Implementation and optimization suggestions for ISI items of CPR1000 steam generator

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Abstract. The implementation logic of different ISI items of steam generator during the refueling outage of the nuclear power plant was studied. Based on the implementation relationship between the implementation window and the main line plan of the refueling outage, some optimization suggestions on the planning, preparation and implementation of relevant items were given, aimed at reducing the inspection time of SG ISI items and reducing the collective dose of the inspectors.

1 Induction

Steam generator (SG) is one of the primary cooling system equipment of nuclear power plant. According to the ISI specification and the regulatory requirements of the nuclear safety administration, the relevant parts of SG need to be inspected during the refueling outage. According to the inspection location, the ISI (ISI) items of SG are divided into primary side inspection items of SG and secondary side inspection items. In terms of inspection methods, the ISI items of SG involve 6 methods: VT, PT, MT, UT, RT and ET. According to the item sources, the ISI items of the SG are divided into standardize statutory requirement items and standardize non-statutory requirements items, and experience feedback items. There are two main purposes for nondestructive testing on the relevant parts of SG: one is to ensure the reliability of the tested object; the other is to ensure that the heat transfer tube is safe and available and the heat transfer efficiency meets the requirements.

The NDT activities in the radiation protection (RP) control area of nuclear power plant mainly include several characteristics: first, the operation activities in the RP control area needs to comply with the radiation protection management requirements and wear radiation protection articles correctly. Second, the preconditions and accessibility of NDT activities need to meet the inspection requirements, such as temperature, roughness, scaffold and thermal insulation. Third, the NDT activities of nuclear equipment shall be carried out in accordance with the inspection process and acceptance standards of civil nuclear safety equipment. The fourth is the plan and implementation of NDT activities during refueling outage, which shall be coordinated and arranged by the technical department and the planning department. This paper focuses on the implementation logic of different SG ISI items, the implementation relationship between the implementation window during

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refueling outage and the main line plan. Some optimization suggestions on the planning, preparation and implementation of relevant items were given.

2 Implementation of ISI items of SG

2.1 Introduction of main inspection items

RSE-M specification divides the ISI items of SG into nuclear safety class I and nuclear safety class II components. Important inspection items of nuclear safety class I components include ET of SG heat transfer tube (SG1-ET), video inspection of surface surfacing layer in primary side water chamber (SG1-CCTV), RT (SG1-RT) and PT(SG1-PT) of welds between lower head and safety end of SG and between safety end and main pipeline, UT of welds on both sides of tubesheet (SG1-UT), PT for the arc surface at the root of the support leg and the weld of the sewage nozzle(SG1-PT), VT and UT for manhole bolts, VT for nuts, UT for ligament area of bolt holes (SG1-others). Important inspection items of nuclear safety level II components include secondary side tubesheet and inter pipe endoscopy(SG2-ITV), UT of connecting welds between outlet nozzle and safety end, UT of connecting welds between upper shell and conical shell, UT of connecting welds between are nozzle and upper shell (SG2-UT), MT of connecting welds between conical shell and lower shell (SG2-MT), VT of welds on the upper internals on the secondary side, the inner surface of the upper shell, the support ring of the upper internals and the top of the SG (SG2-VT), and other inspection items (SG2-others), including VT related to the connection welds between are nozzle and the upper shell and the handhole of the manhole on the secondary side, as well as the hydrostatic test on the secondary side.

2.2 Logical relationship of item implementation

During the previous refueling outages, the ISI items of SG are an important part of the ISI items of nuclear island. Therefore, on the premise of ensuring inspection quality and safe construction, it is necessary to fully consider the logical relationship between different projects and reasonably develop inspection plan to avoid rework and affecting the whole period. The logical relationship of project implementation mainly considers three aspects: the first is the sequence of different project implementation times, the second is the control requirements of collective dose, and the third is the preparation of preconditions. The logical relationship between key projects is analyzed as follows.

At the initial stage of refueling outage, the vessels, pipes and valves of the main circuit system of the unit are full of water, and the main equipment is not perforated, so the overall irradiation degree of the reactor building is low. During this period, the PT, UT and other items in the high-dose area shall be completed at the first time, such as the PT of the weld between the arc surface at the root of the primary support leg and the sewage nozzle, the UT of the ligament area of the bolt hole and the connecting welds on both sides of the tubesheet, the secondary side UT and MT. There are many items related to the water chamber at the primary side of SG, and the inspection period is quite long. The logical relationship is as follows: after the manhole at the primary side is opened, the RT of the welds between the lower head of the generator and the safety end and the connection between the safety end and the main pipe shall be carried out at the first time. Then, the blocking plate shall be installed at the inlet and outlet of the main pipe from the perspective of preventing foreign matters. and the water chamber shall be dried to carry out ET of heat transfer tube and video inspection of surfacing layer in water chamber. At the same time, relevant visual and UT shall be carried out after manhole bolts and nuts are cleaned. The

endoscopy inspection of the secondary side tubesheet and tube room is one of the projects with the longest construction period. Its purpose is to check the cleanliness of the secondary side tubesheet and tube room of the SG. If some foreign matters that may cause damage to the heat transfer tube are found on the secondary side of SG, the inspection items of the SG heat transfer tuber need to develop temporary inspection items. The hydrostatic test on the secondary side of SG is a test to pressurize the secondary side of the evaporator to a certain pressure to test its strength and tightness. Before the implementation of the hydrostatic test, the relevant ISI items need to be completed, such as UT of the weld between the safety end and the main steam nozzle, UT of the weld between the ARE nozzle and the upper shell, MT of the weld between the conical section and the lower shell, VT of upper internals and inner surface of upper shell, VT of the manhole, handhole and eyehole of SG secondary side, and some other items of the ARE, ASG, VVP and GCT system.

2.3 Screening of key path items

Each ISI item is usually arranged in a relatively fixed inspection window, and relevant preconditions need to be prepared in advance, such as opening, scaffold, thermal insulation removal, grinding, etc. The key path items are screened according to the four dimensions of the item impact degree, logical relationship between two items, item impact scope and overall item path. The implementation preconditions, pre items, post items and inspection time of each SG ISI item are seen in table 1.

Table 1. The implementation information of each SG ISI item.

Item description	Precondition	Front/Rear item	time pre SG (h)
SG1-ET	After opening, installing blocking plate and drying	SG1-RT/SG1-CCTV	108
SG1-CCTV	After opening, installing blocking plate and drying	SG1-RT/SG1-ET	12
SG1-RT	After opening and before plugging plate installation	SG1-ET& SG1-CCTV	12
SG1-PT	Before opening and removing insulation	Open manhole	3
SG1-UT	Remove insulation and springboard	SG2-ITV	3
SG1-other	Cleaning of bolts and nuts	Open and Close manhole	1
SG2-ITV	Open handhole	Secondary side water flushing	96
SG2-UT	Remove insulation and polish (as required)	/	3
SG2-MT	Remove insulation	/	3
SG2-VT	Open manhole	/	3
SG2-other	Open manhole	/	1

Based on the information in the above table, it can be seen that the relevant inspection items of the water chamber at the primary side of SG occupy the key path of low and low water level. If SG1-ET, SG1-CCTV and SG1-RT are arranged in the same refueling outage, several aspects need to be fully considered: first, the RT items are carried out at night, and each inspection period is 12 hours. The installation and commissioning time of ET equipment for SG heat transfer tubes is about 3.5 hours. In case of cross inspection with the RT, the equipment installation and commissioning shall be completed before the RT. For the video inspection of SG water chamber, the inspection plan shall be flexibly formulated

according to the RT window and heat transfer tube ET window, so as to shorten the total time of the last SG as far as possible. It should be noted that the main line work performed simultaneously during the low and low water level period includes valve maintenance and inspection, pump maintenance and relevant inspection items of the water chamber at the primary side of SG. All items have a common expected finished time, and the end time of the low and low water level depends on the end time of the last completed item.

3 Implementation suggestions

3.1 ET of SG heat transfer tubes

According to nuclear safety guideline HAD 103/07 [1]and in-service inspection rules for mechanical components of nuclear island (RSE-M) [2], ET is required for SG heat transfer tube. Consider the CPR1000, the current ET strategy of SG heat transfer tube is to inspect all tube bundles of three SGs during ten-year refueling outage. For other refueling outage rounds, select one or two SGs and exam the heat transfer tubes according to a certain proportion. At the same time, ET needs to be carried out on the areas of tubes and tubesheet sections with historical signal display. At present, the main problems in the ET of SG heat transfer tube are that the mechanical equipment is bulky, the failure rate is high, the inspection period is uncertain, and the average collective dose is increasing.

The optimization of ET can be carried out from the following aspects: first, from the perspective of integration, miniaturization and intelligence, development and improvement of ET mechanical equipment can effectively shorten the equipment installation, commissioning and maintenance time, so as to reduce the inspection time and collective dose [3]. The second aspect is that for some refueling outage cycles, when the primary side of the SG also includes one or two of the video inspection of the water chamber and the RT of the connecting welds between the inlet and outlet nozzles and the main pipeline (in table 2) the overall planning, preparation and implementation of each item as a whole can effectively reduce the site transfer, thus saving the inspection time and reducing the collective dose [4]. The third aspect is to optimize the ET of SG heat transfer tubes and develop the strategy of medium and long-term inspection and sampling inspection of the witness equipment during refueling outage.

Table 2. Different ISI items of the primary side of the SG.

No.	Parts to be inspected	Examination methods	Remarks
1	SG channel heads dissimilar metal welds to reactor coolant pipes	RT	Complete ISI; Once between 2 Complete ISI
2	Channel head inner cladding	CCTV	Complete ISI; Once between 2 Complete ISI
3	Safe end to reactor coolant pipes welds	RT	Complete ISI; Once between 2 Complete ISI
4	Exchange tubes	ET	Complete ISI; 1 or 2 SG in each refueling outage

3.2 Inspection items of SG secondary hydrostatic test

According to the requirements of RSE-M specification, the secondary side pressure bearing boundary of SG needs a periodic hydrostatic test. For the parts requiring periodic hydrostatic test, complete ISI shall be carried out at the same time as the periodic hydrostatic test, but some complete ISI can be carried out within 2 years before the

hydrostatic test. According to the relevant contents of the ISI schedule program [5], the complete ISI items include the inspection item of secondary side of SG, ARE system (inside and outside the reactor building), ASG system, VVP system (inside and outside the reactor building) and GCT system (outside the reactor building). Since there are many inspection items involved in the hydrostatic test on the secondary side of SG, especially a large number of RT, scaffold and grinding.

In view of the above situation, the following two aspects can be planned and arranged: first, the inspection items of the same loop are arranged in the same refueling outage. For example, the UT, TM, PT and RT of VVP, ARE, ASG and GCT of the same loop can share the scaffold, the thermal insulation removal, and grinding and inspection can be carried out in turn. It can greatly save the human resource needs of scaffolding, grinding and other coordination disciplines. The second aspect is to reasonably arrange the total amount of inspection items. According to historical experience, there are more than 300 inspection items related to hydrostatic test on the secondary side of SG, which need to be completed during the same refueling outage as the hydrostatic test and the previous refueling outage.

4 Conclusion

This paper focuses on the implementation logic of different SG ISI items, the implementation relationship between the implementation window during refueling outage and the main line plan, and the optimization suggestions on the planning, preparation and implementation of relevant items. The main situations are summarized as follows:

(1) The logical relationship between the implementation of each SG item mainly considers three aspects: the time sequence of different item implementation, the control requirements of collective dose, and the preparation of preconditions.

(2) The screening of key path items is based on four dimensions: the degree of project impact, the logical relationship between projects, the scope of project impact and the overall path of the project.

(3) For the ET item, it is proposed to optimize from three aspects: first, from the perspective of integration, miniaturization and intelligence, develop and improve ET inspection mechanical equipment. The second is to plan, prepare and implement the SG items of the primary side water chamber as a whole. The third is to optimize the ET item and develop the optimization inspection strategy.

(4) For the inspection items of SG secondary hydrostatic test, two aspects can be planned and arranged: first, the inspection items of the same loop are arranged in the same refueling outage. The second aspect is to reasonably arrange the total amount of inspection items during the two refueling outages, and human resources.

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