*Transactions of the Korean Nuclear Society Autumn Meeting*
*Gyeongju, Korea, October 27-28, 2016*

# Application of Reliability Centered Maintenance (RCM) for CVCS- Charging System

Mohamed M. Faragalla [a*], Osama Rezk [a], Victor Ouma [a], Hilda Mpakany [a], Baik Jun-ki [a], Gomaa Mohammad [a], Vaysidin Saidov [a] and Lee,Yong-Kwan [a*]
[a]*KEPCO International Nuclear Graduate School (KINGS), 1456-1 Shinam-ri, Ulsan, South Korea*
[*]*Corresponding author:* leeyk@kings.ac.kr

## 1. Introduction

Reliability Centered Maintenance (RCM) employs Preventive Maintenance (PM), Predictive Testing and Inspection, Repair and Proactive Maintenance techniques in an integrated manner to increase the probability that a machine or component will function in the required manner over its design life cycle with a minimum of maintenance. The goal of the maintenance is to provide the stated function of the facility, with the required reliability and availability at the lowest cost [1]. Chemical and Volume Control System (CVCS) is consist of various components which could possibly cause trouble. Therefore, CVCS is a critical system, needs to monitor its performance and develop maintenance plan to increase the reliability and availability of the system. So the maintenance plan for CVCS charging system will be developed by implementation of RCM and Probabilistic Safety Assessment (PSA).

### *1.1 Basis of RCM process*

RCM utilizes a decision logic tree to identify the maintenance requirements of equipment according to the safety and operational consequences of each failure and the degradation mechanism responsible for the failures, focus on the system functions only [2]. The RCM process involves:

- System selection and system boundary.
- Identify the possible failure modes that could lead to the failure of the system to fulfill its functions.
- Perform failure mode effects (FME).
- Perform criticality analysis to calculate the severity of each failure mode with respect to safety, availability, and maintenance cost.
- Selection of the maintenance task using Logic Tree Analysis (LTA).
- Compare the new tasks with the current tasks and implementation of the process [2].

### *1.2 Objectives of study*

The objectives of this study, Reliability Centered Maintenance (RCM) Process for CVCS charging system are:

- To apply the RCM process for CVCS charging system
- To improve System Performance as well as to improve individual component performance
- To develop maintenance program to be applied on CVCS－Charging System.

## 2. Methods and Results

### *2.1 Designed RCM process for CVCS-Charging system*

As in Fig.1, the RCM process consists from three main phases and each phase consists steps as explained below.

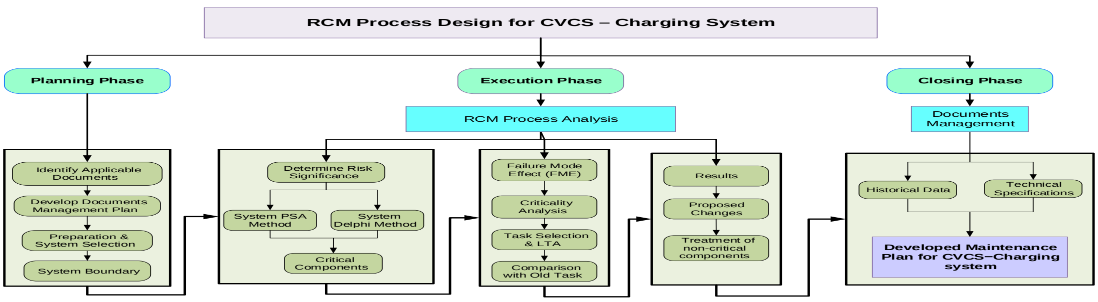

Fig. 1. RCM process for CVCS-Charging system

### *2.2 System Safety Related Functions*

- CV-01:Containment Isolation function is safety related
- CV-02:Auxiliary Charging Pump (ACP) provides a diverse means for RCP seal injection (e.g., for SBO event) for cooling of mechanical seals but this is not a safety related function
- No accident Mitigation function.

### *2.3 Component importance determination*

The component importance determination performed using two methods [3].

*a. Using (SAREX, KEPCO E&C)*

SAREX software used as a tools for modelling the CVCS charging. Fault tree modelling results for CVCS charging system indicate that the probability of failure to supply adequate flow was determined to be 2.462E-02. The results of PSA Evaluation for CVCS as in table 1, identified the most critical in the CVCS. The main components of the system were modeled as in Fig. 2.

*b. Delphi Method*

The Delphi technique depend on the engineering judgment and discussion with expert panel according to their experiences, by using a series of questionnaires to collect data from a panel of selected subjects. The results from Delphi method in table 2 Second column.

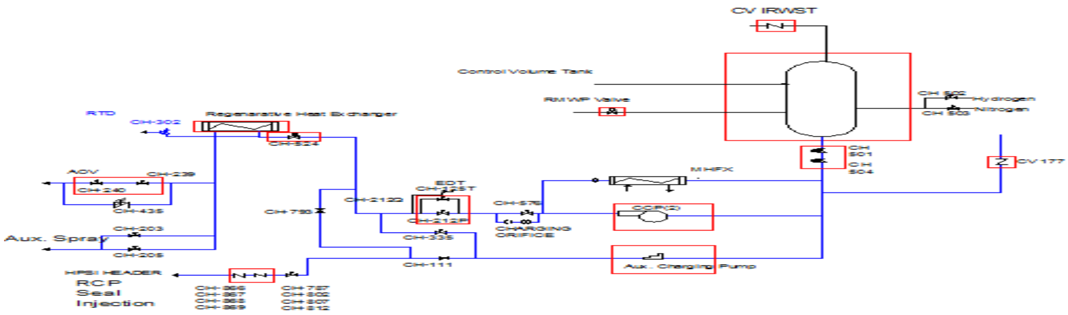


Fig. 2. CVCS Charging System Modelling Diagram

## *2.4 Determination of High Risk Significant Components*

The results of PSA for high safety significance of each components on the system are shown in table 1.

Table 1: PSA results for high safety significance for component on the system

| Event | Event Description | Significance |
|---|---|---|
| CVOPH-S-RCPSEAL | Operator Error when Operating RCP Seal Check Valves | High |
| CVOPH-S-IRWST | Operator Error when Operating IRWST Replenish Check Valves | High |
| CVAVO240 | Charging Back Pressure Valve failure to Open/Close | High |
| CVAVO239 | Charging Back pressure valve failure to Open/Close | High |
| CVMVO524 | Containment Isolation Valve Fail to Open/Close | High |
| CVAVO-S-210Y | Reactor Make up Pump line Fail to Open | High |
| CVMVI-504 | VCT Outlet Isolation valve Spurious Action | High |
| CVMVI-501 | VCT Outlet Isolation valve Spurious Action | High |
| CVMVC-501 | VCT Outlet Isolation valve Fail to Close | High |
| CVMVO-504 | VCT Outlet Isolation valve Fail to Open | High |
| CVTK01 | Volume Control Tank Failure | High |
| CVMVWD2-501/504 | VCT Outlet Isolation valve Common Cause Failure | High |
| CVAVI239 | Charging Back pressure valve Spurious Action | High |
| CVAVFC-S-210Y | Reactor Make up Pump line Fail to Close | High |
| CVAVI240 | Charging Back pressure Valve Spurious Action | High |
| CVMVA524 | Containment Isolation Valve Fail to Open/Close | High |
| CVAVO-M-212P | Charging Flow Control Valve Fail to Open | High |
| CVHE | Regenerative Heat Exchanger Fails | High |
| CVAVI-S-210Y | Reactor Make up Pump line Valve Spurious Action | High |
| CVAVA239 | Charging Back pressure valve 239 Fails to Actuate | High |
| CVAVA240 | Charging Back pressure valve 240 fails to Actuate | High |
| CVMVI524 | Containment Isolation Valve Spurious Action | High |

## *2.5 Results for Safety Significance Determination*

The results of High Risk Significant Components from the PSA and Delphi methods are indicated in table 2.

Table 2: High Risk Significant Components

| PSA Results | DELPHI Results | Identified Critical Components |
|---|---|---|
| - RCP Seal Injection<br>- IRWST Replenish Line<br>- Charging Back Pressure Valve<br>- Containment Isolation Valve<br>- Reactor Makeup Line Valve<br>- VCT Outlet Isolation valve<br>- Volume Control Tank<br>- Regenerative Heat Exchanger | - Volume Control Tank<br>- Charging Backpressure Control Valve<br>- VCT outlet Isolation valves<br>- (Centrifugal) Charging Pumps<br>- Seal Injection Flow Control Valves<br>- Charging Flow Control Valves (CH-241/ 242/ 243/244)<br>- Regenerative Heat Exchanger | - Centrifugal Charging Pump<br>- Volume Control Tank<br>- Air Operated Valves<br>- Motor Operated Valves<br>- Check Valves<br>- Regenerative Heat Exchanger<br>- CCP Mini-Flow Heat Exchanger |

### 2.6 *Critical items selection*

The objective of this step, to identify the analysis items that are potentially critical with respect to the function of the system identified. We should also identify items with high failure rate, high repair costs, low maintainability, long lead time for spare parts, or items requiring external maintenance personnel [4]. The critical component as in table 3.the criticality of the components are ranked consider the following factors; failure rate, repair costs, maintainability, and lead time for spare parts.

Table 3: The critical component

| Criticality Rank | Component | Type |
|---|---|---|
| 1 | RCP Seal Injection | Check Valve |
| 2 | IRWST Replenish Line | Check valves |
| 3 | Containment Isolation Valve | Air Operated Valve |
| 4 | Containment Isolation Valve | Motor Operated Valve |
| 5 | Reactor Makeup Line Valve | Air Operated Valve |
| 6 | VCT Outlet Isolation valve | Motor Operated Valve |
| 7 | Volume Control Tank Failure | Tank |
| 8 | Regenerative Heat Exchanger | Heat Exchanger |

### 2.7 *Failure Mode Effect &Criticality Analysis (FME&CA)*

Failure Mode effect analysis is a technique used to identify the potential functional failures, the effects of those failures modes on component, system, and plant performance. The consequences of each failure mode dictate the type of maintenance task applied to prevent any degradation that can lead to failure [5]. FME&CA was used to determine and analyze component failure, root cause, the failure effect on the system, criticality of failure, task selection, and monitoring parameters. The results of the FME&CA analysis was used to improve the system condition based Maintenance. The components and items analyzed include; Charging pump, Motor Operated Valves, Volume Control Tank, CCP Mini-Flow Heat Exchanger, Check Valve, Air Operated Valve, and Regenerative heat exchanger.

### 2.8 *Criticality Analysis (CA)*

The criticality analysis is based on the effects of the failure modes on the plant's safety (S), availability (A) and maintenance cost (C). The Safety aspect is allocated weight of 50%. Availability of the safety component is assigned 30%. Cost incurred by component failures has a weight of 20%. The criticality class ranges from E to G are shown in Table 4. The ranking level 4 shows higher impact on the criterion as compared to rank level 1. The measure of criticality is calculated using this formula MOC=0.5S+0.3A+0.2C. These values are used to determine the type of maintenance task to be applied on each failure mode [6].

Table 4: The criticality class

| Class | Measure of Criticality | Criteria | Weight |
|---|---|---|---|
| E | 4.0-3.0 | Effect on Safety | 50% |
| F | 3.0-2.0 | Effect on Availability | 30% |
| G | 2.0-1 | Effect on Maintenance costs | 20% |

### 2.9 *Task Selection (LTA)& implementation*

The RCM uses Logic Tree Analysis (LTA) to determine the optimum maintenance tasks with respect to the failures modes. Table 5, summarizes the selected task for the critical items. The maintenance tasks available for consideration are:

- Failure finding tasks: whose failure modes are hidden and require functional tests to detect.
- Condition based tasks: tasks that monitor the degradation levels of failure modes.
- Time directed task: maintenance tasks performed periodically as scheduled.

- Re-design: where there is neither feasible condition directed nor time directed tasks applicable.
- Run to failure: is applied on less safety and economical failure modes.

Table 5: Results of RCM Process for CVCS-Charging System

| Component | CBM | TBM | Redesign | Failure Finding |
|---|---|---|---|---|
| Charging Pump | 40 | 10 | 1 | 2 |
| | 75% | 18.8% | 1.9% | 3.7% |
| MOV | 12 | 10 | 3 | 1 |
| | 46.2% | 38.5% | 11.5% | 3.8% |
| VCT | 14 | 0 | 0 | 0 |
| | 100% | 0 | 0 | 0 |
| Mini flow HX | 4 | 1 | 2 | 0 |
| | 57.1% | 14.3% | 28.6% | 0 |
| CV | 9 | 7 | 0 | 0 |
| | 56% | 44% | | |
| AOV | 7 | 15 | 0 | 3 |
| | 28% | 60% | 0 | 12% |
| Regenerative HX | 3 | 8 | 0 | 0 |
| | 27.3% | 72.7% | 0 | 0 |
| Total Tasks | 89 | 41 | 6 | 6 |
| | 62.7% | 28.9% | 4.2% | 4.2% |

The charging pump, motor operated valves, Air operated valves, regenerative heat exchanger, Mini flow heat exchanger, volume control tank ,and check valves of the CVCS system were identified as the most dominant components from the risk point of view. The unavailability of these components is influenced by; Failure rate, Testing interval, Repair time, Testing and maintenance duration and Human errors. The RCM approach is used to optimize the maintenance activities and decrease failure rates by implementing PM tasks. Hence, for the CVCS 62.7% from the potential failures can be prevented by CBM, 28.9% of failure prevented by time based maintenance, 4.2% needs redesign and 4.2% needs failure finding tasks. There are no run to fail tasks. This will increase the CBM tasks and reduce the maintenance activities by 20%. CBM increased the operational availability of CVCS components because of the increased in the mean -time to failure (MTTF).
Availability is given by the formula [7]:

$$\text{Availability} = \text{MTTF}/(\text{MTTR}+\text{MTTF}) \quad (1)$$

Where:
MTTF: Mean Time To Failure
MTTR: Mean Time To Repair
For example most of the failure modes of charging pump can be monitored using condition based techniques. These tools detect and trend the degradation indicators before the potential failure occurs and around 75 % from its potential failures can be prevented by CBM tasks.

### *2.10 Treatment of non-critical items*

What to do with the items which are not analyzed. Plants already having a maintenance program, should be carried out on the non- critical component.

## 3. Conclusion

Application of RCM maintenance concluded that many of the current task types required major revision in order to maintain the optimum levels of both reliability and availability of CVCS. It is also concluded that in several cases, specific components within the CVCS Systems will benefit from a shift in maintenance strategy from fixed interval invasive routines to a CBM strategy. Such a strategy will ensure close monitoring of system and component performance without compromising nuclear safety or availability. The results of RCM analysis shows that most of the charging pump potential failure can be prevented by CBM tasks. The trends results are used to carry out maintenance on the component before failure. The RCM strategies reduce the number of periodic maintenance activities and therefore save the maintenance cost.

## ACKNOWLEDGEMENTS

This research was supported by the 2016 research fund of the KEPCO International Nuclear Graduate School (KINGS), Republic of Korea.

## REFERENCES

1. IAEA-TECDOC-1590 Application of Reliability Centered Maintenance to Optimize Operation and Maintenance in Nuclear Power Plants, May 2007.
2. Rausand M, Reliability centered maintenance Reliability Engineering and system Safety vol.60, 1998.
3. KHNP, "APR1400 Technical Specification", (2010).
4. EPRI, Critical Component Identification Process - Licensee Examples, TR-1007935, 2003.
5. The basic concepts of failure analysis, Marvin Rausand & Knut Oien, Reliability Engineering and System Safety 53, January 1996.
6. Victor Otieno Ouma, Yong Kwan lee, RCM Process for Steam Generator Reliability ,The 9th Asia-Pacific Conference on Systems Engineering (APCOSEC 2015) Seoul, Korea. October, 2015.
7. Kim, Y. "Risk Informed Allowed Outage Time Change for Units 3&4" (2001).