The discussion of several important safety requirements for the new Nuclear Power Plant

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**Abstract：**Post the Fukushima nuclear accident, the Chinese Government raised higher safety goals and safety requirements for the new Nuclear Power Plant for construction. The paper has expounded the important indicators of safety requirements and the aspects of safety modification that had been developed for the new NPPs. Discussed and analyzed the main field that required by the new NPPs safety requirements in design concept, design method, defenses of internal and external events, severe accident prevention and mitigation, optimized the engineer technical measure. That looks forward to the new requirements which conduct to regulate the site selecting and the design of NPP. The paper had supported the industry better to comprehend the primary position and philosophy of safety requirements which developed for the new NPP.

**Key words:** nuclear safety; new nuclear power plant; safety requirement; discussion.

### Introduction

After several decades of development, China has established a relatively complete legal system of nuclear safety. The nuclear safety standards in line with international standards and meet the basic needs of the nuclear power plant safety management. Practice has proved that this system is effective, the safety of nuclear power plant in operation and under construction is guaranteed. After the Fukushima nuclear accident, the international community recognized the existing nuclear power plants still require further security improvement. International Atomic Energy Agency as well as some of the nuclear organizations, nuclear countries based on the latest research results and the important lessons of Fukushima nuclear accident lessons, are or plan to amend related nuclear safety regulations and standards.

In order to meet the needs of current and future development of nuclear power in our country, the National Nuclear Safety Administration issued a "nuclear safety and radioactive pollution prevention" Twelfth Five Year Plan "and the 2020 vision" (hereinafter referred to as the "Nuclear Safety Plan"), as a higher security objectives and security requirements for New nuclear power plants, and is developing "new nuclear power plant safety requirements" document to guide and standardize the design of new nuclear power plants.

According to China's current nuclear safety regulations, refer to the latest IAEA nuclear safety standards and learn the current preliminary summary of lessons learned from the Fukushima nuclear accident, the major nuclear organizations and countries for nuclear power plant safety improvement requirements, considering the experience of design, construction and operation of nuclear power plants in operation and under construction, several important new safety requirements for pressurized water reactor nuclear power plants were discussed.

### The safety goals

Nuclear power plant designs to meet the "nuclear power plant design and safety requirements" (HAF102) in radiation protection goals and technical safety [1] objectives, it also must fully implement the two probabilities "nuclear safety plan" put forward by the security target that the probability of severe core damage frequency (CDF) event less than Hundred thousandth, the probability of large release of radioactive material (LRF) is less than Millionth. Both probabilistic safety goals as an important indicator to assess the level of safety of nuclear power plant design, technical safety measure to achieve goals, but also as a serious evaluation of accident prevention and mitigation measures completeness indicators. Two probabilistic safety goals is also a new generation of nuclear power plants internationally proposed target. To achieve these two objectives, the new nuclear power plant should improve the prevention and mitigation of severe accidents, to further improve the level of safety based on the nuclear power plants in operation.

For the new nuclear power plants in " "Thirteen Five" period" and after, the actual design and strive to eliminate the possibility of a large release of radioactive material. Must lead to the design of the actual elimination of a large number of events or early release of radioactivity, which requires virtually eliminate the need may lead to early containment failure or accident sequences massive radioactive release, and for the elimination of the substance cannot be accident conditions, shall only the purpose of protection of the public to take a limited area and time frame of the protective measures and shall provide sufficient time for the implementation of these measures.

### Defense in depth

Application of the concept of defense in depth throughout design and operation provides multilevel protection against all kinds of transients and anticipated operational occurrences and accidents, including those resulting from equipment failure or human induced events within the plant, and against consequences of events that originate outside the plant. Thus, the goal of controlling reactivity, cooling the core and spent fuel, containing radioactive substance, controlling the operating discharge and limiting the accidental releases and other basic safety features can be achieved, which can ensure the safety of nuclear power plants.

Nuclear power plants should adopt multilevel defense in depth measures and ensure the effectiveness of the defense in depth measures at all levels and the independence of each level to improve the capability of multilevel defense(inherent features, equipment and procedures)[2]. To prevent consequences of accidents that could lead to harmful effects on people and the environment, a safety concept about the balance of defense and mitigation should be implemented to ensure that appropriate measures are taken for the protection of people and the environment and for the mitigation of consequences in the event that prevention fails.

In addition to the extremely impossible PIEs, the design should as far as possible ensure that the first level up to the second level of defense can stop all PIEs upgrading to accident conditions. Also, events that lead to large-scale damage of the nuclear power plant should be considered, for example, some extreme events caused by man-made sabotage can have a severe effect on the safety of the nuclear power plants. These above should be assessed, and necessary measures based on the assessment results should be taken.

### Safety analysis

A safety analysis for the design of nuclear power plants shall be conducted. In the safety analysis, deterministic and probabilistic analysis methods must be applied and the results of them shall be considered to demonstrate that the design of nuclear power plants is balanced, effective defense in depth measures are implemented, the safety goal is achieved, the nuclear power plant as designed is capable of complying with authorized limits on discharges with regard to radioactive releases and with the dose limits in all operational states, and is capable of meeting acceptable limits for accident conditions[3].

Nuclear power plant should perform the probability assessment of core damage and the risk assessment of large radioactive release that needs early OTC response to confirm the consistency with the probabilistic safety goals; two-level probabilistic safety analysis of nuclear power plant operation, shutdown conditions, internal and external events should be completed, spent fuel storage pools also included [4].

### Site safety

Nuclear power plants should select a site carefully, basing on the full safety assessment. Not only the site needs to avoid high-risk areas of natural disasters, but also the impact of low-probability events should be fully considered in the site safety assessment and the nuclear power plant design basis of the external events defense should be determined appropriately and conservatively. For seismic assessment, the IAEA standards present that no matter how low the level of seismic activity in selected regions of the nuclear power plant site is, the determined limits of nuclear power plant safety seismic activity level should not be less than 0.1g. In the development of "the nuclear power plant site selection safety requirements." (HAF101) and its guides, combined with our seismic safety assessment of siting and seismic activity characteristic of nuclear power plant area, the limit was added to 0.15g. It now appears that the decision at that time is forward-looking, and there is a certain margin in the seismic problem of China's nuclear power plant siting [5].

Nuclear power plants should fully investigate and assess its environmental impact and the feasibility of implementing emergency plan throughout the lifetime in its siting. Nuclear power plant should be compatible with the city or industrial development plan, population, land use planning and water environmental function zoning in the area where the site locates.

### Safety function and safety classification

All the structures, systems and components which are safety important items should be determined first in the design of nuclear power plant, including instrumentation and control software, then the items should be classified according to its safety function and safety importance. The design, construction and maintenance of the items should ensure the quality and reliability consistent with safety classification. The appropriate interface should be provided between different levels of structures, systems and components, to ensure any failure in the lower level will not spread into the higher level.

The higher requirements should put forward to the systems and components which implement the prevention and mitigation of severe accident function, the radioactive release from severe accident in all the operation condition should maintain at the as low reasonably achievable level, these safety systems and components should be independence from the other systems and components in defense-in-depth at the reasonable degree. IAEA<Safety of Nuclear Power Plants: Design> (SSR-2/1) use the item “design extension conditions (including the accident which cause the severe degradation of reactor core)”, and put the particular safety consideration on safety measures and important items which implement “design extension conditions”. For the systems and components which implement the prevention and mitigation of severe accident function, the availability and accessibility satisfied the design requirements at accident conditions should be considered in design, and be proved through analysis, testing or inspection.

### Internal event

The design of nuclear power plant should analyze the postulated initiating events to determine all the internal events that may affect the safety of nuclear power plant. These events may include equipment failure or malfunction. Design should consider the possibility of occurrence of internal events such as: fire, explosion, internal flooding, projectile, structural collapse and falling objects, pipe whip, jet flow impact or damaged systems or fluid release in other facilities, and provide appropriate preventive and mitigation measures to ensure nuclear safety is not compromised.

If the two fluid systems under different pressures are connected with each other, then the two systems should be designed according to the higher pressure, or to take measures to prevent the system operation under low pressure exceeds the design pressure when a single fault occurs. The interface loss of coolant accident should also be analyzed, and the risk should be evaluated, then effective measures should be taken in the design.

### External events

Nuclear power plant should be combined with natural and social environment surrounding area of the site, investigating and assessing the external events which may affect the safety of nuclear power plants, including earthquake, flood, geological, meteorological and other external natural events and external man-made events such as impact of aircraft and dangerous goods explosion, to determine the suitability of the site and the design basis for resisting the external events.

After Fukushima nuclear accident, the influence on the safety of nuclear power plant by extreme external events beyond the design basis is highly concerned. To deal with these extreme external events beyond the design basis (e.g., earthquake, tsunami, flood etc.) the appropriate safety margin should be considered in order to improve nuclear power plants to withstand extreme external events beyond the design basis especially extreme natural disasters [6].

Nuclear power plants may increase the seismic design basis appropriately, and doing seismic margin assessment or seismic probability safety assessment. For the seismic design basis, the new generation reactors have improved the safe shutdown earthquake (SSE) level in different degrees, using the seismic design basis which is more enveloped the site characteristics, such as American standard design of AP1000 reactor use SSE 0.3g, French standard design of EPR use SSE 0.25g, the Russian standard design of VVER reactor use SSE 0.2g.Enhancing the nuclear seismic level not only conducive to the expansion of site scope which is appropriate for nuclear power plant but also improve the safety margin for the site of certain condition. Therefore, nuclear power plants should choose the site has low level of earthquake and increase the seismic design basis in order to ensure adequate seismic safety margin.

The design of flood control should consider the impact of extreme flood events and flood combination, and considering flood control in site selection, "dry site “should be considered in design([grade elevation of plant site](http://dict.cn/grade%20elevation%20of%20plant%20site) higher than the design basis flood level, considering the wave effect).When not using "dry site", engineering measures for flood control must be taken, and consider the appropriate safety margin, to ensure the safety of nuclear power plant in flood control.

### Severe accident

The NPPs are already designed with high reliable systems to address DBA, preventing the core damage and controlling the release of radiation material. Post the Fukushima accident, it is realized that some accident sequences of very low probability still can lead to a severe accident.

The NPPs’ design should consider sufficient severe accident preventive and mitigation measures. Important event sequences that may lead to a severe accident shall be identified using a combination of PSA, deterministic methods and sound engineering judgment. Acceptable measures need not involve the application of conservative engineering practices used in setting and evaluating design basis accidents, but rather should be based upon realistic or best estimate assumptions, methods and analytical criteria. For selected severe accidents, the reasonable preventive and mitigation measures should be established and keep balance of both. Enhancing the plant’s capabilities to withstand accidents that are either more severe than design basis accidents or that involve additional failures, to reduce radiological consequences as possible.

The following main severe accident related issues should be included but not limited to:

The scenarios and treatment measures of Station Blackout should be further considered, such as external event induced. Based upon realistic assumptions, the NPPs should maintain the reactor core cooling and will not lead to core damage when loss on-site and off-site emergency AC power within 8 hours; the NPPs should have corresponding power support system, to ensure the NPPs will not lead to unacceptable radiological release without on-site and off-site emergency AC power within 72 hours. The measures can be: Add the mobile power and pump on the basis of fixed additional power supply; enhance the reliability of on-site power, and give priority to restore the off-site power measures etc.

Reactivity accidents resulting from fast introduction of cold or decorated water must be prevented by design provisions so that they can be excluded. Special attention shall be given to shutdown states and open containment building

High pressure core melt situations must be prevented by high reliability measures; the MCCI effect should be evaluated based on the site and structure conditions, and reasonable engineering measures should be adopted; the design should prevent the accumulation of hydrogen partially, otherwise, the impact of local hydrogen deflagration should be considered.

The integrity of the containment under severe accident condition should be considered, especially the expected combustion effect of possible combustible gas; adequate consideration shall be given to the capability of containment penetrations and air locks to remain functional in the event of a severe accident; Adequate consideration shall be given to the capability to remove heat from the reactor and control the radiological release from the containment in the event of a severe accident; Accident sequences involving containment bypassing should be assessed and reasonable engineering measures should be considered.

Furthermore, severe accident management guidelines (including spent fuel pool severe accident management guidelines) or other procedures should be developed， to address the severe accidents under power operation, low power and shutdown condition and due to external events which lead to widespread destruction.

### Design of reactor core safety

Adequate means of detecting of the neutron flux distributions in the core and their changes shall be taken into account in the design of reactor core safety. Diverse means of shutting down the core shall be provided. In all operation states the core has a negative reactivity power coefficient, and the functions of residual heat removal and emergency core cooling are available. Ensure that there is a capability to shut down the reactor of the nuclear power plant in operational states and in accident conditions, and that the shutdown condition can be maintained even for the most reactive conditions of the reactor core [8].

Priority is given to the mature or proven fuel elements. Adequate test is needed to the new developed fuel element before officially adopting in nuclear power plant. To ensure the reactor core and fuel subassembly have a proper safety margin, the ultimate power parameters shall have an adequate safety margin in design, which is composed with core DNBR margin and linear power density margin, etc. These margins brought such benefits as: 1) operation margin is provided, and thermal load is decreased; 2) the capability and performance against the transients is strengthened; 3) the capability against the abnormal distribution of core power; 4) the back-up is provided for the cases uncovered in design.

### The containment design

The design of the containment system shall ensure its integrity in the DBA, and reduce containment conditional failure probability, enhance the confinement function of the containment under the severe accident as far as possible.

The containment system shall be designed so that the prescribed maximum leakage rate is not exceeded in design basis accidents, the containment effectiveness function and confinement function should be enhanced and improved under the severe accident. The ability of collecting leakage of radioactive material from the containment should be enhanced; otherwise, sufficient engineering measures should be considered, which can make the radioactive material leaked fully retention and decay.

The containment failure mode includes containment bypass, isolation failure, overpressure failure, and the penetration of the basement, which should be analyzed in level 2 PSA, the dominant accident sequence should be identified. Usually, the containment bypass is a main failure mode, the NPPs should adopt effective measures to reduce the probability of containment bypass, and also the confinement function should be ensured when containment bypass occur.

The ultimate capacity of containment under severe accidents of NPPs should be analyzed, the severe accident phenomena such as, hydrogen combustion, HPME, steam explosion, the MCCI effects should be considered. Through the elastic-plastic analysis to ensure the stress and deformation of the containment under elastic-plastic criterion, and pressure boundary will not crack, and the containment penetrations and other vulnerability should be focused to ensure the integrity of the containment. Otherwise, overpressure protection measures of containment should be considered. For the containment that the heat removal capacity cannot be guaranteed and the design margin is not so large, the containment filtration exhaust system should be set, and the efficiency of filtration should be improved as far as possible.

### Design of instrumentation and control systems

Instrumentation shall be provided for the main variables that can affect the fission process, the integrity of the reactor core, the reactor coolant systems and the containment at the nuclear power plant with monitoring throughout normal operation, anticipated operational occurrences, design basis accidents and severe accidents, for obtaining essential information that is necessary for its safe and reliable operation.

Anticipated operational conditions, the available time for executing the action and the requirement for the operators’ mental state shall be considered to help operators to complete their actions successfully. The safety actions shall be triggered automatically to avoid the intervention by the operators during a proper time after an anticipated operational occurrence or design basis accident occurs.

Instrumentation and control systems for items important to safety shall be designed with high reliability and periodic testability commensurate with the safety functions to be performed. Design techniques such as testability (a self-checking capability where necessary), fail-safe characteristics, functional diversity and diversity in component design and in concepts of operation shall be used to prevent loss of a safety function.

The hardware and software used in the instrumentation and control systems for items important to safety shall be with high reliability and the best practices. The independent and effective validation and verification shall be carried out to assess the credibility of the reliability. Other different measures shall be adopted to provide the safety functions when the high credibility of the system cannot be demonstrated.

### Radiation protection management

Nuclear power plants shall be identified and appropriate to consider all the actual and potential radiation sources, and to take measures to ensure that these radiation sources remain under strict technical and control management. Make sure that the radiation and radioactive release produced by NPP is under strict control and met the operation limit and radiation protection standards, and kept as low as reasonably achievable [11].

The radiation protection dose assessment and review on main control room shall be appropriate to consider the effect of severe accident. The concept and occurrence frequency of the severe accident shall be identified. The dose analysis shall be based on the probabilistic safety analysis results, and a set of source terms as reasonable shall be selected [12].

Nuclear power plants shall be allocated with monitoring devices and capable to supply adequate environment radiation monitoring during operation states, accident conditions and post-accident to estimate the radiation impact to environment, and to give technical information to radiation environment management and emergency strategy decision making.

### Conclusion

It can be concluded that the basis of the safety requirements for the new NPP is from the current nuclear safety regulations and codes, and the most advanced international standards are referenced. The requirements of diversity and adopting the latest technique and study in design are reinforced to continually improve the nuclear safety philosophy, which is reinforce and extension for the safety important issues. These safety requirements would improve the safety level and market access for new NPP to protect the public and environment better, and give strong support to the technique development and raising safety level of the peaceful use of nuclear energy.

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