Research & Development on Advanced PWR Design Improvement and Innovation in NPIC

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OUTLINE

1. Development of advanced PWR in NPIC
2. Design refinement of advanced PWR in NPIC
3. Research on key issues of advanced PWR in NPIC
1.1 General Introduction

**PWR: ACP1000**

**Advantages:**
- Good Economy
- Technology Maturity Based on Gen II+
- Active & Passive Reliable, efficient + SBO

**Testing & verification:**
- Reactor integral hydraulic test, by-pass Test, lower plenum mixing test
- Cavity Injection and Cooling System test
- Test for Passive Residual Heat Removal System of Secondary Side (PRS)
- Internals flow induced-vibration test
- Control Rod Drive Line anti-seismic test

**First Site:** Fuqing 5&6, Fujian, China

**SMR: ACP100**

**Advantages:**
- Multi-application
- Flexible site selection
- Inherent Safety

**Testing & verification:**
- Control rod drive line anti-seismic & control rod drive line cold & hot test
- Fuel assembly CHF testing
- Passive emergency core cooling system integration testing
- Internals vibration testing
- CMT and passive heat removal system testing

**Demonstration Site:** Putian, Fujian, China
1.1 ACP1000 (Hualong) Main Parameters

- Core Nominal Thermal Power: 3050MWt
- Nominal Electrical Power: >1100MWe
- TDF flowrate: 22840 m³/h/loop
- Design Pressure: 17.23 MPa
- Design temperature: 343℃
- Fuel assembly number: 177
- Fuel type: CF3
- Operating Pressure: 15.5 MPa
- Reactor inlet temperature: 291.5℃
- Reactor outlet temperature: 328.5℃
- Core average temperature: 310℃
1.1 ACP1000 (Hualong)  

- **Nuclear Design**
  - Loading strategy for **18-month** refueling
  - CF3 advanced fuel assembly

- **Advanced in-core measurements (RII)**
  - LPD & DNBR **online** monitoring system

- **Advanced CRDM (ML-B)**
  - Integrated latch housing & integrated rod travel housing

- **Reactor Coolant System Design**
  - Dedicate depressurization system for severe accident
  - PRV high point venting system
  - LBB technology
  - Passive secondary side heat removal system (PRS): **≥72 hours**
  - Core Cavity Injection and cooling system (CIS): IVR, **≥72 hours**
  - Passive Containment Heat Removal System (PCS): **≥72 hours**

- **Main Equipment**  **60 years**
Development of advanced PWR

1.1 ACP1000 (Hualong) Main Features

- Design Lifetime: 60 years
- Cycle Length: 18 months
- DNB margin $> 15\%$
- Operating Mode: Mode G
- Plant Availability Factor $\geq 90\%$
- Extreme safety ground motion (SL-2): 0.3g
- Core Damage Frequency $< 1 \times 10^{-6}$
- Large Early Release Frequency $< 1 \times 10^{-7}$
Development of advanced PWR

1.2 ACP100 (Longxing) Main Parameters

- Core Nominal Thermal Power: 310MWt
- Electricity power: ~100 MWe
- Best estimate flowrate: 6500 m³/h
- Fuel assembly number: 57
- Fuel enrichment: 4.2%
- Fuel type: CF2 shortened assembly
- Operating Pressure: 15 MPa
- Reactor inlet temperature: 282 °C
- Reactor outlet temperature: 323 °C
- Core average temperature: 303 °C
- SG type: OTSG
1.2 ACP100 (Longxing)  

**Integral reactor module**
- OTSG, Canned motor pump, Integrated reactor head package
- All main components mature

**Inherent Safety**
- Integrated arrangement
- Canned motor pump
- Small power, small residual heat, small source term
- Low Power Density
- Large Reactor Coolant Inventory
- NSSS Underground

**Passive Safety**
- Passive core cooling system
- Passive residual heat removal system
- Passive containment heat removal system
- Passive inhabitation system
- Automatic depressurization system
1.2 ACP100 (Longxing)  

- **Primary system and equipment integrated layout.**
  - The max size of the conjunction pipe is **5-8 cm**, whereas the large PWR is **80-90 cm**

- **Large primary coolant inventory.**

- **Small radioactivity storage quantity.**
  - Total radioactivity of SMR is **1/10** of large PWR’s

- **Vessel and equipment layout is benefit for natural circulation**

- **Assurance decay heat removal more effectively**
  - **2-4 times** of the efficiency of large PWR heat removal

- **Smaller decay thermal power**
  - **1/5-1/10** times of decay thermal power comparing that of large PWR after shutdown, and is easier to achieve safety by the way of “passive”

- **Reactor and spent fuel pool lay under the ground level for better against exterior accident and good for the reduction of radioactive material release**
2.1 ACP600

- 24-month refueling capability
- Load following without boron regulation
- Extended scoping time without operator actions
- Refinement of operation flexibility
- New ZH60 SG design
- On-line fatigue monitoring system
- Refinement of reactor vessel structure design
- Enhanced CIS design
- Fuel assembly seismic against 0.3g
- Enlarged pressurizer volume

Better performance, economy, safety and reliability
2.2 ACP100+

Brand New SMR Design

- Evolutionary improvements on safety
  - Integrated RCS
  - Internal steam pressurizer
  - Internal CRDM
  - Control rods for reactivity control
  - Fully flooded containment
  - Eliminate Large LOCA
  - Eliminate Medium LOCA
  - Eliminate rod ejection
  - Eliminate boron dilution
  - Ensure core flooding

The objective of ACP100+ is to meet the multi-function requirement on nuclear co-generation of heat, electricity, pure water and etc. for in-land and/or coast with more inherent safety features.

- Better safety & Economics
  - Simplified system, Less Devices
  - Shortened construction

- Site flexibility
  - Less site area
Key issues of advanced reactor

Practical elimination of large radioactive release from NPP

Risk Monitoring

- Monitor Operation Parameters
- Estimate NPP Risk Trend
- Online Response & Risk Control

Deterministic Method

- Digitized Nuclear Reactor
- Multi-Physics/Multi-Scale Coupling Methodology

Probabilistic Method

- Risk Monitoring System
  - Based on living PSA
  - Point-in-time Risk

ATF

- Longer Coping time
- Accident Mitigation
- Safety improvement

Zr alloy cladding improvement

Experience in dispersed/inert matrix fuel & New Zr-based alloy development

Alternative fuel forms

Research on SiC/SiC composite Cladding

Alternative cladding materials

Severe Accident Analysis

- Cladding Oxidation
- Debris Bed Cooling Model
- Hydrogen Behavior

Assure the integrity of Three-Barriers of NPP
Thank you!