Difference analysis of in-service hydrostatic test for second and third generation PWR

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Abstract. Hydraulic test of nuclear power plant is an important part of in-service inspection of nuclear power plant, and it is one of the important technical means to test the pressure bearing capacity of equipment. In this paper, the technical requirements of the second generation PWR based on safety classification and the third generation reactor based on radioactive release classification are discussed from the aspects of equipment classification, primary circuit hydrostatic test, steam generator secondary side hydraulic test, hydrostatic test of vessel and pipeline, as well as the difficulty of implementation in hydrostatic test.

Keywords: Hydraulic test, Difference analysis, Nuclear power plant.

1. Introduction
At present, most of China's PWR nuclear power plants are the second generation reactor type based on safety classification, and the subsequent nuclear power plants are basically of the third generation reactor type. Compared with the second generation of pressurized water reactor nuclear power units, the third generation nuclear power units are different in design concept, operating conditions, system composition and equipment classification. More passive safety equipment is added, or the redundant equipment based on defense in depth theory is added. The difference in technology between the second generation and the third generation of PWR results in many technical requirements for in-service hydrostatic test of their equipment. Hydraulic test of nuclear power plant is an important part of in-service inspection of nuclear power plant, and it is one of the important technical means to test the pressure bearing capacity of equipment. In this paper, the technical requirements of the second generation PWR based on safety classification and the third generation reactor based on radioactive release classification are discussed from the aspects of equipment classification, primary circuit hydrostatic test, steam generator secondary side hydraulic test, hydrostatic test of vessel and pipeline, as well as the difficulty of implementation in hydrostatic test.

2. Difference of equipment classification in hydrostatic test
At present, China's upstream regulation based on the second generation reactor is In-service Inspection Rules for the Mechanical Components of PWR Nuclear Island of 1997 edition [1], and its main classification basis is based on the safety function classification of equipment, i.e. RCCP classification...
The main consideration is the ability to perform safety functions under design basis conditions. The safety classification is divided into three levels.

a) Safety level one
   Its failure will result in the loss of reactor coolant beyond the normal replenishment capacity of all equipment.

b) Safety level two
   Equipment and components which are conveying reactor coolant but not safety level one, or for sealing radioactive substances during LOCA moment.

c) Safety level three
   Equipment and components that are important for safety, but whose failure will not have direct radioactive consequences, or whose failure will lead to the release of radioactive gas which is normally stored and decayed.

The upstream regulation of the third generation reactor based on radioactive release classification is RSE-M2010 [3]. The RSE-M2010 has absorbed the new practical experience of French nuclear power operation, and transferred the regulatory requirements of the latest French mechanical pressure equipment regulations (i.e. ESPN law [4], 1999.11.10 resolution [5]) into the code. According to the influence of radioactive transmission caused by its failure, nuclear pressure equipment can be divided into three levels, namely N1, N2 and N3.

a) N1 level
   The main primary loop system and the main secondary loop system of the nuclear steam supply system are classified as N1 nuclear pressure equipment.

b) N2 level
   The nuclear pressure equipment which is not classified as N1 and whose failure can lead to radioactive emission higher than 370G bq is classified as N2 nuclear pressure equipment.

c) N3 level
   The nuclear pressure equipment which is not classified as N1 and N2, and whose failure can lead to radioactive emission higher than 370Mbq is classified as N3 nuclear pressure equipment.

For non N1, N2, N3 pressure equipment, it belongs to the conventional pressure equipment, which is classified as NC level.

3. Difference of primary hydraulic test
The differences between the third generation reactor and the second generation reactor are mainly reflected in the following aspects.

a) The concept of in-depth inspection is introduced.
   That is, for the main primary and secondary circuit equipment, in-depth inspection is required when the following conditions occur:
   - After more than 30 years of continuous operation of main primary and secondary circuit components;
   - Replacement of pressure bearing parts of main primary circuit;
   - When the third type of working condition occurs.
   The specific inspection contents of in-depth inspection should be combined with the aging status of components, and the specific situation should be analyzed.

b) On the schedule of hydrostatic test plan for primary loop, the following inspection requirements are added to the third generation reactor.
   - In principle, the complete in-service inspection should be carried out in the same overhaul period as the hydraulic test. However, some parts of the complete in-service inspection can be carried out no more than two years in advance compared with the hydraulic test.
   - For equipment operated for more than 30 years, a partial requalification (without in-depth inspection of hydrostatic test) shall be carried out within 4 - 6 years after each complete requalification.
For MSS devices, this lead time can be set at 40 months. This allows these inspections to be performed during the partial in service inspection prior to the requalification outage.

As a general rule, all complete in-service inspection should be completed before hydrostatic test in principle, except for some special inspection (such as inspection of evaporator heat transfer tube, inspection of reactor pressure vessel). These inspections may be postponed after the hydrostatic test, with the approval of the regulatory authority (in particular, to confirm that the hydrostatic test has not resulted in an unacceptable extension of minor defects).

c) The following inspection requirements are added for the dismantling and insulation of primary hydraulic test.

- For the surge pipeline of pressurizer, the circumferential weld and longitudinal weld need to be removed for insulation;
- Special areas of components shall be removed and insulated according to sampling selection or equipment design particularity, and shall be specified in the requalification procedure.
- During hydrostatic test, visual inspection shall be used instead of visual inspection to ensure no leakage. The requirements shall be defined and met in the requalification procedure.

d) The following inspection requirements are added to the test pressure and test range.

- It should be at least equal to 1.2 times of the design pressure of the main primary circuit equipment;
- After replacement of components, overpressure coefficient 1.2 times higher than design pressure can be required. This test replaces the hydraulic test of components in the name of manufacture.
- The pressure at the top of the pressurizer spray line at the highest point of the main loop system (MPS) must reach the legal hydrostatic test pressure.
- The small pipe line is only pressed to the first isolation device.

4. Difference of steam generator secondary side hydraulic test

The steam generator secondary side hydraulic test of second generation reactor only has the following requirements:

a) In the case of no primary side back pressure, the subsequent hydraulic test is carried out regularly on the secondary side pressure bearing boundary of steam generator;

b) In order to avoid the risk of brittle fracture of heat transfer tube, the water temperature used in the test shall be the maximum value of the following conditions:

- Water temperature specified in the first secondary hydraulic test;
- The highest RT\textsubscript{NDT} of the secondary side barrier material plus 30 °C.

In addition to the above requirements, a number of new regulations have been added for the steam generator secondary side of the third generation reactor based on radioactive classification.

a) The hydrostatic test pressure is equal to 1.2 times of the maximum allowable pressure of the steam generator;

b) However, after the parts are replaced, a higher overpressure coefficient can be required to replace the hydraulic test of components in the name of manufacturing;

c) The inspection area during the test is defined in the requalification procedure.

d) When the definition of witness component is needed, the selection of witness component and relevant special conditions shall be specified in the requalification procedure which is meeting the requirements of the appendix.

e) The test report shall be completed to record the actual pressure and temperature, the inspection results and the leakage rate shall be measured.

f) The periodic arrangement of the secondary side hydraulic test of the evaporator is made clear. The reference standard is the implementation date of the latest hydraulic test of the corresponding steam generator, and the first periodic hydraulic test is carried out within 10 years after it.
5. Difference of vessel hydraulic test
The difference between the second and third generation reactors is mainly reflected in the classification of vessels and the determination of test pressure.

The second generation reactor type vessels are divided into steam, superheated water medium and gas medium, the test pressure determination principles of the three types of vessels are as follows:

a) For gas medium vessels, the subsequent hydrostatic test pressure shall not be less than 1.5 times of the design pressure of the pressure vessel.

b) Steam medium vessel or superheated water pressure vessel test pressure shall not be lower than the table 1 below.

Table 1. Hydrostatic test pressure selection with steam medium vessel or superheated water pressure vessel

| maximum working pressure: P(bar) | Hydrostatic test pressure: P_t(bar) |
|---------------------------------|-----------------------------------|
| 0.5<P≤6                         | 1) 2P                              |
| 6<P<12                          | 2) P+2                             |
| P≥12                            | 3) 1.17P                           |

The test pressure of the third generation reactor does not distinguish the operating medium of the equipment, but unifies the setting principle of the test pressure.

The specific test pressure setting principle is as follows.

If it is a N2 or N3 level vessel, the hydrostatic test pressure is set as 1.2 times of the maximum allowable operating pressure or the overpressure coefficient is reduced to 1/3 of the first hydrostatic test pressure.

If it is an NC level container, the pressure of hydrostatic test is the pressure of the first hydrostatic test or the pressure determined by reducing the overpressure coefficient to 1/3 of the first hydrostatic test.

6. Difference of pipeline hydraulic test
No subsequent hydrostatic test is required for the second generation reactor, provided that the first hydrostatic test has been conducted by the manufacturer in the presence of a representative designated by the nuclear safety management department, and the test pressure is not less than 2 times of the maximum operating pressure of the pipeline.

For the third generation reactor, higher inspection requirements are proposed.

a) The subsequent hydrostatic test is not applicable to N3 pipeline and the safety and pressure accessories connected.

b) For the N2 pipeline and the safety accessories and pressure accessories connected, the subsequent hydraulic test can be replaced by the overall system test during operation. This test shall provide the equipment safety information equivalent to the hydraulic test carried out on the removed insulation pipeline.

c) External inspection is also applicable to piping, pressure containing accessories connected to the equipment and components permanently connected to the equipment.

d) For the pipeline with thermal insulation removed and pressure bearing accessories connected to the equipment, when the external inspection will lead to the risk of personnel contamination or excessive radiation dose, these inspections can be partially implemented and focused on the sensitive areas judged to have defects and failures. In this case, the identification of these areas should be approved by the agency conducting the hydrostatic test or, if necessary, by the nuclear safety administration for Level 3 components; For Level 2 components, when these inspections are tracked by the nuclear safety management department, the determination of these areas shall be approved by the nuclear safety management department in advance; when these inspections are not tracked by the nuclear safety management department, the operating unit shall determine the supervision methods for
sensitive areas and other parts according to the provisions for the contents of the regular inspection and supervision and maintenance program of these components.

c) The internal inspection of pipeline and its pressure bearing accessories can be replaced by non-destructive inspection according to regulations.

7. Difference of implementation difficulty on site
Because the scope of equipment supervision has been expanded based on radioactive classification, the number of hydrostatic tests that need to be carried out on the whole is greatly increased. Therefore, the number of vessels requiring hydrostatic test in a single overhaul is greatly increased, and that puts forward higher requirements for manpower, spare parts and time window for overhaul preparation. At the same time, due to the pipeline hydrostatic test and the complexity of the pipeline route, many workshops are involved. When the pipeline hydrostatic test is involved, more attention should be paid to the setting of the boundary range of the pipeline hydrostatic test. The pipeline hydrostatic test often involves the disassembly and assembly of large-scale pipeline flange. When installing the flange, attention should be paid to the production of temporary flange gasket and the setting of test torque. In the field implementation, due to the different requirements of radiation protection management, the implementation mode of field work is also very different.

8. Summary
As the amount of nuclear vessels grows quickly with the construction of nuclear power station in China, hydrostatic test work is becoming more and more important. This paper summarizes the differences in technical requirements of hydrostatic test between the second generation PWR and the third generation PWR. It can be used as a reference for the establishment of hydrostatic test procedure for the second and third generation reactor type vessels and the implementation on site.

References
[1] RSE-M In-service Inspection Rules for the Mechanical Components of PWR Nuclear Island, AFCEN, 1997 edition.
[2] RCC-P Design and construction rules for system design of 900MWe PWR nuclear power plants, EDF and FRAMATOME, 4th Revision, 1995
[3] RSE-M In-service Inspection Rules for the Mechanical Components of PWR Nuclear Island, AFCEN, 2010 edition.
[4] Order dated 12 December 2005 concerning nuclear pressure equipment, French Order.
[5] Decree No. 99-1046 of 12.13.99 concerning pressure equipment, French Decree.