Application of Reliability-centered Maintenance Method in Maintenance and Control Optimization in NPPs

Tao ZHANG, Yu CHEN, Cong-ling WANG and Sheng ZHANG
Suzhou Nuclear Power Research Institute, Shenzhen, China

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Abstract. The safety is a prerequisite for the nuclear power plants’ operation. Various measures have been considered at the design stage to ensure the reliability of the NPPs. During the nuclear power plants’ operation, equipment reliability management is one of the primary means to ensure NPPs operate safety. RCM, Reliability-centered Maintenance, an important method for the equipment reliability management in NPPs, can be used to complete FMEA analysis for the systems and components, and develop or optimize maintenance strategies to ensure the effectiveness of preventive maintenance strategy according to RCM decision logic. At the same time, it can be used to find the insufficient of the design, improve the control logic and layout. This article describes the RCM analysis process, illustrates the application and effectiveness of the RCM analysis in maintenance and control optimization combined with the practice of nuclear power plants.

Introduction

RCM, Reliability-centered Maintenance, is currently one of the general engineering mythologies to determine the equipments’ maintenance needs, develop and optimize maintenance strategy, optimize the initial design.

Domestic civil aviation and military departments began to introduce the concept of RCM and expand tracking research & applications from around 1980s. Nowadays the RCM has been applied in our nuclear power, hydropower, thermal power, railways, subways, mining, petrochemical, manufacturing, and some other related industries. Applications within the domestic nuclear power industry has been basically formed a mature RCM technology system, and achieved good effect.

Implementation of RCM

Human Resource

A nuclear power plant is consist of hundreds systems, and a system involves a number of professionals, such as operation, maintenance, equipment management and other departments, these engineers have their own needs that may be not same, while they have their own different understanding for the system. An analysis group is formed to conduct RCM analysis work to ensure that the results of the analysis can be implemented and accuracy.

Process

The process of classical RCM is as following seven questions and the questions should be answered in the sequence:

What are the functions and associated desired standards of performance of the asset in its present operating context?
   In what ways can it fail to fulfill its functions (functional failures)?
   What causes each functional failure?
   What happens when each failure occurs?
   In what way does each failure matter?
   What should be done to predict or prevent each failure?
What should be done if a suitable proactive task cannot be found?
The functions, functional failures, failure modes, failure effects, failure consequences, failure management policies are analyzed as the questions are answered and recorded in specified formats.

**Functions**

The functions and the performance standards of the system that the users need should be identified.

The functions include primary and secondary functions. The primary functions are the user’s main needs for the system and equipment, or the reason why the system and equipment exist. The secondary functions are other functions in addition to the primary functions, such as environmental integrity, safety/structural integrity, control/containment/comfort, appearance, protective devices and systems, economy/efficiency, superfluous, etc. In function analysis, the control logic analysis is one of the main input, and it is the foundation to acquire whole system’s logic for the function and follow-up analysis. Control logic of the whole system of control is complete basic functional analysis and follow-up analysis.

**Functional Failures.** The various states that the system and equipment fail to fulfill the user’s needs should be analyzed and record completely after the functions analysis.

Functional failures include total failures and partial failures. For partial failures, exceeds the upper limit and below the lower limit of the performance standards are both failure states.

**Failure Modes.** All the reasonably likely events that cause the failed states should be identified in the failure modes analysis. A description of a failure mode should consist of a noun and a verb. Failure modes include those as follows:

- occurred on the same or similar equipment;
- not occurred yet but reasonably likely on the same or similar equipment.

The analysis results of other systems or industry common data can be used in failure modes analysis because of the universal of the equipment, but those results should be evaluated before using as input.

**Failure Effects.** Failure consequences analysis is to as Failure effect statement describes what would happen if a failure mode were to occur without any preventive management. All condition should be considered in failure effects analysis.

**Failure Consequences.** Sess the consequences of each failure mode upon the description of the failure effects, and be categorized according if it can be realized and failure effect.

- Evident and Hidden Failures. The former is the failures that can be realized when happen, while the latter is not.
- Safety, Environmental, Operational, and Non-Operational Consequences.

**Failure Management Policies.** According to the decision algorithm select the failure management policy for every failure mode. The decision algorithm is shown in Fig. 1.
It should be considered when the analysis group select failure management policies according to the comprehensive result of failure consequences, failure mode features, maintenance technical feasibility, economy and some other related factors. The analysis group should consider how to make the probably failure (or multiple failures) risk tolerable (i.e. an acceptable level) by predictive and preventive maintenance, or think about other method otherwise like periodic test or system improve.

**RCM Implementation Results**

Maintenance base is the document of the analysis results, which is mainly consist of information worksheet, decision worksheet, maintenance program worksheet, regulation/maintenance program comparison worksheet(see Fig. 2). The content includes the all functions, functional failures, failure modes, failure effects, failure consequences, failure management policies and system improvement, etc.
RCM Cases

Maintenance Optimization

The generator stator cooling water system in a nuclear power plant has been analyzed by RCM. There is a float valve in the cooling water tank as shown in Fig. 3.

![Cooling water tank diagram](image)

After analysis, the analysis group found that the corrosion of tank and stuck of float valve may cause a generator trip (analysis process is shown in Table 1), and thought that it should be prevented and added preventive maintenance including water tank regularly internal inspection and operation test of float valve.

<table>
<thead>
<tr>
<th>F</th>
<th>FF</th>
<th>FM</th>
<th>Failure Modes</th>
<th>Failure effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>A</td>
<td>1</td>
<td>Tank corrodes</td>
<td>Tank splits, internal water leak outside, then the water level drops, when the water level falls below the low limit, there will be an alert in control room and the operator should manually control the level, check and eliminate the leakage, but if the leakage is severe, the level will not be maintained, inlet pressure before stator cooling water pump drops, and the stator cooling water flow drops, an generator trip signal will be triggered automatic when the flow drops below 27.8kg/s.</td>
</tr>
<tr>
<td>10</td>
<td>A</td>
<td>2</td>
<td>Float valve stuck</td>
<td>Water cannot be supplied normally, water level drops, when the water level falls below the low limit, there will be an alert in control room, the following is same as 10-A-1.</td>
</tr>
</tbody>
</table>

Control Optimization

The primary coolant treating system in a nuclear power plant has been analyzed by RCM. The flow chart of boron concentrates collection and delivery is shown in Fig. 4.

Boron concentrates are delivered to collection tank T1 after cooled by a heat exchanger E1, when tank T1 is full the purification loop pump will be started for purification.
After analysis, the analysis group found that the boron concentrates will not be cooled enough because of the heat exchanger failure, the hot concentrates will be delivered continually to tank T1, but when the purification loop operates when the tank is full, the temperature sensor I2 will send a protection signal as the temperature exceeds 60°C to shut off the T1 outlet isolation valve V1 and purification loop pump for preventing downstream resin filter burned, while the whole boron concentrates in tank T1 should be cooled again or drained off, it will result in economic losses for the plant operation. According to the analysis result and in order to manage this failure impact, an alarm logic signal (>60°C) is added in the temperature sensor I1 which is located on the outlet of the heat exchanger E1, so there will be an immediate alarm when the heat exchanger fail and the temperature is high, and operator can pause the concentrates delivery into tank and isolate the loop immediately, avoid recognizing the failure too late until starting to purify and causing greater loss.

**Conclusions**

RCM, as a reliability analysis technology, plays an important role in the maintenance strategy develop and optimization in nuclear energy field. It is based on reliability maintenance theory, aims to maintain the expected function, recognizes all failure effects by function and function failure analysis, categories failure consequences with standardized logical decision, analyzes the maintenance requirement and makes the maintenance strategy or design improvement to ensure system or equipment achieve user’s needs. It can improve equipment reliability; reduce operating and maintenance costs by RCM analysis and application of the results.

**References**

