**The Influence of Fukushima Nuclear Accident on Chinese Nuclear Power Plants Design**

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**Abstract.** The Chinese nuclear safety regulation HAF102-2004 is based on IAEA Safety Standard Series No.NS-R-1“Safety of Nuclear Power Plants: Design” (2000), which was superseded by No.SSR-2/1 in 2012. The main different requirements of HAF102 and SSR-2/1 are identified. According to the feedback of Fukushima nuclear accident, SSR-2/1 is revised and some augmented requirements are put forward. Some new safety requirements for Chinese NPPs are proposed and the influence on the design of Chinese nuclear power plants is analyzed.

### 1. Introduction

The Chinese nuclear safety regulation HAF102-2004 is based on IAEA Safety Standard Series No.NS-R-1“Safety of Nuclear Power Plants：Design”(2000). With the establishment of the long-term set of IAEA Safety Standards, NS-R-1 was superseded by No.SSR-2/1 in 2012. It is necessary to identify the different requirements of SSR-2/1 and HAF102, in order to study the advanced safety standards of IAEA and to prepare for the revision of HAF102.

After the Fukushima nuclear accident, IAEA developed the Action Plan on Nuclear Safety, the 6th item of which is to review and strengthen IAEA Safety Standards and improve their implementation. The Safety Standards were reviewed and revised by the existing process in a more efficient manner and in a prioritized sequence. SSR-2/1 is the one of the first-reviewed safety standards and some augmented requirements are put forward, which will be issued in 2015.

According to the feedback of Fukushima nuclear accident and the experience of IAEA’s Member States, the National Nuclear Safety Administration (NNSA) of China made the comprehensive safety inspection in 2011, and issued the department code “General Technical Requirements for NPP Improvement Actions after Fukushima Accident” (Tentative version) in 2012. Another department code “Safety Requirements for new NPPs in the 12th 5-year Plan” is in the phase of opinion collection.

The main differences between SSR-2/1 and HAF102 are described in section 2. Based on Fukushima accident feedback, the strengthened requirements of SSR-2/1 are reviewed and interpreted. And the requirements of the design of Chinese nuclear power plants is specified and analyzed in section 3. In the end, the conclusion is made.

### 2. Main Differences between SSR-2/1 and HAF102

The nuclear power technology has developed fast in these years. The experience and feedback of the nuclear power industry have been collected, analyzed and reflected on the revision of safety requirements of nuclear power plants design. There are many items upgraded and improved in SSR-2/1, and 5 important items are selected as followed.

1) The function of heat removal from the fuel store is added to the fundamental safety functions in SSR-2/1.

2) Figure 1 describes the plant states of HAF102, and the beyond design basis accidents consist of beyond design basis accidents without significant core degradation and severe accidents.



*FIG. 1 the plant states of HAF102*

The detail of plant states of SSR-2/1 are described in figure 2. Design extension conditions include accidents with significant degradation of the reactor core.



*FIG. 2 the plant states of SSR-2/1*

3) The requirements of mitigating the consequences of severe accidents are reinforced in SSR-2/1.

4) SSR-2/1 added the requirement for multiple unit plant sites. The design shall take due account of the potential for specific hazards giving rise to simultaneous impacts on several units on the site.

5) In the short term, the safety of the plant shall not be permitted to be dependent on the availability of off-site services such as electricity supply and fire fighting services in the requirement of external hazards of SSR-2/1.

SSR-2/1 was issued in 2012, the draft of which had been fixed already when the Fukushima nuclear accident happened in 2011. The improved items, such as heat removal from the fuel store, mitigating the severe accidents consequences, the availability of on-site services and consideration of multiple unit plant sites was proved important and essential by the Fukushima nuclear accident. If these requirements had been satisfied by the Fukushima nuclear power plants, maybe the occurrence of nuclear accident could have been avoided.

### 3. Fukushima Accident Feedback

According to the lessons and feedback of the Fukushima nuclear accident, some augmented requirements are added to the revised SSR-2/1. In the “General Technical Requirements for NPP Improvement Actions after Fukushima Accident”, some new and specific safety requirements are proposed by NNSA, aimed at Chinese NPPs in operation and in construction.

#### 3.1. Requirements of Revised SSR-2/1

Lessons learned from the Fukushima nuclear accident show the importance to keep the reliability of safety functions. The proper implementation of the Defence-in-Depth (DiD) concept is essential to improve the reliability of safety functions. To enhance defense in depth, the design shall include provisions to keep the ultimate heat sink and power supply and to avoid short-term cliff-edge effect in case of:

* an extreme external hazard of an intensity or a duration exceeding the one considered as the general design basis ;
* a complex combination of events, or multiple failure events.

*The ultimate heat sink*

Consistently with the DiD approach, The loss of the primary ultimate heat sink or access to it should be considered in the design. The alternative means for providing an ultimate heat sink for an extended period is required and should function independently with the primary means.

*The power supply*

In order to cope with common cause failures of the primary emergency electrical power supply, the backup power supply shall be required as a part of DiD safety features. Other actions for increasing the reliability of electrical power supply at NPPs deal with enhanced provisions of long term fuel and lubricating oil reserves for all emergency power units at the site and ensuring possibilities to use mobile power supply units. Adequate battery capacity shall be secured. The backup power supply shall be able to provide support of key important safety functions, including the cooling of the core and the inventory of spent fuel in pools, for several days of blackout.

#### 3.2. General Technical Requirements of NNSA

8 items are specified in the “General Technical Requirements for NPP Improvement Actions after Fukushima Accident”. Each item will be described in the following section.

*Improvements on flood capability*

The validity of design basis flood (DBF) level should be reviewed, taking into account the latest observation data, and the surrounding environment changes. Also the drainage capacity and water depth in the scenario of beyond design basis flood (e.g. DBF+ 1000 years recurrence rainfall) should be reviewed. The underground galleries connected with safety-important buildings should be taken waterproof measures, which need to withstand the pressure of proper water level.

*Emergency water makeup and relative equipments*

The mobile pumps should be used to make up water to the secondary loop, primary loop and spent fuel pool in case of loss of the primary ultimate heat sink or access to it. And the preparation of water makeup should be completed in 6 hours and the duration of water makeup should last for at least 72 hours without offsite support. The operation of emergency water makeup should be included in the guide of severe accident management (SAMG) or related procedures. The mobile pumps should be stored and placed at the elevation beyond the DBF for 5 meters.

*Mobile emergency power supply*

The load of mobile emergency power supply consists of monitoring and control of plant parameter, communication, ventilation and lighting, shaft seal of main pumps and mobile pumps. The better choice of mobile power supply is the mobile diesel generator. The fuel capacity should meet 4 hours full-load and 72 hours with fuel supplement. The mobile diesel generators should be stored and placed at the elevation beyond the DBF for 5 meters.

*Monitoring of the spent fuel pool*

The water level and temperature monitoring of the spent fuel pools is emphasized. The equipments should be available in design basis seismic, and the power supply should be available in the case of lost of all AC power.

*Improvement of hydrogen monitoring and controlling systems*

The function of hydrogen monitoring and controlling systems in severe accident condition is hydrogen concentration less than 10%, with the uniform distribution of the hydrogen produced by the reaction between100% fuel cladding in active zone and coolant. The hydrogen monitoring and controlling measures should be included in SAMG or related procedures. And the monitoring data should be available in main control room and emergency control center.

*Habitability and functions of emergency control room*

The emergency control room should be capable to obtain important plant parameters, on-site and off-site radioactivity information and meteorological data, and be available of communication and transmission. The effective dose of staff should be less than or equal to 100 mSv during the given emergency response period (usually 30 days) in order to keep the habitability and accessibility of emergency control room.

*Radiation environmental monitoring and emergency response*

Reasonable and representative placement of monitoring points, with backup monitoring measures should be set in case of severe accidents. For multi-unit sites, the plant should be evaluated as a whole in emergency response capability, and emergency plan, training and drill should be coordinated.

*Response to external hazards*

Early warning system, the warning classification and on-site warning release for natural hazard should be established. And the disaster prevention program for extreme external events should be improved.

### 4. Conclusion

Fukushima nuclear accident highlights the advancement of the IAEA safety standard, such as the requirements of heat removal from the fuel store, the availability of on-site services and consideration of multiple unit plant sites. The most important lesson and feedback of Fukushima nuclear accident is to keep the reliability of safety functions. Implements of DiD approach are effective to improve the safety of nuclear power plants. “General Technical Requirements for NPP Improvement Actions after Fukushima Accident” in China is based on the practice of NPPs in China and preliminary feedbacks of Fukushima nuclear accident. It will be revised and improved with the further study and understanding to Fukushima accident.

In China, the “Safety Requirements for new NPPs in the 12th 5-year Plan” and the “Safety Requirements for new NPPs in the 13th 5-year Plan” is in preparation, which is suitable for new nuclear power plants. The advanced and strict safety requirements for NPPs in China keep the operation of Chinese NPP in safety.

**Appendix 1: Reference**

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants：Design, IAEA- No.NS-R-1, Vienna (2000).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants：Design, IAEA- No.SSR-2/1, Vienna (2012).

[3] National Nuclear Safety Administration, Safety of Nuclear Power Plants：Design, HAF102, Beijing (2004).

[4] National Nuclear Safety Administration, General Technical Requirements for NPP Improvement Actions after Fukushima Accident (Tentative version), 2012.

[5] National Nuclear Safety Administration, Safety Requirements for new NPPs in the 12th 5-year Plan (Opinion Collection Phase).

[6] WENRA Reactor Harmonization Working Group, Safety of new NPP designs, 2012.