Safety Approach and Safety Assessment of Hualong One

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New Requirements

1.1 New Requirements for NPPs today

1.2 Hualong One (HPR1000)

1. New requirements

1.1 Requirements for NPPs today

Safer

EUR and URD

Safety of new NPP design, WENRA

Safety of nuclear power plants : design , IAEA SSR2/1

HAF-102 Safety regulations for design of nuclear power plant， NNSA

Fukushima nuclear accident

More Economical

Economic competitiveness

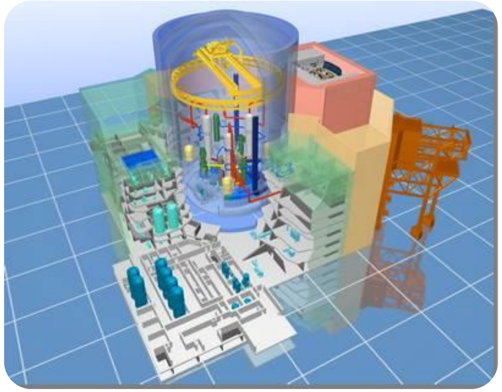
Cost and construction time under control

Plant availability and operational flexibility

1. New requirements

1.2 Hualong One (**HPR1000**, **H**ua-long **P**ressurized **R**eactor **1000**MW)

- 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, keeping in line with the state laws and regulations
- Improved safety, reliability and economic efficiency of the HPR1000



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Safety Approaches and Design Features

2.1 Safety Targets and Technical Characteristics

2.2 Safety Principles

2.3 Design Features

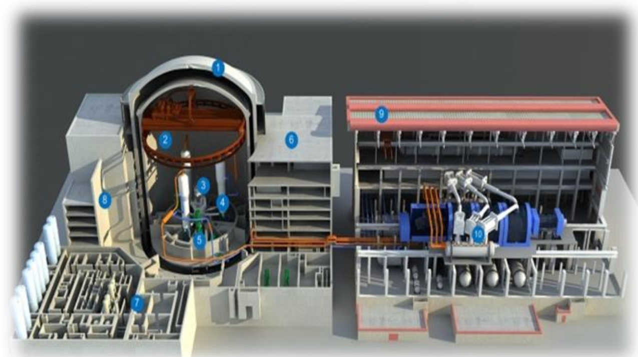
2.4 Feedback from Fukushima accident

2. Safety Approaches and Design Features

2.1 Safety Targets and Technical Characteristics （1/2）

- 177 12-feet advanced fuel assemblies
- Active + passive safety measures
- Reactor core thermal power 3180MWt, Nominal power ≥1200 MWe
- CDF $<1\times10^{-6}$/reactor • year

  LRF $<1\times10^{-7}$/reactor • year
- Safety margin ≥15%
- Single-unit layout
- Safety Shutdown Earthquake(SSE): 0.3g
- Double shell containment with large free volume



2. Safety Approaches and Design Features

2.1 Safety Targets and Technical Characteristics （2/2）

- Protection against large commercial aircraft crash
- Design lifetime of 60 years
- Refueling cycle of 18~24 months
- Average plant availability ≥90%
- Minimum 30min non-intervention
- Design counter-measures for Design Extension Conditions(DEC)
- Digital Control System (DCS) and advanced Main Control Room (MCR)
- Improved in-core instrumentation inserted from upper head
- In-Containment Refueling Water Storage Tank (IRWST)
- Leak-Before-Break (LBB)
- Solid rad-waste volume < 50 m^3/reactor · year
- Collective dose of occupational exposure < 0.6 person · Sv/reactor · year

2. Safety Approaches and Design Features

2.2 Safety Principles （1/4）

- **Defense in Depth**

■ Following Chinese regulation HAF102 and compliance to IAEA SSR 2/1 Rev.1 Safety of Nuclear Power Plants: Design

■ Strengthening each level of DiD with optimization of DBC Design Features while emphasizing DEC countermeasures

■ Improving independence between DiD levels as far as practicable, such as levels between level 3 and level 4a, as well as level 4b and other levels.

	DBC			DEC	
Plant Condition categories	**Normal operation**	**Anticipated operation occurrences**	**Postulated single Initialing event**	**Multiple failure (DEC-A)**	**Severe accidents (DEC-B)**
IAEA SSR2/1	1	2	3	4a	4b
WENRA	1	2	3a	3b	4

Classification of Conditions

2. Safety Approaches and Design Features

2.2 Safety Principles （2/4）

- **Reliability Design**
  - Single failure criterion
  - Independence
  - Redundancy
  - Diversity
  - Fail safe
  - Equipment qualification

Diverse Safety Design

- Reactor shut-down means
- Core residual heat removal
- Containment heat removal
- In-Vessel Retention (IVR) approach
- U.H.S
- Power supply
- I&C systems
- Supporting systems

2. Safety Approaches and Design Features

2.2 Safety Principle （3/4）

- **Protection from Internal and External Hazards**

  - Prevention-Protection-Mitigation
  - International good practice considered

- **Deterministic and Probabilistic Safety Analysis**

  - Deterministic
  - Probabilistic
  - Engineering judgement
  - Practically elimination of large radiological release

2. Safety Approaches and Design Features

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2.2 Safety Principle （4/4）

- **Autonomy**

■ Minimum 30min nonintervention
■ 72 hours plant autonomy requirement (no off-site support needed) for both DBCs and DECs

- **Radiation Protection - ALARA**

■ Radiation doses are kept as low as reasonably achievable in operational states for the entire lifetime of the plant
■ Radiation doses remain below acceptable limits and as low as reasonably achievable in, and following, accident conditions

2. Safety Approaches and Design Features

2.3 Design Features（1/9）

- **General Parameters**

Core rated power	3180 MW
Nominal power	1200 MW
RCS Operation pressure	15.5MPa (abs)
RCS Design pressure	17.23 MPa (abs)
RCS Average temperature	310℃
RCS Design temperature	343℃
Nominal primary flow-rate (Best Estimated)	~25000 m^3/h/loop
Active length of fuel	12 ft
Number of fuel assemblies	177
Average linear power density	181.2 W/cm
Number of control rod assemblies	69

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2.3 Design Features（2/9）

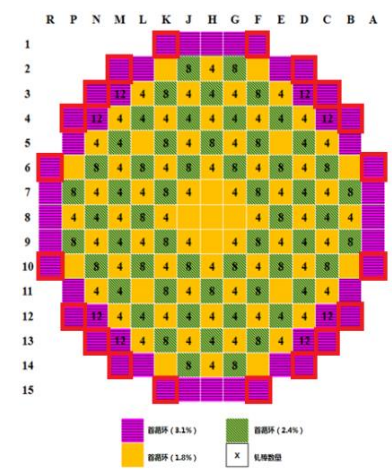
- **General Parameters**

Heat transfer area of SG	~6500 m^2
Secondary side design Temperature SG	316 ℃
Design pressure of primary containment	0.52MPa (abs)
Design temperature of primary containment	145℃
Containment free volume	>73000 m^3
Turbine Rotating speed	1500 r/min
Voltage of auxiliary power	10 kV

2.3 Design Features（3/9）

- **Core Design**

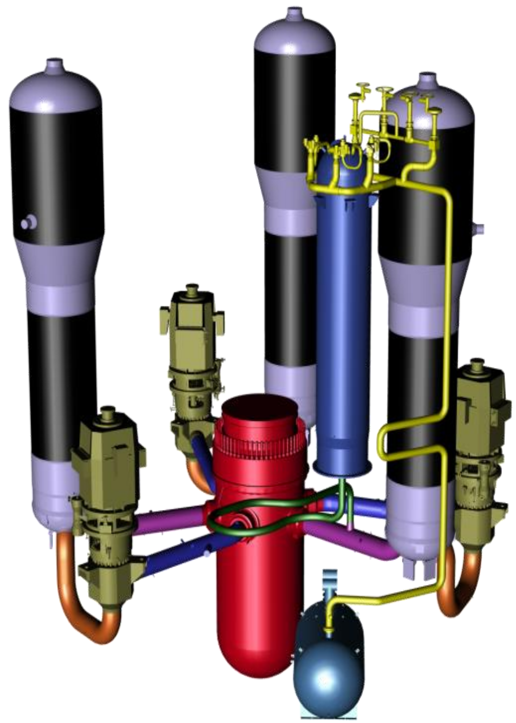
- 177 fuel assemblies with 12 feet active length
- Low leakage fuel loading pattern, refueling cycle of 18~24 months
- Fuel assembly average discharge burn-up ≥45 GWd/tU
- Load follow ability and low-power operation ability
- Capability of fuel cycle with MOX fuel
- 69 RCCAs
- In-core neutron measurement system with SPND detector
- In-core instrumentation top mounted, no penetration in the RPV bottom head



2.3 Design Features（4/9）

- **Reactor Coolant System**

  - Three-loop configuration
  - Pressurizer equipped with safety valves, Dedicated Depressurization valves and High-point Venting valves
  - Vertical inverted U-tubes SG
  - Shaft seal reactor coolant pump
  - Forged reactor coolant pipe



2. Safety Approaches and Design Features

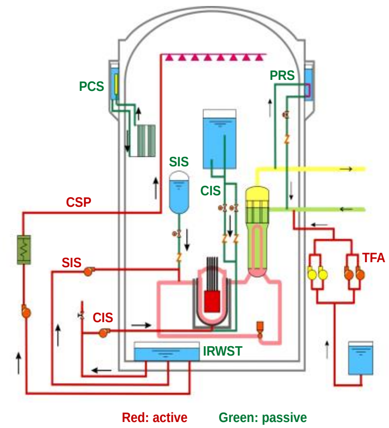
2.3 Design Features (5/9)

- **Safety System**

■ DBC Counter-measures

Defense in depth(Level 3)

•Safety Injection System
•Auxiliary Feed-water System
•Containment Heat Management System
•Atmospheric steam dump system
•Emergency diesel generators



Active Trains + Passive features

■ DEC-A counter-measures

Defense in depth(Level 4a)

•Passive cooling from SG secondary side
•SBO Diesel Generator
•Emergency Boron Injection System
•Diverse Actuation system
•Diverse Cooling Source

■ Server accident mitigation measures

Defense in depth(Level 4b)

•Diverse Containment Cooling System
•Fast Depressurization System for RCS
•Containment Hydrogen Control System
•Reactor Cavity Injection and Cooling System
•Containment Filtration and Exhaust System
•Severe Accident I&C and large capacity batteries
•On-site emergency water makeup and mobile diesel generators

2. Safety Approaches and Design Features

2.3 Design Features（6/9）

- **Safety System**

■ DEC-A Counter-measures

Typical Multiple Failure	Safety Features
ATWS	Emergency boron injection system
Station blackout (SBO)	SBO diesel generators/Standstill seal of main pump
Loss of U.H.S.	Auxiliary feedwater supply + atmospheric steam dump passive cooling from SG secondary side
Common mode failure of protection system	Diverse actuation system

2. Safety Approaches and Design Features

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2.3 Design Features （7/9）

- Server accident mitigation measures

	DEC-B phenomena	Countermeasures
Containment Failure	Hydrogen detonation	Containment Hydrogen Control System
Containment Failure	High pressure molten corium ejection, DCH	Fast Depressurization System for RCS
Containment Failure	long term overpressure	Passive or Diverse Containment Heat Removal Sys. Containment Filtration and Exhaust System
Containment Failure	Basement melt-through	Reactor Cavity Injection and Cooling System
	I&C, Habitability and specific procedures	Dedicated I&C control system for Severe Accident and reliable power supply batteries; ; Habitability Design of Main Control Room and emergency facilities; SAMG (Severe Accident Management Guideline)
	On-site emergency measures	emergency water makeup, mobile power supply and connection interfaces reserved

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2. Safety Approaches and Design Features

2.3 Design Features (8/9)

- **Verification Tests**
  - Reactor Coolant System

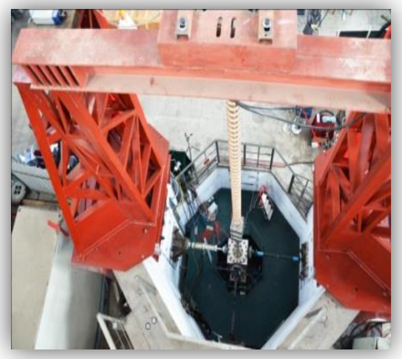
◆ Main mechanical systems (such as RPV) are progressively improved based on validation of long term engineering practice from existing PWR NPPs

◆ The design improvements are verified by tests (e.g., Flow-induced Vibration Simulation Test of Reactor Internals)

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. Safety Approaches and Design Features

2.3 Design Features（9/9）

- **Verification Tests--Safety System**

◆ 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

Test of Cavity Injection and Cooling System

Passive residual heat removal test for secondary side

2. Safety Approaches and Design Features

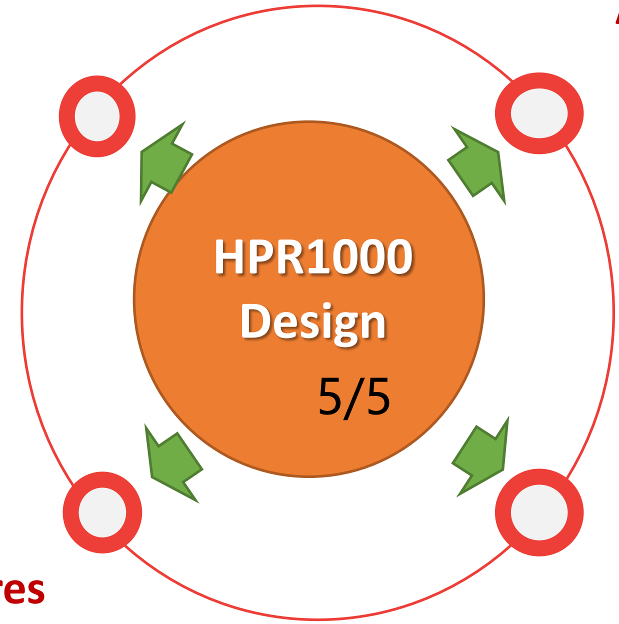
2.4 Feedback from Fukushima accident （1/6）

1. External Hazards

- Anti-seismic design
- Anti-flooding design
- Early warning mechanism

2. Safety Function and Accidents Mitigation

- 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

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

4. Emergency Facilities and Emergency Response

- Radiation monitoring and emergency response
- Emergency facility availability

2. Safety Approaches and Design Features

2.4 Feedback from Fukushima accident （2/6）

- **Diversity of Power Supply**

Two Independent Off-site Power Supplies

Emergency Diesel Generators +2 H Batteries

SBO Diesel Generators/ DEC Batteries

Mobile Power Supply

2. Safety Approaches and Design Features

2.4 Feedback from Fukushima accident （3/6）

- **Anti-flooding Design**

Assessed the risk of flooding comprehensively and properly determined the plant elevation to eliminate the possibility of flooding inundation risk.

Using “design basis flood (DBF) + precipitation once in 1000 years” as a beyond design basis to verify the drainage design.

DBF has considered the influence of the seaside floods including the tsunami.

Important equipment such as mobile power supply is located in higher elevation.

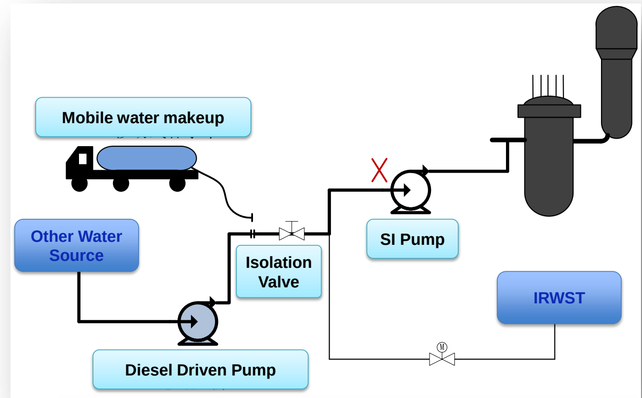
Flooding zones are properly designed. Sufficient flooding protection measures are designed to reduce the risk.

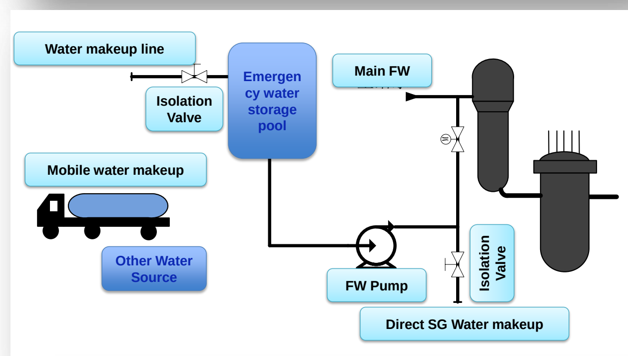
2. Safety Approaches and Design Features

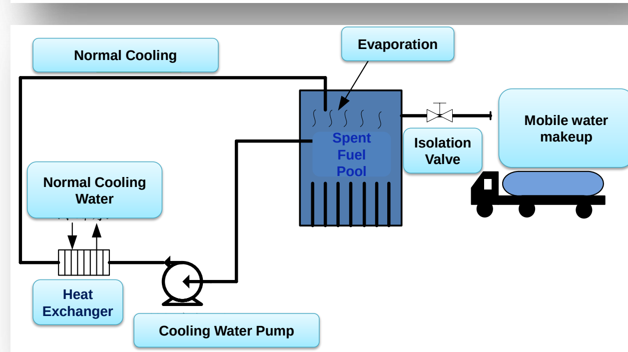
2.4 Feedback from Fukushima accident (4/6)

● Emergency Water Supply

- The Spent Fuel Pool is equipped with passive water supply system
- the primary and secondary loop, and the spent fuel pool are all equipped with water supply interfaces for mobile water source



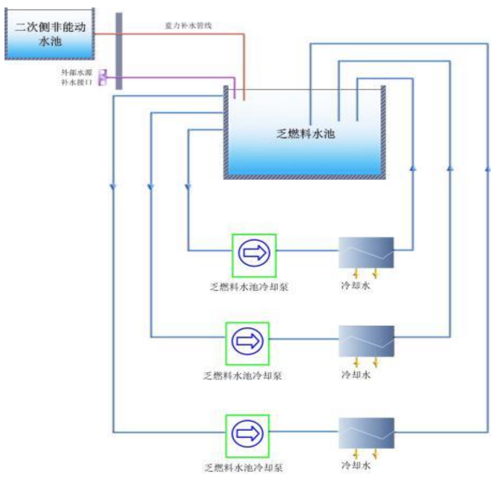




2. Safety Approaches and Design Features

2.4 Feedback from Fukushima accident （5/6）

- **Spent Fuel Pool Cooling and Monitoring**



■ **Improve spent fuel pool cooling function**

◆ Increased cooling capability of each train

◆ Additional cooling train

■ **Improve spent fuel pool monitoring measures**

◆ Upgraded electrical classification of monitoring instruments

◆ Continuously monitoring SFP water level

2. Safety Approaches and Design Features

2.4 Feedback from Fukushima accident （6/6）

- **Radiation Monitoring and Emergency Response**

■ Radiation monitoring

Mobile emergency monitoring system is provided as a back-up of automatic monitoring station

■ Improved capability on Emergency measures and response

■ Habitability and availability of emergency control center

◆ Protective measures

- Anti-seismic design is above the site precautionary level
- Anti-flooding design can withstand beyond design basis flood scenario

◆ Habitability

- Improved HVAC and radiation protection design

◆ Functional reliability

- Two ways to obtain the important parameters
- Multi-redundant communication means

03

Safety Evaluation and Assessment

3. Safety Evaluation and Assessment

Nuclear Power Plant in mainland China

Fuqing 5 and 6 HPR1000
FCD 07,May,2015 & 22,Dec,2015

Fangchenggang 3 and 4 HPR1000
FCD 24,Dec,2015 & 23,Dec,2016

3. Safety Evaluation and Assessment

◆ Evaluation and Assessment of PSAR

Evaluation and Assessment Based on Documentation	• More than 1800 questions and answers was issued. At the mean time more than 650 working sheets was issued and discussed • 3 dialogue meetings on technical discussion and Two meetings on specific topics
Focus on Specific Topic	• The sufficiency of the verification test and adequacy of the calculation code • Seismic analysis and the structure integrity of the containment • Active and passive design on safety system • Classification on equipment, system and structure
Independent Analysis and Calculation	• Independent modelling and calculation for typical and important safety issues by assessment team. Comparing the calculation results with the applicant
Inspection and Site Witness of Verification test	• Inspection and site witness of verification test. Some independent tests for key important safety issues were designed and carried out by the technical support organization of NNSA

3. Safety Evaluation and Assessment

◆ Focus issues on PSAR review

- New safety requirements in Codes and standards
- Internal and external flooding
- Seismic qualification for high level earthquake 0.3g
- Environmental qualification condition of SSE
- Analysis and structure integrity on against the commercial aircraft crash
- Leak before break(LBB)for mainpipe
- Flowrate distribution test of the reactor inlet

3. Safety Evaluation and Assessment

- The effectiveness of water injection to the reactor cavity
- The analysis for the passive heat removal system of the containment
- The startup condition of the passive heat removal system of the secondary side
- The improvement of steam generator blowdown system
- The process of the waste treatment facilities
- The selection and application of the safety analysis codes
- The analysis and layout of the hydrogen recombiner on DBE and SA condition
- Human factors engineering (HFE) for main control room

04

Summary

总结

4. Summary

- **Safety standards，** Hualong One meets the latest Chinese nuclear safety codes, taking into account the relevant IAEA Safety standards.
- **Feedback，** Comprehensive consideration of feedback of Fukushima accident and other good practice as appropriate according to **Vienna Declaration on Nuclear Safety.**
- **Safety enhanced，** Large safety margin， Active & passive design features，DEC counter-measures， Strengthen the design on against internal and external hazards， Emergency response capability improved.
- **Economy balanced，** Design lifetime 60 years， Long period of fuel cycle，high plant availability， Short construction period
- **Proven technology，** Evolutionary design， Based on proven technology，Experienced manufacturing suppliers， Adequate tests for new technology and design.

THE END

Thanks for listening.