SAFETY FEATURES AND LICENSING OF CNNC-ACP100

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Abstract -*ACP100 is an innovatory modular pressurized water reactor, the engineering safety systems fully adopt passive safety design technology. Its inherent safety and passive features/systems are verified via testing facilities and are highlighted at certain levels of defence in depth. The licensing of ACP 100 is within current LWR framework and meets up-to-date codes and requirements in nuclear safety.*

Keywords: *SMR, licensing, innovatory, heating, desalination*

I. INTRODUCTION

ACP100 is a modular pressurized water reactor (SMR, small and medium size reactor)developed by China National Nuclear Corporation (CNNC) for the small electricity grid, district heating, process heating supply and seawater desalination. ACP100 is an innovative reactor based on existing PWR technology, adopting "passive" safety system and "integrated" reactor design technology. The passive safety system is designed to operate without the use of active equipment such as pumps and AC power sources, depends on reliable passive components and processes such as gravity injection and expansion of compressed gases.

ACP100, for three years research and development, has finished overall design, conceptual design and basic design. The R&D on safety related experiments will be carried out in 2014. The construction of ACP100 will be started around the end of 2015.

Ⅱ. MODULAR DESIGN OFREACTOR

ACP100 integrated reactor is shown in Fig.1. Its Main specifications are given in Table 1.

The main design features of ACP100 are the following:

- Modular design of reactor unit(shown in Fig.1):
  - **Integral Reactor Vessel:** Core, Control rod drive mechanisms(CRDMs), Once through steam generator(OTSG), and Integral head package;
  - **Reactor Coolant Pumps(RCPs):** Leak tight primary circuit with canned motor pumps, welded directly to Reactor vessel nozzles, without using long pipelines;
  - Pressurizer**:** Connected pressure vessel via a surge line.
- Use of passive safety systems.
- Use of proven techniques for equipment assembly, repair and replacement; incorporation of proven diagnostics equipment and proven monitoring systems.

Fig.1 General View of ACP100

− No operator intervention needed in 72 hours of accident.

− Passive severe accident prevention and mitigation action, such as for containment hydrogen eliminator, cavity flooding etc. to ensure the integrity of pressure containment.

Table 1 The Main Specifications of ACP100

Reactor type	PWR
Thermal power	310 MWt
Electrical power	100 MWe
Design life	60 years
Refueling period	2
Coolant inlet temperature	282 ℃
Coolant outlet temperature	323 ℃
Coolant average temperature	303 ℃
Best estimate flow	6500 m^3/h
Operation pressure	15.0 MPa,a
Fuel assembly type	17×17 square assembly
Fuel active section height	2150 mm
Fuel assembly number	57
Fuel enrichment	4.2% ^{235}U
Control rod number	25
Reactivity control method	soluble boron, rod insertion
Engineering Safety system	passive
CDF	10^{-7}
Steam generator type	OTSG
Steam generator number	16
Main steam temperature	>290 ℃
Main steam pressure	4 MPa,a
Main steam output	450 m^3/h
Main feed water temperature	105 ℃

The reactor building covers two reactor units. Each reactor unit is located in a containment that is a leak tight physical barrier designed to limit the propagation of radioactivity and to localize fission products in case of a loss of coolant accidents(LOCAs), using emergency containment cooling systems. The reactor building can farther limit radioactivity to release to environment, and provide protection of the systems important for safety from external impacts. ACP100 layout is shown in Fig.2.

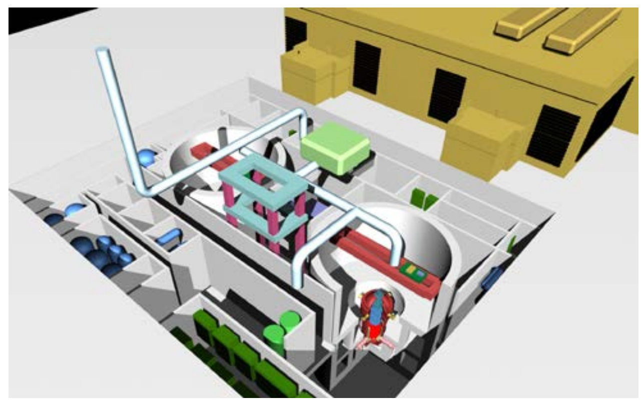

Fig.2 Layout Underground of ACP100

Ⅲ. ENGINEERING SAFETY STRATEGY

The passive safety system is to provide emergency core cooling following postulated design basis events. To accomplish this primary purpose, the passive core cooling system is designed to perform the following functions:

Emergency core decay heat removal: Provide core decay heat removal during transients or accidents or whenever the normal heat removal paths are lost. This heat removal function is available at all reactor coolant system conditions including shutdowns.

Reactor coolant system emergency makeup and boration: Provide reactor coolant system makeup and boration during transients or accidents when the normal reactor coolant system makeup supply from the chemical and volume control system is unavailable or is insufficient.

Safety injection: Provide safety injection to the reactor coolant system to provide adequate core cooling for the complete range of loss-of-coolant accidents, up to and including the double-ended rupture of the largest pressurizer surge piping.

Containment pH control: Provide for chemical addition to the containment during post-accident conditions to establish flood up chemistry conditions that support radionuclide retention with high radioactivity in containment and to prevent corrosion of containment equipment during long-term flood up conditions.

Passive containment cooling: Transfer decay heat and sensible heat released to the containment atmosphere from the reactor coolant system to ex-containment water storage tank and finally to the ultimate heat sink – the atmosphere outside of containment.

Ⅲ-1. Emergency Core Decay Heat Removal

For events not involving a loss of coolant, emergency core decay heat removal is provided by the passive core cooling system via the passive residual heat removal heat exchanger. The heat exchanger is located in the in-containment refueling water storage tank, which provides the heat sink for the heat exchanger.

The passive residual heat removal heat exchanger, in conjunction with the passive containment cooling system, can provide core cooling for an indefinite period of time.

Ⅲ-2. Emergency Makeup and Boration

The core makeup tanks provide reactor coolant system makeup and boration during events not involving a loss of coolant when the normal makeup system is unavailable or insufficient. There are two core makeup tanks located inside the containment at an elevation slightly above the reactor coolant loop elevation. During normal operation, the core makeup tanks are completely full of cold, borated water. The boration capability of these tanks provides adequate core shutdown margin following a steam line break.

Ⅲ-3. Safety Injection during Loss-of-Coolant Accidents

The passive core cooling system uses 3 different sources of passive injection during loss-of-coolant accidents: consists of two containment condensers, water storage tank and associated valves, piping, The passive residual heat removal heat exchanger is used to maintain a safe shutdown condition.

- Accumulators provide a very high flow for a limited duration of several minutes;
- The core makeup tanks provide a relatively high flow for a longer duration;
- The in-containment refueling water storage tank (IRWST) provides a lower flow, but for a much longer time.

Ⅲ-4. Containment pH Control

Control of the pH in the containment sump water post-accident is achieved through the use of pH adjustment baskets containing granulated trisodium phosphate (TSP). The baskets are located below the minimum post-accident flood up level, and chemical addition is initiated passively when the water reaches the baskets. The baskets are placed at least a foot above the floor to reduce the chance that water spills in containment will dissolve the TSP.

Ⅲ-5. Passive Containment Cooling

The passive containment heat removal system consists of two containment condensers, water storage tank and associated valves, piping, and instrumentation.

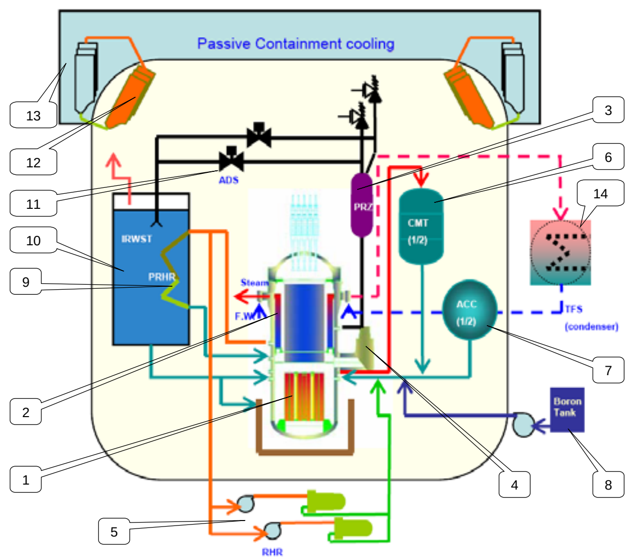

Fig.3 Passive Safety Features of ACP100

1-Core

2- OTSGr

3- Pressurizer

4-RCPs

5- Normal Residual Heat Removal System

6- Core Makeup Tanks (CMTs)

7- Accumulators (ACCs)

8- Emergence Boron Injection System

9- Passive Residual Heat Removal Heat Exchanger (PRHR HX)

10- IRWST

11- Depressurization Valves

12- Passive Containment Cooling Condenser

13- External Cooling Water Storage Tank

14- Startup Feed Water System

Ⅳ. ROLE OF PASSIVE SAFETY DESIGN FEATURES IN DEFENCE IN DEPTH

The structure of the defence in depth system is based on the recommendations of IAEA, providing for the following levels:

Level l：Prevention of abnormal operation and failure;

Level 2：Control of abnormal operation and detection of failure;

Level 3：Control of accidents within the design basis;

Level 4：Control of severe plant conditions, including prevention of accident progression and mitigation of consequences of severe accidents;

Level 5：Mitigation of radiological consequences of significant release of radioactive materials.

The role of inherent and passive safety features/systems of ACP100 at certain levels of defence in depth is highlighted in brief below.

Level 1: Prevention of abnormal operation and failure

Inherent safety features of ACP100 contributing to this level are the following:

- The use of integral design of the reactor and reactor cooling system without large diameter primary piping, actually eliminate large and medium break loss of coolant accidents (LOCAs);
- The use of the canned pumps cancels pump sealing system;
- The large inventory in the primary circuit results in large thermal inertia and long response time in the case of transients or accidents.

Level 2: Control of abnormal operation and detection of failure

ACP100 uses state of the art DCS to monitor plant operation. The contribution of the passive safety systems at this level would be as follows: a larger thermal inertia would be slower progression of a loss of heat sink accident.

Level 3: Control of accidents within the design basis

This level would be contributed to the passive safety systems.

Level 4: Control of severe plant conditions, including prevention of accident progression and mitigation of consequences of severe accidents

The following passive safety features/systems contribute to fulfill this level:

- Passive flooding of the reactor cavity following a LOCA;
- Passive containment cooling system provides a mean of core cooling;
- Passive hydrogen recombines;
- Very low leakage containment, double-decker containments and reduction of containment penetrations.

Level 5: Mitigation of radiological consequences of significant release of radioactive materials

This level would be contributed to the following passive safety features/systems：

- Small fuel load, reduced radioactivity release;
- NI is underground, limit radioactivity release;
- Double-decker containments and reduction of containment penetrations, deposited of radionuclide.

Ⅴ. TESTING & VERIFICATION

To reduce licensing uncertainty by resolving all design issues via testing (Fig.4 passive safety integration testing facility), six test research subjects have be taken in ACP100 as following:

- Control rod drive line cold and hot test;
- Control rod drive line anti-earthquake test;
- Internals vibration test research;
- Fuel assembly critical heat flux test research;
- Passive emergency core cooling system integration test;
- Coolant storage tank and passive residual heat removal system test research.

Table 2 Verification Testing and Schedule of ACP100

Name	Period
control rod drive line cold and hot testing	Done in 2013
passive safety system integration testing	Done in 2013
internals vibration testing	Done in 2013
fuel assembly critical heat flux testing	End of 2014
coolant storage tank and passive residual heat removal system testing	Done in 2013
control rod drive line shock testing	Done in 2013

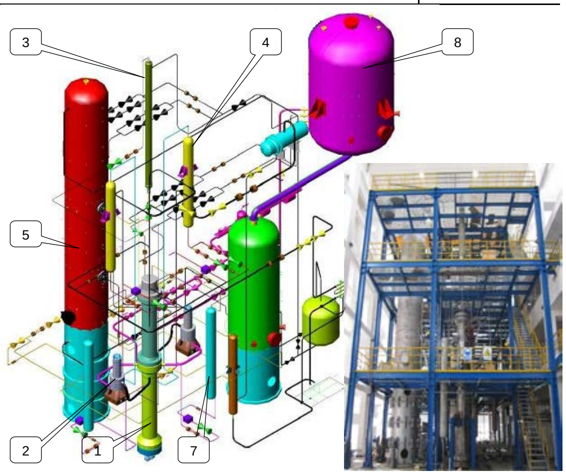

Fig.4 Passive Safety Integration Testing Facility

1- Reactor

2- Pump

3- Pressurizer

4- CMT

5- IRWST

6- Sump

7- ACC

8- Containment

Ⅵ. LICENSING STRATEGY OF ACP100

The following activities have been accomplished related with licensing.

- ACP 100 licensing within current LWR framework
- Signed a contract of ACP100 combined research with National Nuclear & Radiation Safety Center in 2011;
- Developed the following works: National Nuclear & Radiation Safety Center gave the comments on the SMR research report of design preparation phase; Had a technical exchange of SMR containment design after Fukushima nuclear accident; Passive integration test research technical exchange, and the test program was approved;
- Completed the Q1 questions and question reply of concept design stage, and the concept design was approved;
- Signed several specific research programmers and standard design safety analysis combined research with National Nuclear & Radiation Safety Center in year 2013.

Ⅶ. CONCLOSE

R&D work of ACP100 is now near completion and the standard design and the preliminary safety analysis report have been finished. The safety review center deems that the design scheme meets up-to-date codes and requirements in nuclear safety and can be used widely after complementation of a high and new technology demonstration project.