2014 Canada-China Conference on Advanced Reactor Development (CCCARD-2014)
Niagara Falls Marriott Fallsview Hotel & Spa, Niagara Falls, Ontario Canada, April 27-30, 2014.

CCCARD2014-008

Safety Aspects of Small and Medium Size Reactor ACP100

SONG Danrong[1,2] ZENG Wei[1,2] LIU Songtao[2]
[1]Science and Technology on Reactor System Design Technology Laboratory
[2]Nuclear Power Institute of China
songdr@gmail.com zengwei02@sina.com liusongtao.npic@gmail.com

Abstract

Developing nuclear energy is the measure of meeting national economic development and satisfying the need of energy conservation and emission reduction. Large size nuclear power units are hardly suitable to the application of regional network and the non-electric fields. Small size reactor needs from the great majority of developing countries and the vast Midwest area of China. Due to the integral reactor design and passive safety system, small and medium size reactor ACP100 has its unique safety feature during accident condition. This paper will introduce ACP100 major safety analysis results.

1. Introduction

SMR is suitable for small electricity grid, district heating, process heating supply and seawater desalination. According to different condition, different countries have different goals in China. In north of China, The demand of energy for city heat consumes is several hundreds of millions tons coal per year, sharing over 10% that the total energy consumption. Due to air pollution in winter, SMR district heating is one of the choices. While in east China, Energy consumption industry in our country, such as building materials, metallurgy, chemical engineering etc, set up their own thermal power plant. The emission occupies over 70% of the total emission in our country. Most of industries locate in east China coastal areas, the serious lack of fresh water resources having become the bottleneck of economic. So SMR used for process heating supply and seawater desalination is also one of the choices. In outlying areas of China, such as mountain area and islands, SMR will be the best choice for electricity generation [1].

Since the 2010, one kind of small and medium size water cooled pressurized reactor called ACP100 has developed by China National Nuclear Corporation (CNNC). ACP100 is an innovative reactor based on existing PWR technology; “passive” safety system and “integrated” reactor design technology were adopted. Through about 4 year’s development, Overall design, conceptual design and basic design has finished step by step. A number of testing facilities are constructed. R&D on safety related experiments will be finished in the following 1 years. The construction of the ACP100 will be planned to start at 2015.

2. Main safety characteristics for the ACP100

The ACP100 design has the following remarkable safety features:

- Primary system and equipment are integrated layout and large break LOCA is eliminated.
- Larger primary coolant inventory per unit power.
- Small radioactivity storage quantity. Total radioactivity of SMR is 1/10 of large NPP's, meanwhile multi-layer barrier is added to keep the accident source-term at a low level.
- Vessel and equipment layout is benefit for natural circulation.
- Assurance decay heat removal more effectively. 2 to 4 times of the efficiency of large NPP heat removal from the vessel surface.
- Smaller decay thermal power. 1/5 to 1/10 times of decay thermal power comparing that of large PWR after shutdown, and reactor safety can be achieved by the way of "passive" easily.
- Reactor and spent fuel pool lay under the ground level for better against exterior accident and good for the reduction of radioactive material release.
- No operator intervention needed in 72 hours of accident ;
- Passive severe accident prevention and mitigation action, such as for containment hydrogen flooding etc. to ensure the integrity of pressure containment;

3. Design of the engineered safety feature

The safety design philosophy of ACP100 is to realize high level of safety and, at the same time, to simplify the design of the systems by the means of passive engineering safety system. There is no emergency diesel generator needed. The emergency measures outside the plant boundary should be made technically not necessary or reduced to a minimum level. The passive system of ACP100 including: Long term passive residual heat removal system coped with station blackout accident, passive core cooling system coped with loss of coolant accident and cavity flooding system during serve accident, passive containment heat removal system which is used to take the heat away by the gas and steam convection between containment and ultimate heat sink based on the natural circulation. The containment integrity under accident condition can be ensured.

- The absence of large diameter piping associated with the primary system, removes the possibility of large break loss of coolant accidents (LOCA). The elimination of large break LOCA substantially reduces the necessity for emergency core cooling system components, alternate current (AC) supply systems, etc.
- Large coolant inventory in the primary circuit results in large thermal inertia and long response time in the case of transients or accidents.
- Inherent safety features: Integrated primary coolant system, eliminating large break LOCA; Long characteristic times in the event of a transient or severe accident, due to large coolant inventory and the use of passive safety systems; Negative reactivity effects and coefficients.

- Passive safety systems : Systems are duplicated to fulfil redundancy criteria. According to Chinese nuclear safety regulations, the shutdown system is diversified. Residual heat removal system, Emergency injection system, Safety relief valves which protect the reactor pressure vessel against over-pressurization in the case of strong differences between core power and the power removed from the RPV. All safety systems mentioned in this paragraph of the ACP100 are passive systems.

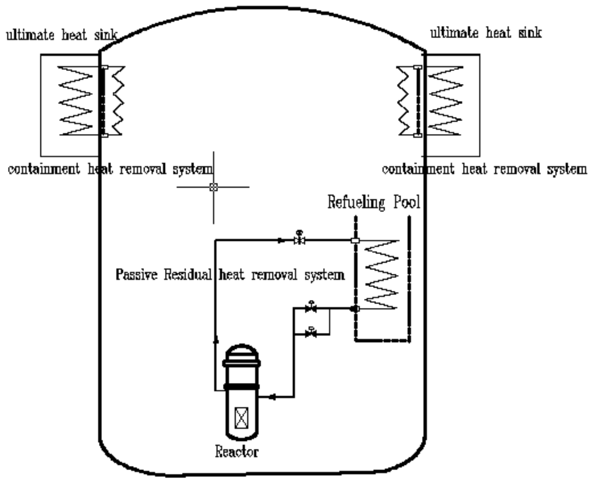

Figure 1 A diagram of safety systems during ACP100 design.

4. Role of passive safety design features in defence-in-depth

- Level 1: Prevention of abnormal operation and failure

  Contributions of ACP100 inherent and passive safety features at this level are as follows: Due to the absence of large diameter piping in the primary system, large break LOCAs are eliminated; canned pump eliminates boron injection for pump sealing system.

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

  The ACP100 passive safety feature for this level is as follows: A large coolant inventory in the primary circuit results in a larger thermal inertia and in longer response times in the case of transients or accidents.

- Level 3:Control of accidents within the design basis

  ACP100's safety systems are based on passive features obviating the need for actions related to accident management over a long period.

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

  Contributions of inherent and passive features of ACP100 at this defence-in-depth level are as follows: When core uncover is assumed, only for analytic purposes, low heat-up rates of fuel elements in the exposed part of the core are predicted, if the geometry is still intact. The characteristic time of core melting is long, eventually preventing temperature excursion due to a metal-water reaction, which in turn limits the hydrogen generation rate; Reduction of the hydrogen concentration in the containment by catalytic recombiners; sufficient floor space for cooling of molten debris; Extra layers of concrete to avoid direct exposure of the containment basement to debris.

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

  The following passive features of ACP100 make a contribution to this defence-in-depth level: Relatively small fuel inventory, when compared to larger NPPs; Slower progression of accidents and increased retention of fission products (facilitated by such features as reduced power density, increased thermal inertia, etc.); The containment is located inside the airplane protection concrete and underground building, which reduces the release of fission products due to local deposition. The ACP100 concept provides for extended accident prevention and mitigation by relying on the principles of simplicity, reliability, redundancy, and passivity.

5. After "Fukushima" Action

After "Fukushima" accident, design and operation nuclear power plant should strictly comply the requirements of safety code. In addition, the combination of various internal and external accidents should be considered. The following accidents are analysed after "Fukushima" accident.

- 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 loss of power, and can sustain the residual heat removal for 72 hours. The calculated results are shown in figure 2 and figure 3. Exhaust in the upper reactor is not taken into account in case1, and Exhaust in the upper reactor is taken into account in case2 and case3 after 12h and 24h respectively.[3]

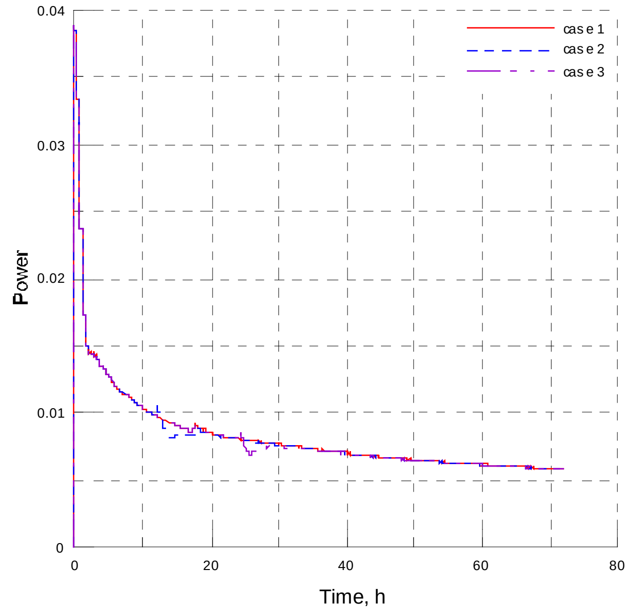

Figure 2 power in the PRHR heat exchanger.

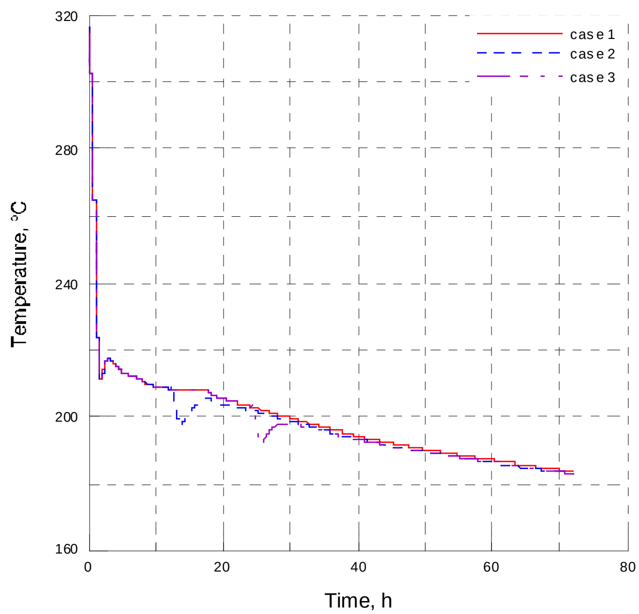

Figure 3 Average reactor coolant temperature.

- 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. The calculated results are shown in figure 4-6All the cases above are calculated by RELAP5/MOD3.2.[2]

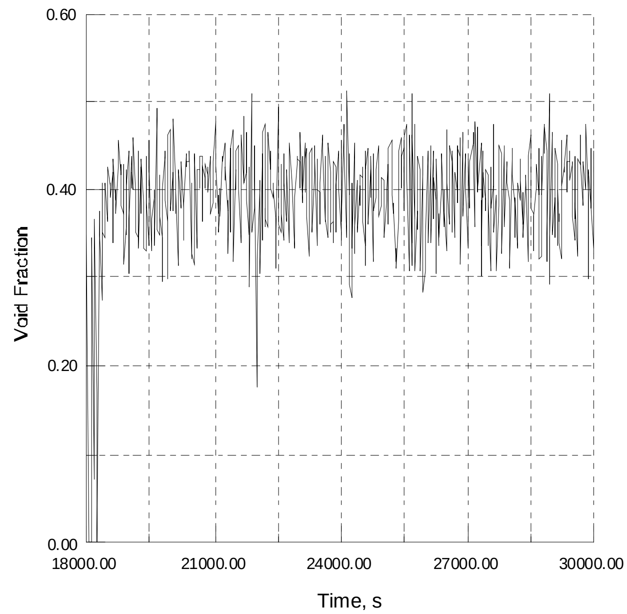

Figure 4 Void Fraction in Core Hot Assembly Top Cell.

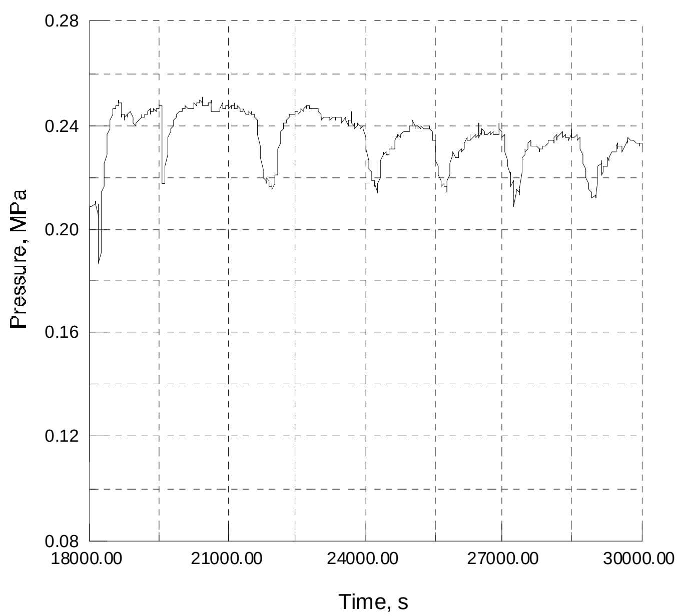

Figure 5 Upper Plenum Pressure.

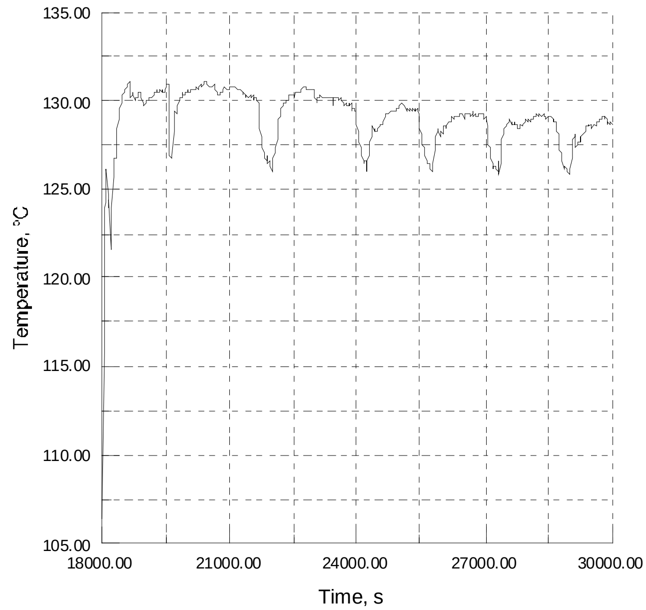

Figure 6 Peak Cladding Temperature.

- Safety and accident risk of the spent fuel storage pool

The spent fuel pool of ACP100 small modular reactor lays underground 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 lost for the loss of power.

- Core-melt

ACP100 meet the requirement of 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 serve accident prevention and mitigation action, such as core injection system (CIS), hydrogen recombiner and the corresponding accident management guide.

6. Testing & Verification

Six test research subjects will be taken in ACP100. Their names and schedule is following:

Table 1 Verification testing and schedule of ACP100

number	Name	Period
1	control rod drive line cold and hot testing	2011-2013
2	passive emergency core cooling system integration testing	2011-2013
3	internals vibration testing	2012-2013
4	fuel assembly critical heat flux testing	2011-2013
5	CMT and passive residual heat removal system testing	2011-2013
6	control rod drive line shock testing	2012-2013

7. Conclusion

All the tests above has been finished and the design is demonstrated to the available. The requirements of the engineering construction also have been met. The demonstration ACP100 nuclear power plant with two 310Mwth reactors, will be located in Putian City, Fujian Province in the east coast area of China.

8. References

[1] China Energy Statistical Yearbook (2008).

[2] RELAP5/MOD3 Code Manual, User’s Guideline, Vol.5, Rev.1, 1995.8

[3] ZHOU Ke, Long term cooling for the loss of power in the ACP100. Internal report, Nuclear power institute of china.2012.10

[4] DANG Gaojian, LI Zhe, Long term cooling for the loss of coolant accident in the ACP100. Internal report, Nuclear power institute of china.2012.8