Research of ACP100 – Small Modular Reactor of China

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Abstract： The small modular reactor, code ACP100, is a new innovatory, integrative and multi-purpose pressurized water reactor, which is being developed by China National Nuclear Corporation (CNNC), with electric power of 100MW. ACP100 is suitable for small electricity grid, district heating, process heating supply and seawater desalination, and starts a new era for multi-purpose nuclear power use in China. The paper introduces the technique features and solution, the research progress, the key research tests and licensing, and lists subjects need to be solved next.

Key words: Small Modular Reactor, ACP100, research, progress

1 Background

The Fukushima nuclear accident in Japan sounds the alarm for the nuclear safety again. It highly arouses the attention of the international society on nuclear development and nuclear safety. Undoubtedly, the development of the nuclear power must be based on safety, and the reactor must have much more safety features. Thus, the global nuclear society should take innovatory technology to increase safety and to develop much safer reactor ultimately.

On the other hand, a series of objective factors, such as the increasing demand of energy sources, the increasingly lack of fossil energy sources, the warming up of global climate, and the rising price of mineral fuel, etc., show that to stop developing nuclear power is not a mind choice.

The small modular reactor can provide another safe, economic and reliable clean energy source for the world. In fact, many countries are convinced that the small modular reactor has a good market foreground, and regard it as the next nuclear choice to cope with the slowly increasing demand of electric power, the substitute of small thermoelectric plant with high pollution and high energy consuming, and the demand for high safety and antiterrorism. For this reason, main countries in nuclear power area, especially America, Russia and Korea, kept developing the small modular reactor over the past 20 years.

The small modular reactor, code ACP100, is a new innovatory, integrative and multi-purpose pressurized water reactor, which is being developed by China National Nuclear Corporation (CNNC), with electric power of 100MW. It can be used to generate electricity by nuclear power, can supply district

heating for residents, can supply steam for industrial process, and can be used for desalting seawater, and so on. ACP100 starts a new era for multi-purpose nuclear power use in China.

2 ACP100 technique features

2.1 ACP100's choice of reactor type

In order to research safer reactors, IAEA started up a development plan for small and medium reactors in June, 2004. IAEA established a collaborative research project of "innovatory nuclear reactor" with up to 30 member countries total. After many years' research, more than 45 kinds of reactors appear. Most of the countries choose integrative reactor with modularization technique, such as the SMR of Westinghouse (America), the m-Power of B&W (America), and the SMART of KAERI (Korea). Compact layout modular reactor, using much mature technique, is another choice, of which KLT40S and VBER150 of Russia are the representative. It is obvious for the small modular reactor that traditional distributed layout reactor is abandoned on the whole.

ACP100 also abandons the traditional distributed layout. It adopts integrative layout, eliminates large LOCA accident by design, and has better natural circulation capability.

2.2 ACP100 technique route

As pressurized water reactor has mature technology, and is the main force reactor in nuclear energy industry, which provides almost 70% nuclear power electricity, has good running performance and mature spent fuel disposal technique, thus, ACP100, as most of the international developing innovatory reactor, choose pressurized water technique route, which can utilize the existing technique storage and industry foundation effectively, decrease the research for new techniques, and eliminate the technique risk to the most extent.

2.3 ACP100 technique solution

ACP100 is based on CNNC's existing techniques of pressurized water reactor, aimed at multi-purpose utility of joint produce for electricity-heat-water, satisfies the target requirement for the third generation nuclear power system, absorbs the feedback of the experience of Fukushima nuclear accident, and has favorable prevention and mitigation methods for severe accident.

ACP100 adopts modular design concept. Reactor and reactor coolant system are integrated as the reactor module. See Figure 1. The reactor module contains many sub-modules. Each sub-module is manufactured in factory separately, transported compositively, and fast installed on site. ACP100 realizes scale economy of nuclear power plant by serialization of modules combination.

The overall technical solutions of ACP100 are described as below.

1) OTSGs are placed inside RPV. Main coolant pumps sit on the pump headers of RPV. PZR links with RPV by a surge line.

2) In-core instrumentations are introduced from the top head of RPV, and there is no penetration on the bottom head of RPV.

3) CF2 shortened fuel assemblies, the 17×17 square pitch arranged fuel assemblies developed independently by CNNC, are adopted. Refueling cycle is 24 months.

4) ML-B CRDMs, the magnetism lifting type CRDM developed independently by CNNC, are adopted.

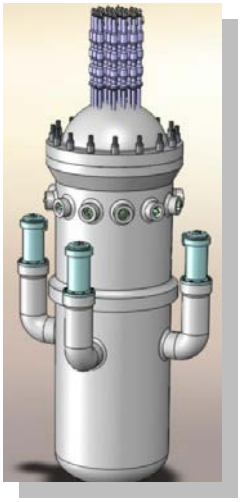

Figure 1. ACP100 Reactor Module

5) The Compositive Head Package (CHP), which unites the RPV head, lifting rigs, in-core instrumentations and anti-seismic structure, is introduced.

6) RPV support modules reliably support RPV onto the reinforced concrete structure.

7) Reactor coolant pumps are canned pumps.

8) Passive core cooling system is composed of core makeup tank, accumulator and in-containment refueling water storage tank, by which core residual heat is exported , and finally long term cooling is realized by reactor cavity flooding recycle.

9) Passive residual heat removal system is used for transferring heat from primary side to in-containment refueling water storage tank.

10) Digital I&C system and advanced main control room are adopted, which have excellent man-machine interface.

11) Small concrete containment with steel plate membrane encased and passive containment heat removal system are adopted.

12) Double reactors share the fuel assembly building, the electrical building and nuclear auxiliary building. Maximize sharing facilities to control the cost.

13) Severe accident prevention and mitigation methods are established:

- Passive reactor cavity flooding prevents RPV melted by melted core debris.
- Passive hydrogen recombination system is set to prevent containment hydrogen explosion and resulting early failure of the containment under severe accidents.
- Automatic pressure relief system is set in first loop to prevent high pressure meltdown

- RPV off-gas system is set to remove non-condensed gas gathered at RPV head after accidents.

2.4 Safety features of ACP100

The high safety of ACP100 profits from the following technical aspects.

1) Multiple inherent safety features

   - Integrative layout of reactor eliminates the large LOCA. High natural circulation capability is established in first loop.
   - Bottom head penetrations are cancelled by utilizing CHP.
   - Canned pump replaces shaft seal pump, which eliminates the seal water LOCA.
   - ACP100 has lower core power density, thus, it has more thermal-hydraulic safety margin and fits better with the anticipated transient related to CHF.
   - Lower reactor power and lower residual heat.
   - Bigger unit coolant inventory, higher system heat capacity and higher heat inertia. Weaken the system response to core warm up transient. Better self-stability and self-adjustability.

2) Passive safety technique

   - ACP100 has the passive emergency core cooling system, the passive emergency residual heat release system, the auto pressure release system, and the passive combustible gas control system; while it doesn't have the safe related emergency AC supply. The system has been simplified, the accident is reduced, and the reactor safety in accident condition is realized by natural forces.

3) Radioactivity safety and counter-terrorist

   - The radioactivity source of ACP100 is low, and it has multiple barriers for radioactivity inclusion.
   - The reactor and spent fuel assembly building is placed under ground. The rock is natural radioactivity isolation barrier, and the rock can be used to resist terror attack, too.

2.5 Main design parameters of ACP100

The Main design parameters of ACP100 are shown in table 1.

Table 1. Main design parameters of ACP100

Main parameters	Value
Thermal power	310MWt
Single modular power	～100MWe
Design life	60 years
Refueling period	2 years
Coolant inlet temperature	282.6℃
Coolant outlet temperature	323.4℃
Coolant average temperature	303℃
Pressure –stabilizing type	External steam
Operation pressure	15MPa
Fuel assembly type	CF2 shortened assembly
Fuel active section height	2150mm
Fuel assembly number	57
Fuel enrichment	4.2%
Drive mechanism type	Magnetism lifting
Control rod number	25
Reactivity control method	Control rod, solid burnable poison and solvable boron
Steam generator type	OTSG
Main steam temperature	>290 ℃
Main steam pressure	4MPa
Main steam output	450t/h
Main feed water temperature	105 ℃

Main pump type	Canned pump
Extraction temperature	235.5 ℃（reheat）
Extraction loop pressure	0.294MPa
Heating temperature	125 ℃
Heating loop temperature pressure	1.6MPa
Reactor power-control operation program	Constant average temperature
Thermal power plant operation model	Base load operation （Mode-A)
SSE level ground seismic peak acceleration	0.3g
Core damage frequency（CDF）	＜10^{-5} /efpy
Large Release frequency（LRF）	＜10^{-6} /efpy

2.6 Actions after Fukushima

After Fukushima nuclear accident, ACP100 considers following aspects to avoid the potential similar severe accidents.

1) The loss of off-site power supply and the emergency diesel power supply

ACP100 has integrated primary coolant system and removes residual heating to large capacity containment pool through heat exchanger depending on primary coolant natural circulation. The reactor will not lose cooling in case of the loss of power, and can sustain the residual heat removal for 72 hours.

2) The combination of loss-of-coolant accident and loss of all the power

After the loss of coolant accident, ACP100 achieving core cooling and the containment heat removal completely due to the passive facility in this process, and the accident aggravation will not happen for the loss of power.

3) Safety and accident risk of the spent fuel storage pool

The spent fuel pool of ACP100 small modular reactor lays under ground elevation and a standby makeup pool set outside of the plant, the fuel uncover will not happen under the extreme condition of the structure of spent fuel pool breaking under seismic condition and the cooling loss for the loss of power.

4) Core-melt

ACP100 is the third generation PWR, having inherent safety characteristics, no big LOCA etc., adopting complete passive safety feature which obviously reduce the accident probability and the consequence. Besides, consider the severe accident prevention and mitigation action, such as passive Cavity Flooding System (passive CIS), hydrogen recombiner and the corresponding accident management guide.

3 The key research tests of ACP100

The ACP100 research is integrative innovation based on the existing technique of CNNC. The technique risk is eliminated basically, for some single techniques were already applied in nuclear project. But in order to get the necessary design input parameter, and verify the integrated technique, five key research tests and verification are carried out by CNNC.

1) Fuel assembly critical heat flux test research

Through the CF2 shortened fuel assembly critical heat flux test research, considering typical cell uniform heating, typical cell non-uniform heating and untypical cell non-uniform heating, the critical heat flux formula which is specially applicable in ACP100 will be obtained.

2) Control rod drive line cold and hot test

Through the control rod drive line cold and hot test, the rod drop characteristics of drive line under different conditions will be obtained, the synthesis operating characteristics of ML-B CRDM under high temperature and high pressure will be checked, and the rationality and reliability of control rod guide structure will be verified.

3) Control rod drive line anti-seismic test

Through the control rod drive line anti-seismic test, the rod drop time and the curve of time and distance of control rod in static-water and specified seismic load will be measured, and the anti-seismic capacity will be estimated

4) Passive emergency core cooling system integration test

The Passive emergency core cooling system integration test will verify the rationality and reliability of passive system design.

5) Rector internals vibration test research

The test mainly includes the measurement of vibration characteristic of internals in air condition and in static-water condition, the motile-water response, and the anti-vibration verification.

4 The progress of ACP100

4.1 The developing progress of ACP100

Under the National Energy Administration's support, CNNC took the ACP100 small modular reactor as the Major Scientific Special Project of Group in June 2010. The top general design was finished in October 2010, the conceptual design was finished in May 2011, and the optimized conceptual design was finished in Nov 2011. Now the preliminary standard design and key research tests of ACP100 are proceeding. It is estimated that the preliminary standard design and the preliminary safety analysis report will be finished in the end of 2012, the key research tests will be finished in the end of 2013, and the project application condition will be satisfied simultaneously.

4.2 The licensing progress of ACP100

In order to ensure the high safety of ACP100 small modular reactor, and satisfy the nuclear safety regulation, Nuclear Safety Center (NSC) participates the research of ACP100 during all the process. NSC witnesses key points and appraises the safety at each stage of ACP100 research, and now it is processing the individual verification calculation and compiling the design principle of small modular reactor.

It is estimated that the design of ACP100 will be approved in the middle of 2014.

5 Subjects demand to be researched

Although ACP100 is regarded as one of the most important nuclear research projects of China, and essential techniques have been or are being verified, there are 4 subjects demand to be researched further, which will be very pivotal for application and development of small modular reactor.

1) Nuclear Safety Review System, especially the policies and regulations of nuclear safety review in the process of design and development of a new type reactor;

2) Standards and methods of safety review for small reactors near the cities;

3) Standards and regulations for small reactor design and manufacturing;

4) Standards, regulations and analysis for reduction of emergency areas outside NPP.

6 Conclusions

1) ACP100 is a multipurpose SMR, which could be used to supply electricity, heating, water, or their combinations;

2) ACP100 utilize much existing and proven techniques of PWR, to lower the potential risks, to shorten the period of research, and to satisfy the application condition soon;

3) ACP100 is much safer than traditional PWR, for adopting integrative layout reactor and passive concepts;

4) ACP100 establish favorable prevention and mitigation methods for severe accidents;

5) Licensing of ACP100 is still within current PWR framework, which demands further research.

About the author： XU Bin（1973-）; Male; Senior Engineer; Deputy Chief Designer of ACP100 Project of Nuclear Power Institute of China with near 20 year experience in Reactor Overall Design especially in Reactor Structure Design; graduated as Bachelor of Engineering from Shanghai Jiao Tong University; postgraduated as MBA from Southwest Jiao Tong University.