The Analysis for Method of I&C Equipment Period Demonstrating in NPP Refueling Cycle Extension Project

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Abstract. Before the implementation of the extended fuel cycle improvement in nuclear power plants, it is necessary to conduct an adaptive analysis of the relevant systems and equipment cycles. The purpose is to show that the improved cycle still meets the requirements for safe operation of nuclear power plants. This paper firstly introduce some problems: How to demonstrate the equipment cycle affected by the refueling cycle, and what methods can be used to analysis many type of I&C equipment's cycle which are manufactured by suppliers in nuclear power plant 18-month refueling. Based on the engineering experience of extending the refuelling cycle of domestic and international nuclear power plants, this paper briefly introduces several periodic demonstration methods and explains their characteristics at the same time, which provides guideline and practices for the nuclear power plants that implement the fuel cycle extension plan.

Keywords: Nuclear power plant · Refueling cycle · Period · Technical analysis centered maintenance · Reliability · Failure mode

1 Introduction

Since the birth of the PWR nuclear power plant in 1978, the 18-month refueling cycle has had more than 30 years of practical experience. At present, there are 75 in the United States and nearly 30 reactors in France for 18 months. Extending the fuel cycle is one of the mature technologies to improve the performance of nuclear power plants in the world.

The Daya Bay Nuclear Power Plant in Guangdong Province, China has implemented 18-month of refueling. The Lingao Phase II nuclear power plant project will adopt an 18-month refueling fuel cycle model. Other nuclear power plants such as Qinshan Nuclear Power Plant Phase II, Jiangsu Lianyungang Tianwan Nuclear Power Plant have started 18-month of refueling improvement.

The so-called 18-month refueling means that the nuclear power plant has a cycle length of about 540 calendar days (including about 500 days of full-power operation day and about 35 days of overhaul day), that is, a cycle time of about 18 months is completed [1].

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The 18-month refueling optimization improvement has the following advantages: 1) It can reduce the cost of nuclear fuel cycle, thereby reducing the cost of power generation and improving the economic efficiency of the power plant; 2) It can reduce the number of overhauls in the life of the power station by one-third and increase the availability of the unit; 3) It is beneficial to extend the life of the power station, especially to extend the life of the pressure vessel and increase the revenue of the power station; 4) It can reduce the annual average production and discharge of radioactive waste and reduce the occupational radiation dose received by the staff.

The 18-month refueling improvement design involves fuel design, nuclear design, thermal hydraulic design, accident analysis, system demonstration, and periodic demonstration; among them, periodic demonstrations and periodic testing of system equipment operating in power plants from 12-month to 18-month related to maintenance [2].

Obviously, it is necessary to demonstrate the cycle of system equipment involved in extending the fuel cycle. The reliability, maintainability and performance of the system equipment should be adapted to the requirements of safe and stable operation of the unit, maintenance plan optimization and power plant economy under the new fuel cycle before the fuel cycle is extended by the nuclear power plant.

But there are problems, how to demonstrate the different I&C system equipment's cycle of periodic test, and what methods can be used to analysis many type of I&C equipment's cycle which are manufactured by suppliers.

This paper firstly introduces the requirements for the frequency of supervision including reliability objective etc. Then the paper briefly analyzes the periodic demonstration methods and characteristics of instrument control equipment in the long fuel cycle of several nuclear power plants, which are based on the current domestic experience and international experience of nuclear power plant 18-month refuelling cycle extension. Lastly, the summary is given for the methods which are applied in several nuclear power projects.

2 Regulatory Standards Requirements

2.1 Regulation Standards for the Frequency of Supervision

According to the provisions of the Supervision of Nuclear Power Plant Safety Important Items HAD 103/09 [3], when determining the frequency of supervision of important items of safety, the following items need to be considered:

(1) The safety importance of the item and the need to meet the reliability objectives;
(2) The manufacturer's recommendations and the results of the type test, durability test and cyclic load test results;
(3) Expected failure mechanism, results of feasibility analysis, years of use of items and systems, component types and conditions of use;
(4) Experience in obtaining failure rates from maintenance and from the experience of this nuclear power plant and other similar nuclear power plants;
(5) The degree of automation of supervision.

2.2 Requirements for Periodic Test Intervals for Regulatory Standards

According to the provisions of Section 6.5 [Test Interval] in the Periodical Test and Test of Nuclear Power Plant Safety System GB/T 5204-2008, the following factors need to be considered [4]:

(1) Technical specifications or recommendations of the manufacturer;
(2) Historical experience of similar equipment use, such as failure rate data (including data obtained from the reliability database), pre-operational tests, quality data, and industrial use experience and operating experience of the power plant;
(3) Equipment quality appraisal report and analysis;
(4) Fault data: important fault mode, fault mechanism, probability distribution of faults and maintenance, these distributed determination of test interval time are mainly considered problems, they are characterized by parameters. For example: Mean Time Between Failure (MTTF), Mean Time To Repair (MTTR), probability of failure and variability, historical data and engineering judgment.

It is indicated in sub-clause 5.6.5 that "the test interval can be changed to suit the mode of operation of the plant, but it is to be demonstrated that such changes have no detrimental effect on the expected performance of the equipment being tested,…".

With reference to the above-mentioned relevant laws and regulations, the basis for determining the frequency of periodic test supervision and the principle of determining the interval between tests, the relevant equipment cycle demonstration method needs to be carried out from the perspectives of power plant experience, equipment suppliers, and equipment technical characteristics.

3 Equipment Cycle Demonstration Method

According to the practical experience of prolonging the fuel cycle at home and abroad, there are many demonstration methods for the equipment cycle of long fuel cycle projects. In view of the limited space of the article, this article mainly explains the three demonstration methods.

3.1 Power Plant Experience Feedback Method

Power plant Experience Feedback mainly uses power plant projects that have successfully implemented the same type of long fuel cycle improvement and have many years of safe operation experience as Reference Power Station [5]. Comparing the system design and equipment technical performance index with Reference Power Station, if the technical performance index of the equipment to be demonstrated is basically the same as that of Reference Power Station, or the technical performance is advanced and better than that of Reference Power Station, then the period of this part of equipment can be extended to a long cycle.

Since there is an inconsistency between the equipment Supply Contractor of Nuclear Power Plant and Reference Power Station to be demonstrated, equipment suppliers with the same functional location should be compared when comparing equipment.

If the equipment suppliers are different, it is necessary to contact the suppliers to provide opinions on equipment reliability and test cycle. If the requirements for prolonging the fuel cycle can be met, the demonstration is passed. If the requirements cannot be met, design changes or engineering modifications need to be carried out.

If the equipment suppliers are the same, continue to compare the functions, safety levels, quality levels, mechanical manufacturing levels, electrical manufacturing levels, operating environment conditions, etc. of the equipment; If there is no difference in comparison results or the power station equipment index to be demonstrated is better, Moreover, if the reliability of the corresponding equipment in Reference Power Station meets the requirements of initial demonstration in the actual operation process after long-term refueling, the cycle of Reference Power Station Item Concerned can be directly adopted, and the cycle of the equipment to be demonstrated can be adjusted to be consistent with that of Reference Power Station equipment. Otherwise, further supplementary analysis and demonstration are needed.

The process is shown in Fig. 1.

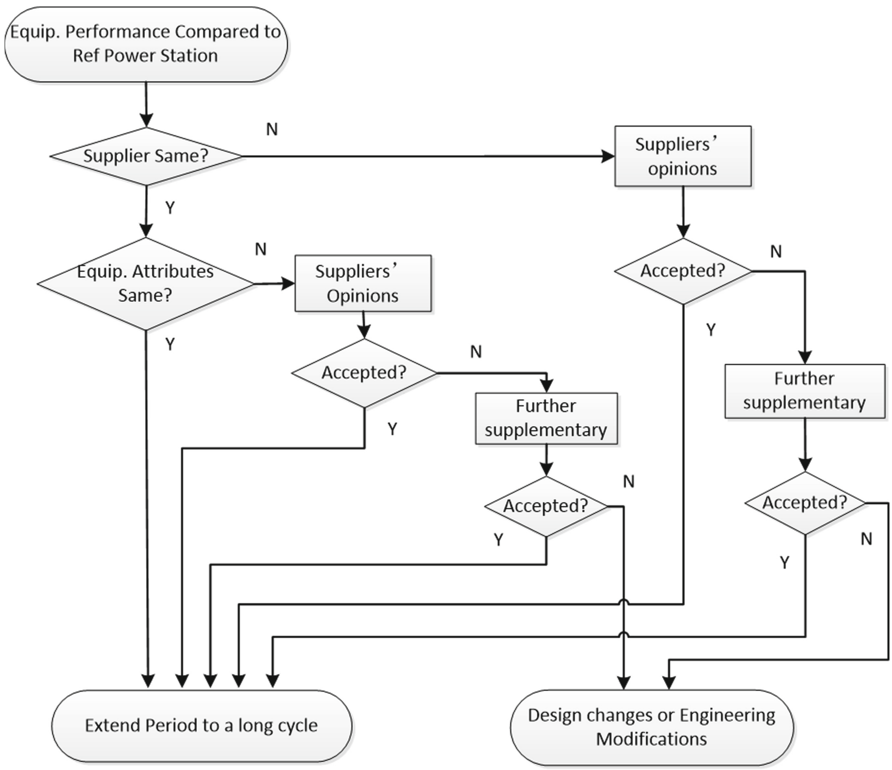

Fig. 1. NPP experience feedback flow diagram

3.2 Supplier Feedback Method

For the performance of the device, the supplier's recommendations and information can be used as a basis for the extension of the equipment cycle. There is a life cycle for each device from production to final loss. When evaluating product reliability, it is usually characterized by failure rate. After a lot of experimental research and statistical analysis, it is found that the relationship between the failure rate of general product equipment and time satisfies the bathtub curve [6], as shown in Fig. 2. During the life of the product, the equipment generally experiences early failure period, infrequent failure period and loss-loss period until decommissioning.

(1) Early failure period: It is characterized by very high failure rate, but with the increase of product working time, the failure rate decreases rapidly. The failure of products at this stage is mostly caused by defects in design, raw materials and manufacturing process. If we strengthen the inspection of raw materials, strengthen quality management, improve technology and other measures, we can greatly reduce early failure.
(2) Infrequent failure period: It is characterized by low failure rate and stable working period of the product; the failure causes are diversified and accidental, mainly caused by some defects that cannot be eliminated. At this time, the fault is in a completely unpredictable state, and the failure occurs randomly according to a certain ratio.
(3) Damage failure period: The failure rate gradually increases with time, and the failure causes are mainly caused by wear, wear and aging. Faults generally occur in a certain period of time, so it is difficult to determine the time point of equipment renewal, which can only be obtained according to a large number of statistical experiences.

In view of different products or the same products but different levels of design, manufacture, use and maintenance, the values, slopes and duration of each section of the corresponding bathtub curve are different. Therefore, for each kind of equipment, Supply Contractor usually carries out some typical product performance tests, such as anti-fatigue test, cyclic loading test, reliability measurement test, reliability verification test, etc. At the same time, according to the historical use data of this type of equipment, the durable working time and average trouble-free time MTBF of vulnerable parts are determined by statistical methods. According to the advice and information provided by the supplier, if the reliability of the equipment can be fully guaranteed within the cycle range of Nuclear Power Plant regulations, standards and relevant supervision requirements, the relevant cycle of this part of equipment can be extended to a long cycle.

3.3 TCM Analysis Method

The TCM analysis method (Technical analysis Centered Maintenance) not only solves the problem of "why equipment is repaired, when it is repaired", but also solves the problem of "how to repair equipment". It is a combination of device functional analysis and technical analysis; functional analysis and technical analysis are two important and

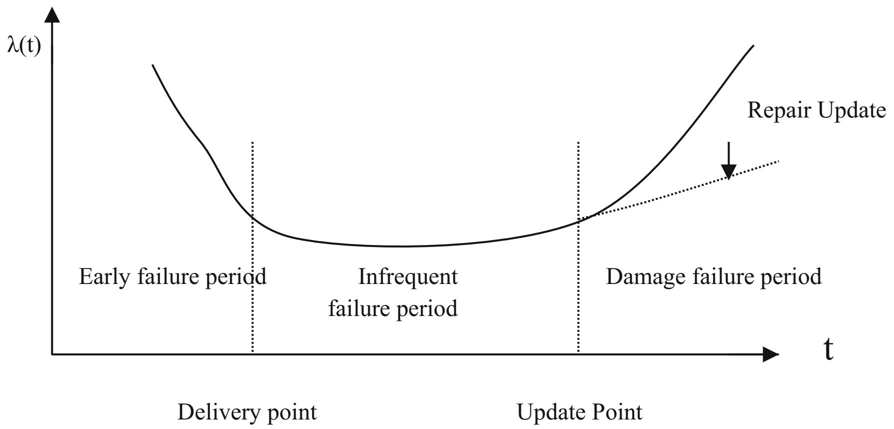

Fig. 2. Bathtub curve

different ways of analysis; functional analysis is the function of the device in the system, and the direction of technical analysis is the device type.

The TCM analysis method adopts the equipment hierarchical management method. In the analysis process, the equipment and the system are classified into key sensitive equipment related to nuclear safety, key sensitive equipment related to availability, important equipment related to maintenance cost, and non-essential equipment according to the result of functional analysis. Different maintenance combinations and decisions are taken based on the results of the equipment classification [7].

Functional analysis of the equipment can determine the need for maintenance activities; Focusing on the technical characteristics of the equipment, the working principle analysis, reliability analysis, failure mode analysis and aging detection analysis of the equipment are carried out to determine the correct maintenance method, maintenance frequency, technical guidelines and cycles of relevant maintenance activities.

The TCM analysis equipment also considers the requirements of equipment aging and life management. The related results can guide the preventive maintenance and trend analysis of the equipment, thus providing technical support for equipment condition monitoring and fault prediction strategy formulation. The TCM analysis process is shown in Fig. 3. The technical analysis process is shown in the dotted line frame of the left branch in Fig. 3, which is briefly described as follows [8]:

(1) Working principle analysis: A description of the physical principle analysis of a certain type of equipment and how the equipment operates. This analysis provides information for failure mode analysis and understanding of equipment aging.
(2) Failure mode analysis: Based on the understanding of the working principle of the equipment, the sensitive components of the equipment are analyzed, and the maintenance activities and execution methods that may be needed for the degradation of the weak links of the sensitive components are obtained to effectively detect or delay the Downgrade process.

(3) Reliability analysis: Based on a large number of power plant operation and maintenance experience as the basis for equipment reliability assessment, to determine the frequency of related maintenance activities. For example, the French EDF600 multiple piles of years of operational maintenance experience feedback data.
(4) Aging detection analysis: for equipment that meets the aging mechanism and the aging phenomenon, the failure mode analysis has determined the components affected by fatigue; Tracking the level of surveillance fatigue by setting up appropriate predictive maintenance, or extracting predictive maintenance that effectively detects aging from identified preventive maintenance activities.

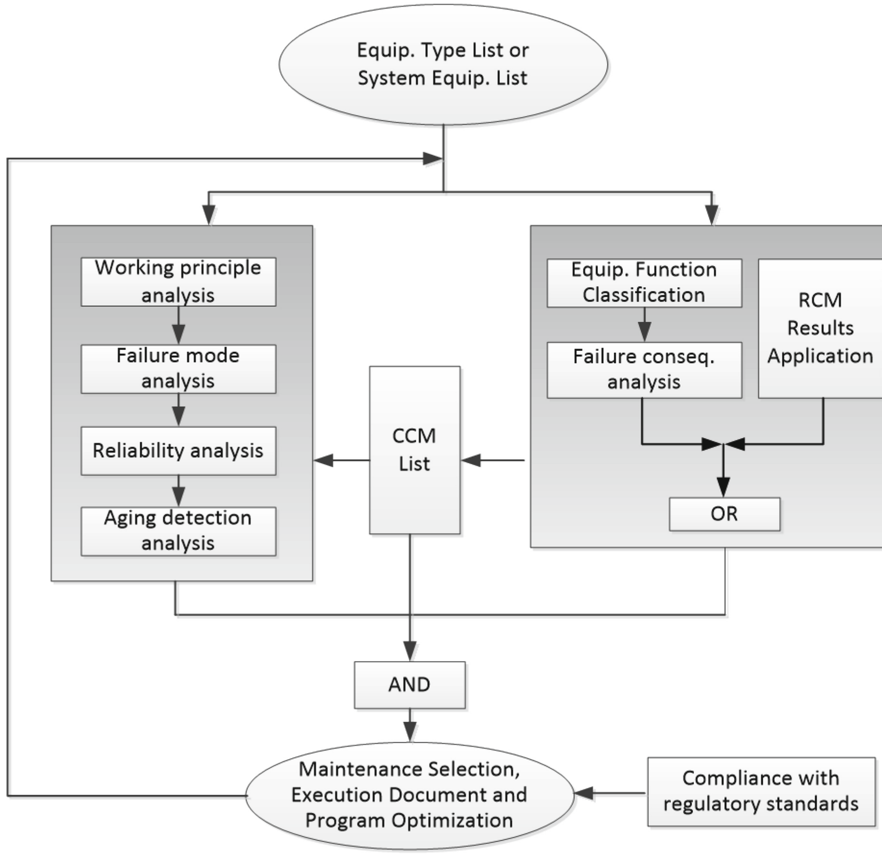

Fig. 3. TCM analysis process

Based on the results of functional analysis and technical analysis of the equipment, combined with the Experience Feedback in the actual operation process of the power station, the possibility of establishing the corresponding system equipment cycle of the power station under the long fuel cycle is explored. If the period of the analyzed equipment can be extended to a long period, an appropriate period can be extended.

3.4 Characteristics of Equipment Cycle Demonstration Method

For the above three demonstration methods, their characteristics are analyzed as follows:

(1) The main feature of power plant Experience Feedback method is to compare the equipment attributes (such as function, manufacturer, model, etc.). Through comparison with the same or similar equipment in the reference nuclear power plant, it can be directly or indirectly obtained whether the equipment cycle can be prolonged. For equipment that cannot be determined whether the cycle can be prolonged through comparison, supplementary demonstration shall be carried out through other means. The advantage of this method is that it is simple to apply, but the disadvantage is that if there is no similar nuclear power plant as a reference, its applicability will be reduced.
(2) The main feature of the supplier feedback method is to have a deep grasp of equipment performance (anti-fatigue, reliability, life, maintenance frequency, durability time, etc.). Starting from the equipment itself, professional information and guidance can be given, and whether to extend the equipment cycle to a long cycle can be decided by combining the manufacturer's opinions with the requirements of regulations and standards. The advantage of this method is its strong universality. Theoretically speaking, all equipment cycle demonstrations can be completed by this method. The disadvantage is that there are many types and quantities of equipment to be demonstrated, which makes it difficult to collect supplier information.
(3) The essence of TCM analysis method is to put forward classification requirements for equipment itself according to the importance of functions. Its main characteristics are comprehensive analysis of key equipment, key analysis of secondary key equipment and analysis of general equipment according to the situation. The method has clear objectives, high technical requirements and large foundation data requirements. It is a dynamic closed-loop process and can be continuously optimized in the execution process.

4 Summary

This paper introduces several Instrument and Control system Equipment cycle demonstration methods according to the international and domestic practical experience of nuclear power plant long-term fuel cycle projects. And the characteristics of the above-mentioned demonstration methods are analyzes. These methods are applied successfully in CPR1000 nuclear power plant of 18-month refuelling cycle extension project. Besides, these methods can also provide a technical support for the equipment aging management and maintenance strategy formulation of Nuclear Power Plant that has implemented long fuel cycles.

The methods introduced in this paper have important guiding significance for improving the reliability of nuclear power plant Instrument and Control system equipment and periodic test.

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