Vessel hydrostatic test duration analysis in pressurized water reactor nuclear power plant overhaul

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Abstract. The vessel hydrostatic test is one of the important test means of the nuclear vessel sealing and pressure resistance, and it is an important project in the plant overhaul. Because the vessel hydrostatic test involves many key systems and key vessels, and it belongs to the critical path or time critical path in plant overhaul, how to estimate the vessel hydrostatic test duration in overhaul is necessary. This paper discusses the actual hydrostatic test time of different vessels in pressurized water reactor nuclear power plant overhaul, and divides the test time into three categories, that is long (more than 6 days), medium (3 to 6 days), and short time duration for a project (less than 3 days). This paper also discusses the key factors that influence the vessel hydrostatic test duration and puts forward the optimization suggestions of vessel hydrostatic test duration.

1. Introduction
During the refueling overhaul of a nuclear power plant, nuclear vessel hydrostatic test is an important part in the process of refueling overhaul, and it is one of the important test means of the nuclear vessel sealing and pressure resistance, the clear technical requirements standard about the nuclear vessel hydrostatic test is described in the RSE -M PWR nuclear equipment in service inspection rules [1] and the RCC -M PWR nuclear machinery and equipment design and construction rules [2]. Nuclear vessel hydrostatic test involves many key systems and vessels and the preparation and implementation workload is large in the process of plant refueling overhaul. Nuclear vessel hydrostatic test belongs to the critical path or time critical path in plant refueling overhaul and it has an important impact on the outage duration. Therefore, how to analyze and optimize the nuclear vessel hydrostatic test duration is worthy of an in-depth discussion. This paper mainly analyses the specific hydrostatic test duration of different vessels, and discusses the influence factors of the nuclear vessel hydrostatic test duration, and puts forward the corresponding optimization suggestions of the nuclear vessel hydrostatic test duration.

2. The specific hydrostatic test duration of different vessels in refueling overhaul
The PWR models involving the need to implement nuclear vessel hydrostatic test system are RCP/RCV/RIS/EAS/SAP/SAR/GCT/ASG/APG/LHQ/LHP and many other key systems. Its equipment including RCP002BA /RCV002BA /RCV001EX /RCV002RF /RIS001BA /RIS002BA /RIS003BA /EAS001RF /EAS002RF /ASG001ZE /ASG003ZE and other key equipment related to nuclear safety quality. The nuclear vessel hydrostatic test scheme is different. The specific hydrostatic test duration of different vessels is also different. According to the actual vessel hydrostatic test duration in different rounds of overhaul, the actual vessel hydrostatic test duration can be divided into
three categories, that is the long time vessel hydrostatic test duration (more than 6 days), the medium time vessel hydrostatic test duration (3 to 6 days), and the short time vessel hydrostatic test duration (less than 3 days). Many nuclear vessel hydrostatic test projects can easily become the critical path in the process of refueling overhaul, the nuclear vessel hydrostatic test directly affects the duration of refueling overhaul time. Combined with the actual implementation results of nuclear vessel hydrostatic test in refueling overhaul, there are 9 vessels hydrostatic test which are easy to become the critical path project. They are the RRA001RF/RRA002RF/RIS001BA/RIS002BA/RIS003BA/RCV002BA/RCV002RF/ASG001ZE/ASG003ZE vessel hydrostatic tests. Based on the characteristics of a PWR refueling overhaul, the hydrostatic test working window can be divided into two categories, that is whether it has the implementation conditions before the low water level period. The corresponding statistical analysis classification in refueling overhaul of the nuclear vessel hydrostatic test duration is as follows (Table 1, Table2, and Table3).

Table 1. Long time vessel hydrostatic test duration (more than 6 days).

| Vessel name | Hydrostatic test duration | Whether it has the possibility to become the critical path project | Whether it has the implementation conditions before the low water level period |
|-------------|---------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------|
| RIS001BA    | 10                        | YES                                                             | YES                                                                      |
| RIS002BA    | 10                        | YES                                                             | YES                                                                      |
| RIS003BA    | 10                        | YES                                                             | YES                                                                      |
| RCP002BA    | 7                         | YES                                                             | NO                                                                       |
| APG001RF    | 7                         | NO                                                              | YES                                                                      |
| APG002RF    | 7                         | NO                                                              | YES                                                                      |

Table 2. Medium time vessel hydrostatic test duration (3 to 6 days).

| Vessel name | Hydrostatic test duration | Whether it has the possibility to become the critical path project | Whether it has the implementation conditions before the low water level period |
|-------------|---------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------|
| RCV002BA    | 5                         | YES                                                             | NO                                                                       |
| RCV001EX    | 6                         | YES                                                             | NO                                                                       |
| RCV002RF    | 4                         | YES                                                             | NO                                                                       |
| ASG001ZE    | 5                         | YES                                                             | NO                                                                       |
| ASG003ZE    | 5                         | YES                                                             | NO                                                                       |
| JPI004BA    | 3                         | NO                                                              | YES                                                                      |
| JPI005BA    | 3                         | NO                                                              | YES                                                                      |
| JPI006BA    | 3                         | NO                                                              | YES                                                                      |
| SAP001BA    | 4                         | NO                                                              | NO                                                                       |
| SAP002BA    | 4                         | NO                                                              | NO                                                                       |
| SAR003BA    | 4                         | NO                                                              | NO                                                                       |
| EAS001RF    | 5                         | NO                                                              | YES                                                                      |
| EAS002RF    | 5                         | NO                                                              | YES                                                                      |
### Table 3. Short time vessel hydrostatic test duration (less than 3 days).

| Vessel name | Hydrostatic test duration | Whether it has the possibility to become the critical path project | Whether it has the implementation conditions before the low water level period |
|-------------|---------------------------|---------------------------------------------------------------|------------------------------------------------------------------------|
| RRA-001-RF  | 2                         | YES                                                          | YES                                                                     |
| RRA-002-RF  | 2                         | YES                                                          | YES                                                                     |
| GCT001BA    | 2                         | NO                                                           | YES                                                                     |
| GCT002BA    | 2                         | NO                                                           | YES                                                                     |
| GCT003BA    | 2                         | NO                                                           | YES                                                                     |
| JPI001BA    | 2                         | NO                                                           | NO                                                                      |
| JPI002BA    | 2                         | NO                                                           | NO                                                                      |
| JPI003BA    | 2                         | NO                                                           | NO                                                                      |
| LHP250BA    | 2                         | NO                                                           | YES                                                                     |
| LHP251BA    | 2                         | NO                                                           | YES                                                                     |
| LHP252BA    | 2                         | NO                                                           | YES                                                                     |
| LHQ250BA    | 2                         | NO                                                           | YES                                                                     |
| LHQ251BA    | 2                         | NO                                                           | YES                                                                     |
| LHQ252BA    | 2                         | NO                                                           | YES                                                                     |
| SAR016BA    | 2                         | NO                                                           | YES                                                                     |
| RCP004BA    | 2                         | NO                                                           | NO                                                                      |
| RCP005BA    | 2                         | NO                                                           | NO                                                                      |

From the above statistics, there are 37 different types of vessels involved in the plant refueling overhaul. The number of long time vessel hydrostatic test duration is 6 (16.2%), the number of medium time vessel hydrostatic test duration is 13 (35.1%), the number of short time vessel hydrostatic test duration is 18 (48.7%). The medium and short time vessel hydrostatic test duration have the largest proportion of the nuclear vessel hydrostatic test duration.

### 3. The main factors influencing vessel hydrostatic test duration

The main factors which influence the vessel hydrostatic test duration are as follows:

#### 3.1. The difficulty of the hydrostatic test scheme

The difficulty of the hydrostatic test scheme is the main factor influencing the hydrostatic test duration. The difficulty of the hydrostatic test scheme is mainly determined by the following aspects: the volume of vessel size, the difficulty of the water filling device installation, the risk of contamination and the limited on-site space. First, the volume of vessel size affects the hydrostatic test duration, because it mainly has impact on the rate of filling with water and the drainage of water. In the process of the refueling outage at present, the water filling rate is approach 2 cubic meters per hour or so, the drainage rate is approach 1 cubic meter per hour, the filling and drainage time needed for different volume of vessel can refer to the above rate. Second, the difficulty of the water filling device installation affects the hydrostatic test duration, if the difficulty of device installation is large, then the installation time is long. Taking the device installation of RCP002BA vessel for example, the difficulty of device installation is large because of the big size of device, so the device installation...
needs about 4 days. Third, the risk of contamination affects the hydrostatic test duration. If the risk of contamination is high, such as the RCV/RCP/RIS/EAS/RRA system vessels, the person need to work in the SAS and wear radiation protective equipment repeatedly, the hydrostatic test duration will increase accordingly. Finally, the limited on-site space also affects the hydrostatic test duration, if the on-site space is limited, the person works in and out the on-site space section is difficult, the hydrostatic test duration will increase accordingly. Taking the hydrostatic test of RCV002RF vessel for example, due to the operation space is narrow, it is difficult for person to operate the equipment; the vessel hydrostatic test duration will increase accordingly.

3.2. The cooperate work duration of vessel hydrostatic test
There are many cooperate works of vessel hydrostatic test need to do, such as the internal and external visual inspection of vessel, opening manhole, changing the gasket after test, dismantling the valve, cutting and welding pipe, nondestructive testing, probe atresia, scaffolding, laying venues, demolition thermal insulation, anticorrosion, etc. The cooperate work of a vessel hydrostatic test also takes up corresponding hydrostatic test period, its actual implementation work time for a vessel hydrostatic test often restricts the hydrostatic test duration. The common cooperate work duration of a vessel hydrostatic test is shown in Table 4 below.

| cooperate work species                          | Common work duration(hours) |
|------------------------------------------------|----------------------------|
| opening manhole                                 | 4-6                        |
| scaffolding                                     | 2-4                        |
| demolition thermal insulation                   | 2-4                        |
| laying venues                                   | 4-6                        |
| changing the gasket after test                  | 4-6                        |
| internal and external visual inspection of vessel| 1-2                        |
| cutting and welding pipe                        | 6-8                        |
| probe atresia                                   | 1-2                        |
| dismantling the valve                           | 2-4                        |
| nondestructive testing                          | 4-8                        |
| anticorrosion                                   | 2-4                        |

4. Hydrostatic test duration optimization
The optimization of the hydrostatic test duration mainly through the hydraulic test scheme optimization and the optimization cooperated work.

4.1. The hydrostatic test scheme optimization
The optimization of hydrostatic test scheme mainly through three aspects to achieve, the optimization of water filling device, the optimization of cutting and welding seam choice, and the optimization of operation space. First, in the preparation of manufacturing water filling device, it should meet the technical requirements and reduce the weight of the water filling device as far as possible, so it is easy for installation. Second, the optimization of cutting and welding seam choice should meet the technical requirements, and reduce the number and size of cutting and welding pipe as far as possible. Taking the RCV001EX hydrostatic test which is in the critical path for example, the hydrostatic test scheme expands the isolation boundary, then the new hydrostatic test scheme can choose a more reasonable cutting and welding seam, the size of the welding seam changes from 3 inch into 1/2 inch, and the
space position also gets a big improvement, it significantly reduces the work load of person, and save the hydrostatic test duration. Finally, the optimization of operation space can change the working point from bad position to a good place by using the high-pressure hose.

4.2. The optimization cooperate work of vessel hydrostatic test
Due to the vessel hydrostatic test involving many cooperate works, it is worthy to discuss how to optimize the cooperate works. The working ticket type of cooperate work is mostly the PW blocking certificate, but the working ticket type of vessel hydrostatic test is mostly the PR blocking certificate. The PW blocking certificate cannot share isolation boundary with the PR blocking certificate, the working ticket is easy to block, and the cooperated work cannot be implemented without the working ticket. If the workload of cooperate work needs short time to implement, the cooperate work tickets can hook up to the vessel hydrostatic test tickets, the cooperated work can share isolation boundary with the PR blocking certificate, the JPI/GCT/SAP/LHP/LHQ system vessel hydrostatic test can use this way to work. If the workload of cooperate work needs a long time to implement, it suggests that the cooperated work should use the PW ticket, it can reduce the PR ticket time, and the RIS/RCV/EAS/APG/RCP system vessel hydrostatic test can use this way to work.

5. 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 discusses the actual hydrostatic test time of different vessels in pressurized water reactor nuclear power plant overhaul, and divides the test time into three categories, that is long (more than 6 days), medium (3 to 6 days), and short time duration for a project (less than 3 days). This paper introduces the specific hydrostatic test duration of different vessels, and discusses the influence factors of the nuclear vessel hydrostatic test duration, and puts forward the corresponding optimization suggestions of the nuclear vessel hydrostatic test duration. The optimization of the hydrostatic test duration mainly through the hydraulic test scheme optimization and the optimization cooperated work.

References
[1] RSE-M In-service Inspection Rules for the Mechanical Components of PWR Nuclear Island, AFCEN, 1997 edition
[2] RCC-M Design and Construction Rules for Mechanical Components of PWR Nuclear Islands, AFCEN, 2000 edition