Coolant System　　反应堆冷却剂系统**

Pressurizer　稳压器



- A vertical cylindrical shell, closed at two ends by hemispherical heads
- Low carbon alloy steel
- Large steam and water volume
- Direct immersion electric heater of PRZ

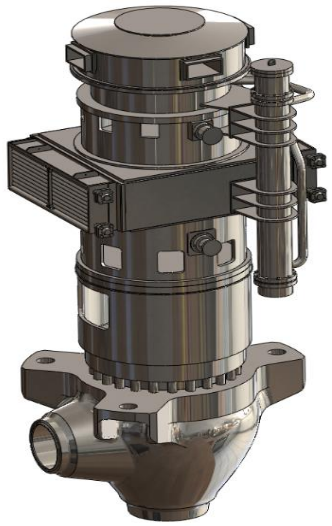
  - 采用立式圆柱形稳压器
  - 采用低合金钢制造
  - 足够大的汽水空间
  - 稳压器电加热器采用直接浸入式结构

2.3 Design feature
设计方案

- **Reactor Coolant System　　反应堆冷却剂系统**

Reactor coolant pump　反应堆冷却剂泵

- Single stage and vertical shaft
- Reliable and efficient shaft seals structure
- The stand still seal system to maintain the integrity of primary system at least 72 hours under SBO (station blackout) condition

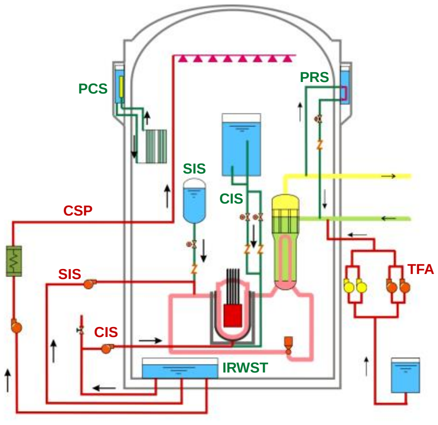


- 单级、立式结构;
- 采用成熟高效的轴封设计;
- 安装有停车密封系统,可确保全厂断电工况下72小时内边界完整。

2. Design feature
技术方案

2.3 Design feature
设计方案

- **Safety system 安全系统**



Red: active Green: passive

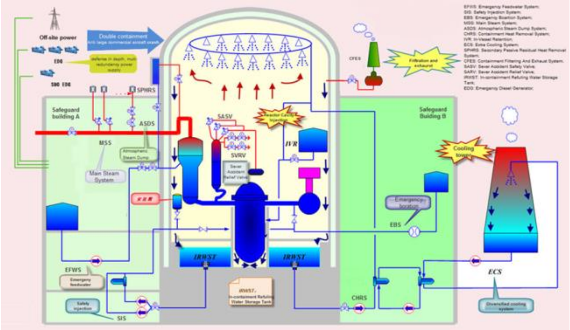
Option 1 选项一

2 Active Trains + Passive features

“二列能动安全系列+非能动安全系统”

Tailored safety systems to meet customers’ demands

可根据用户需求选择使用。



Option 2 选项二

3 Active Trains + Passive features

“三列能动安全系列+非能动安全系统”

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2.3 Design feature
设计方案

- **Safety system 安全系统**

■ DBC Counter-measures

设计基准工况应对系统

Defense in depth(Level 3)
纵深防御第3层次

•Safety Injection System安注系统
•Auxiliary Feed-water System辅助给水系统
•Containment Heat Management System安全壳能量管理系统
•Atmospheric steam dump system大气排放系统
•Emergency diesel generators应急柴油发电机

■ DEC-A counter-measures

DEC-A 应对措施

Defense in depth(Level 4a)
纵深防御第4a层次

•Passive cooling from SG secondary side二次侧非能动余热排出系统
•SBO Diesel Generator SBO电源
•Emergency Boron Injection System应急硼注入系统
•Diverse Actuation system DAS系统
•Diverse Cooling Source 多样化冷源

■ Server accident mitigation measures

严重事故缓解措施

Defense in depth(Level 4b)
纵深防御第4b层次

•Diverse Containment Cooling System 多样化安全壳热量导出系统
•Fast Depressurization System for RCS一回路快速卸压系统
•Containment Hydrogen Control System安全壳消氢系统
•Reactor Cavity Injection and Cooling System堆腔注水冷却系统
•Containment Filtration and Exhaust System安全壳过滤排放系统
•Severe Accident I&C and large capacity batteries 严重事故专用仪控系统与大容量蓄电池
•On-site emergency water makeup and mobile diesel generators厂区应急补水与移动电源

2. Design feature
技术方案

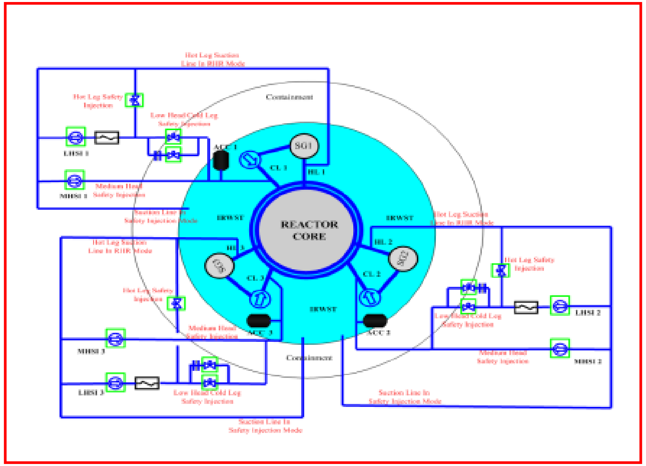
2.3 Design feature
设计方案

● **Safety system 安全系统**

■ Design Basis Condition Counter-measures
设计基准工况应对系统

Improved configuration:

- Independent MHSI
- IRWST
- large ACC
- Improved Sump strainer
- Large capacity Atmospheric Steam Dump



Design enhancement to prevent SG overfill

- Automatic adjustment of feed water flow
- Redundant automatic isolation of feed water lines
- Additional SG blow-down for accident

2. Design feature
技术方案

2.3 Design feature
设计方案

- **Safety system 安全系统**

■ DEC-A Counter-measures
DEC-A 应对措施

Typical multiple failure 典型多重故障	Safety features 安全措施
ATWS 未能紧急停堆的预期瞬态	Emergency boron injection system 应急硼注入系统
Station blackout (SBO) 全场断电	SBO diesel generators/Standstill seal of main pump SBO柴油发电机/主泵停机轴封
Loss of U.H.S. 丧失最终热阱	Auxiliary feedwater supply + atmospheric steam dump /passive cooling from SG secondary side 辅助给水系统+大气排放/二次侧余热排出系统
Common mode failure of protection system 保护系统共模失效	Diverse actuation system 多样化驱动系统

2. Design feature
技术方案

2.3 Design feature 设计方案

- **Safety system**
  - Server accident mitigation measures 严重事故缓解措施

DEC-B phenomena DEC-B 现象	Countermeasures 预防和缓解措施
Containment Failure 安全壳失效: Hydrogen detonation 氢气爆燃	Containment Hydrogen Control System 非能动消氢系统
Containment Failure 安全壳失效: High pressure molten corium ejection, DCH 高压堆芯熔融物喷射、安全壳直接加热	Fast Depressurization System for RCS 一回路快速卸压
Containment Failure 安全壳失效: Long term overpressure 安全壳长期超压	Passive or Diverse Containment Heat Removal Sys. Containment Filtration and Exhaust System 非能动或多样化安全壳热量导出系统/安全壳过滤排放系统
Containment Failure 安全壳失效: Basement melt-through 底板熔穿	Reactor Cavity Injection and Cooling System 堆腔注水冷却系统
I&C, Habitability and specific procedures 仪控系统，应急设施可居留性， 专用规程	Dedicated I&C control system for Severe Accident and reliable power supply batteries; 采用蓄电池供电的专用严重事故仪控系统; Habitability Design of Main Control Room and emergency facilities; 充分考虑主控室与应急设施的可居留性 Development of SAMG (Severe Accident Management Guideline) 开发严重事故管理大纲
On-site emergency measures 厂区应急手段	emergency water makeup, mobile power supply and connection interfaces reserved 应急补水，移动电源，并预留相应接口

2. Design feature
技术方案

2.3 Design feature
设计方案

- **Diversity of Power Supply 多样化电源系统**

Two Independent Off-site power supplies

两路独立厂外电源

Emergency Diesel generators +2 h batteries

应急柴油发电机

SBO Diesel Generators/ DEC batteries

SBO柴油机/直流电源

Mobile power supply

移动电源

2. Design feature
技术方案

2.3 Design feature
设计方案

- **I&C design　仪控系统**

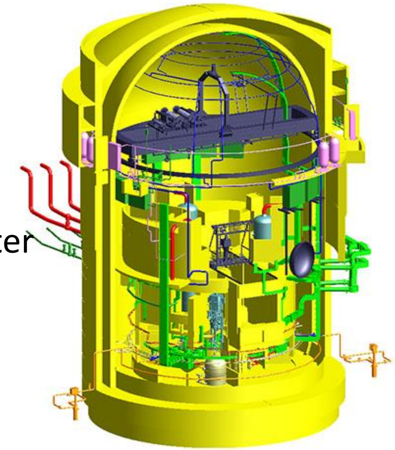
  - **Optimized DCS system and the advanced operator information system**
  - **DAS(Diversity Actuation System),to cope with DCS software CCF**
  - **Severe Accident Control System**
  - **Improved ventilation system, to improve the habitability of main control room**

  - DCS系统及操纵员信息系统;
  - DCS软件发生共模故障时采用DAS系统
  - 严重事故控制系统
  - 提升主控室可居留性

2. Design feature
技术方案

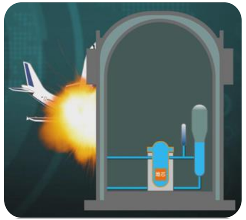
2.3 Design feature
设计方案

- **Layout of Nuclear Island 核岛总体布置**



- Single unit layout
- Double Shell Containment
- IRWST to avoid failure of Safety injection water suction switch-over
- Space separation between different safety buildings
- Physical separation between different series
- All natural events and human induced events related to site considered
- Necessary protection measures for internal hazards provided

- 单堆布置
- 双层安全壳
- **IRWST**，消除长期阶段安注水源切换风险
- 各列安全厂房区域分隔
- 不同系列之间实体隔离
- 考虑了所有与厂址相关的外部自然事件以及外部人为事件
- 也对内部灾害进行了分析并采取了必要的措施



Enhanced protection against external events

加强的外部灾害防护措施

- SSE:0.3 g
- Protection against Large Commercial Aircraft Crash
- External Flooding

- 安全停堆地震0.3g
- 抗商用大飞机撞击设计
- 外部水淹

2. Design feature
技术方案

2.3 Design feature
设计方案

- **Verification Tests** **试验验证**

■ Reactor coolant system 主系统

- ◆ Main mechanical systems （such as RPV） are progressively improved based on validation of long term engineering practice from existing PWR NPPs
- ◆ The design improvements are verified by tests (e.g., Flow-induced Vibration Simulation Test of Reactor Internals)
- ◆ 华龙一号主系统（如压力容器等）基于现有压水堆核电厂长期工程验证开展渐进性改进设计；
- ◆ 具有试验验证。

Flow-induced Vibration Simulation Test of Reactor Internals

Core inlet flow pressure drop test

Mixing Tests of reactor vessel down-comer

Seismic Test of Control Rod Driven Line (CRDL)

2. Design feature
技术方案

2.3 Design feature
设计方案

- **Verification Tests 试验验证**

■ Safety system 安全系统

- The configuration and operation of normal operating systems and "active" engineered safety features have been verified by long term engineering practice from existing PWR NPPs
- The design concept and technologies adopted for "passive" safety features have been verified by specific experiments/tests
  - 正常运行系统和能动专设安全设施经过现有压水堆核电厂长期工程经验验证;
  - 非能动安全系统设计的理念和技术已经过专门的试验验证。

Test of Cavity Injection and Cooling System

堆腔注水冷却系统性能试验

Passive residual heat removal test for secondary side

二次侧非能动余热导出系统试验

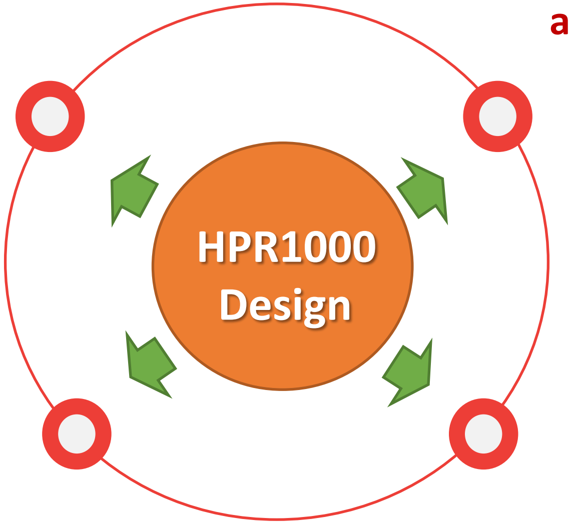
2. Design feature
技术方案

2.4 Feedback from Fukushima accident
福岛事故反馈

1. External Hazards　外部灾害

- Seismic design
- Flooding design
- Early warning mechanism

- 抗震能力
- 防洪能力
- 灾害预警机制



2. Safety function and accidents mitigation
安全功能和事故缓解

- 多样化或非能动设计
- 电源多样化与纵深防御
- 应急补水策略
- 乏燃料池冷却与监测

- Diverse or passive design
- Diverse power supply and defense-in-depth
- Emergency water makeup strategy
- Spent fuel pool cooling and monitoring function

3. DEC counter-measures
DEC工况应对措施

- The robust containment design
- DEC counter-measures
- Development of SAMG

- 坚固的安全壳设计
- DEC工况应对措施
- 制定严重事故管理导则

4. Emergency facilities and emergency Response　应急设施与应急响应

- 辐射监测和应急响应能力
- 应急设施可用性

- Radiation monitoring and emergency response
- Emergency facility availability

03

Project Progress

项目进展

3. Project progress (1/4)

项目进展

Fuqing 5&6 Units 福清5&6号机组

Construction completion of 5RX internal structure
5RX内部结构施工完成

2017.05.03

2017.05.25

Hoisting completion of the dome

穹顶吊装完成

Introduction of the first SG
首台蒸汽发生器引入

2017.11.10

2018.01.11

Roof sealing of 5RX primary Containment

5RX内层安全壳封顶

Installation of Reactor pressure vessel
压力容器安装完成

2018.02.14

2020.01.15

First fuel loading
首次装料

Commercial operation

商运

2020.01.15

3. Project progress (2/4)

项目进展

FCG 3&4 Units 防城港3&4号机组

Introduction of the first Accumulator

首台安注箱引入

2017.10.05

Staged progress of internal structure construction

内部结构11.6m板施工完成

2017.12.12

Start of equipment debugging of Unit 3

3号机开始调试

2020.02.29

First fuel loading of Unit 3

3号机首次装料

2020.10.31

2017.10.16

Start of equipment installation

核岛安装开始

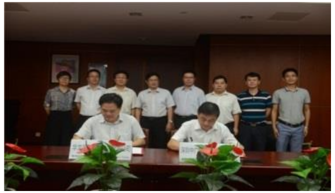
2017.12.31

Staged progress of Containment Hoisting

钢衬里筒体第九层吊装完成

3. Project progress (3/4)
项目进展

Other domestic projects 其他国内项目


Zhangzhou Phase I 漳州一期工程

Ningde Phase II 宁德二期工程

Taipingling Phase I 太平岭一期工程

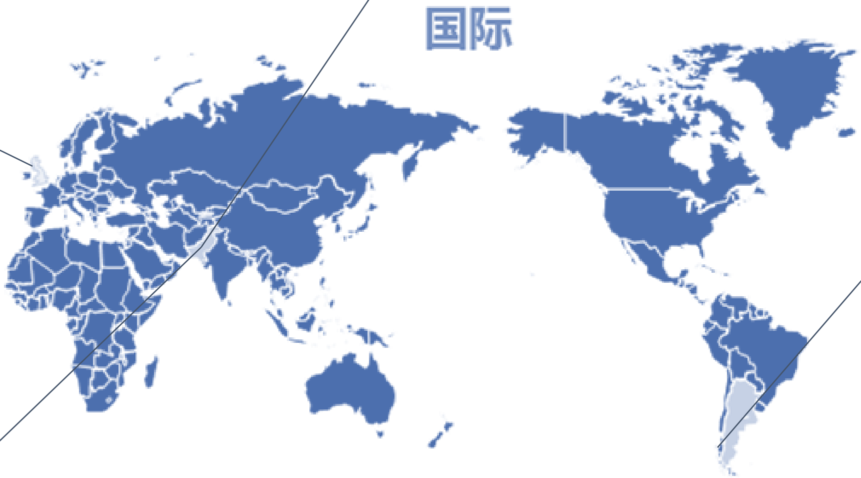
Changjiang Phase II 昌江二期工程

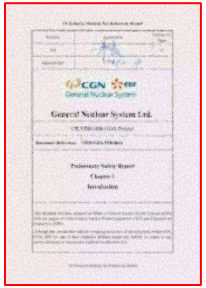
The works of pre- projects proceed smoothly.

目前项目的前期工作正按计划顺利推进。

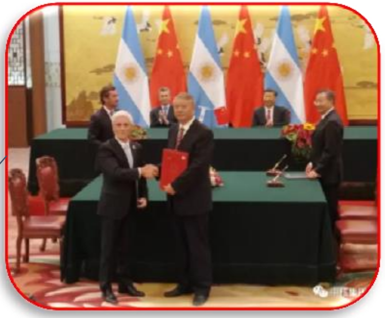
3. Project progress (4/4)
项目进展

- Commercial contract of C5 has signed.
- 恰西玛5号机组签订合同。





- The UK HPR1000 GDA has entered Step2 phase.
- 目前，华龙一号通用设计审查已经进入STEP2阶段。



Agreement with Argentine Nuclear Power Company to start construction of HPR1000 .

- The Pakistan K2 project started NI installation
- 巴基斯坦K2项目正处于核岛设备安装阶段

- 根据约定，阿根廷将开工建设一台百万千瓦级“华龙一号”压水堆核电机组。

04 Summary 总结

4. Summary

总结

- HPR1000 meets the latest Chinese nuclear safety codes, taking into account the relevant IAEA Safety standards.

- Comprehensive consideration of feedback of Fukushima accident and other good practice as appropriate according to **Vienna Declaration on Nuclear Safety.**

- HPR1000   is a safe, clean, economic and reliable energy solution.

- HPR1000满足最新的中国的核安全法规,同时参考了IAEA最新的安全标准;

- 按照《维也纳核安全共同宣言》的要求，考虑了福岛事故反馈并酌情考虑了其他良好实践。

- HPR1000是安全、清洁、经济和可靠的能源解决方案。

THANKS

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