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Reliability Centered Maintenance (RCM) Methodology and Application to the Shutdown Cooling System for APR-1400 Reactors

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1. Introduction

Shutdown Cooling System (SCS) is a safety-related system that is used in conjunction with the Main Steam and Main or Auxiliary Feedwater Systems to reduce the temperature of the Reactor Coolant System (RCS) in post shutdown periods from the hot shutdown operating temperature to the refueling temperature. The SCS is design to satisfy Korean regulatory authority requirements that are specified as licensing designed basis for the APR1400 design [1]. In this paper RCM methodology is applied to (SCS). RCM analysis is performed based on evaluation of Failure Modes Effects and Criticality Analysis (FME&CA) on the component, system and plant. The Logic Tree Analysis (LTA) is used to determine the optimum maintenance tasks. The main objectives of RCM is the safety, preserve the System function, the cost-effective maintenance of the plant components and increase the reliability and availability value.

1.1 RCM Methodology

RCM is a logical methodology which uses the failure mode, effect, and criticality analysis (FMECA) tool to identify maintenance requirements according to safety and operational consequences of each failure. As shown in Fig.1. RCM presented a viable approach for optimizing maintenance of systems by having an optimal mix of reactive, time-based, condition-based, and proactive maintenance tasks [2].

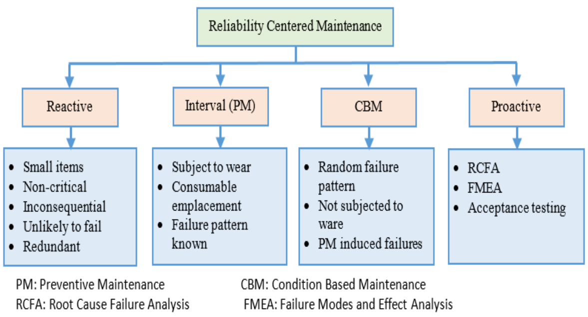

Figure 1. Components of RCM program.

1.2 Basis of RCM process

RCM analysis is a systematic evaluation approach for developing or optimizing a maintenance programme. 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 [3]. The RCM process involves:

- System selection and data collection
- System boundary definition
- Functional failure analysis (FFA).
- Failure Mode and Effective Analysis (FMEA)
- Criticality analysis
- Maintenance task selection using Logic Tree Analysis (LTA) and Implementation [3].

1.3 Objectives of the study

The objectives of Apply the RCM process for SCS are:

- To preserve the Shutdown Cooling System (SCS) function.
- To Improve System Performance as well as to improve individual component performance.
- To develop maintenance program to be applied on SCS.

2. Methods and Results

2.1 Designed RCM process for (SCS)

RCM process consists from three main phases and each phase has many steps as shown in Fig.2.

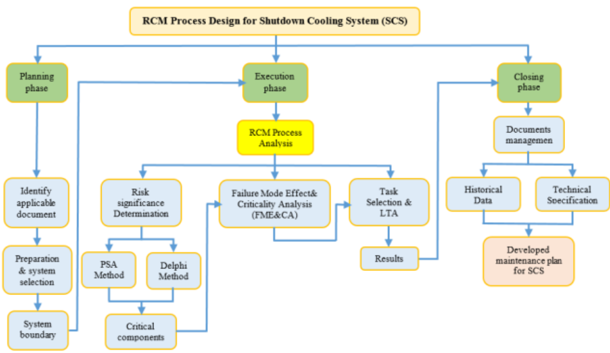

Fig.2. RCM process design

2.2 Function of Shutdown Cooling System

1. Reduce the temperature of the Reactor Coolant System (RCS) from hot shutdown temperature to refueling temperature and maintain its temperature.

2. Cooldown the RCS following design basis accidents (SBLOCA, MSLB, MFLB or SGTR)
3. Provide water for initial External Reactor Vessel Cooling (ERVC) under hypothetical core melting severe accident
4. Cooldown the IRWST during feed and bleed operations.
5. Transfer the RCS fluid to the CVCS for purification during SCS operation (Non-safety function).
6. Transfer borated water between the IRWST and refueling pool (Non-safety function) [1].

2.3 System boundary

As shown in Fig.3, the boundaries of the SCS are from the SCS nozzles located on the hot leg pipes to the SIS direct vessel injection (DVI) nozzles.

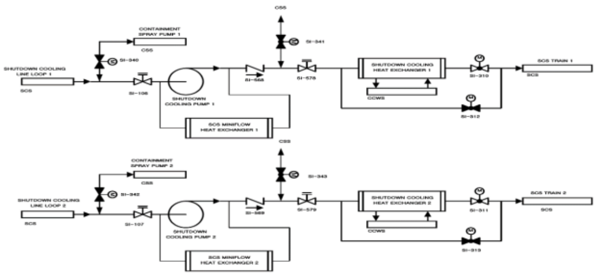

Fig. 3. System boundaries and flow path [1].

2.4 Data collection

The various steps of the RCM analysis require a variety of input data, like design data, operational data, and reliability data. This data collect from the following sources.

1. Design specifications.
2. Review INPO, EPRI and APR1400 SSAR documentations.
3. Operating experiences from the operations staff.
4. History of Maintenance from maintenance personnel.
5. Probabilistic Safety Assessment results from PSA experts.

2.5 Component importance determination

SAREX software developed by KEPCO E&C is used to model the SCS. SAREX is used to determine the safety significance of each component and identify the critical component by using the following parameters:

- Risk Reduction worth (RRW).
- Risk Achievement worth (RAW).
- Core Damage Frequency Contribution (CDFC).

Risk Importance Measures give the probabilistic contribution of a certain component to the overall risk associated with the system Identification of the High Safety Significance (HSS) and Low Safety Significance (LSS) components from the flowchart in fig.4, [4]. The results of PSA Evaluation for SCS shown in table I.

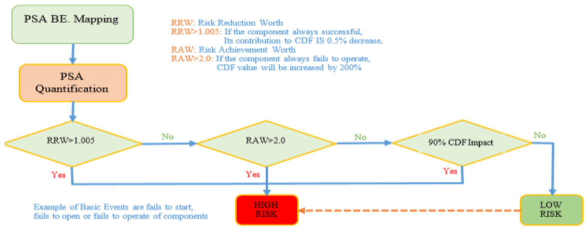

Fig.4. Safety significant determination process.

2.6 Critical items selection

The objective of this step is to; identify the components that are potentially critical with respect to the function of the system identified. We should also identify components with high failure rate, high repair costs, low maintainability, long lead time for spare parts, or components requiring external maintenance personnel [5]. Shutdown Cooling Pump, Motor operated Valve, Check Valve, and b Heat Exchanger are selected as critical components. The Selection of Critical Component process are shown in Fig.5.

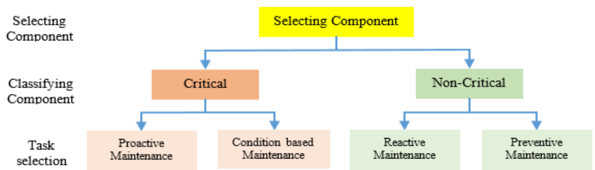

Fig.5. Selection of Critical Component process.

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

Failure Mode and effect analysis is a step-by-step approach to identify system component failure modes, failures causes and study the consequences of these failures on the system. The consequences of each failure mode dictate the type of maintenance task applied to prevent any degradation that can lead to failure [6].

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 H are shown in Table II. 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 [7].

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

Event	Event Description	Significance
SCPTM	Shutdown cooling pump unavailable due to testing and maintenance	High
SCHX	Shutdown cooling heat exchanger unavailable due to testing and safety	High
CCF	Common cause failure of MOVs 651,652,653,654,655&656	High
SCPCCF	Shutdown Cooling CCF for SCPs in train A and B	High
SCHXMOVCCF	Common cause failure of SC heat exchanger MOVs 310&311	High
CCFSCHXMOV	Common cause failure of SC heat exchanger discharge line MOVs 610&600	High
SCPP01B-2	Shutdown cooling pump train B fails to start	High
SCPP01A-2	Shutdown cooling pump train A fails to start	High
CCFWLMOV	Common cause failure for warm up line MOVs 691&690	High
SCIV654-1	Suction line isolation valve 654 fails to open	High
SCIV653-1	Suction line isolation valve 653 fails to open	High
SCIV652-1	Suction line isolation valve 652 fails to open or close	High
SCIV655-1	Suction line isolation valve 655 fails to open or close	High
SCIV691-1	Warmup line isolation valve 691 fails to open or close	High
SCIV690-1	Warmup line isolation valve 690 fails to open or close	High
SCIV656-1	Suction line isolation valve 656 fails to open or close	High
SCCV313-1	SC heat exchanger bypass control valve 313 fails to open or close	High
SCIV340-1	Containment spray system isolation valve 340 fails to open or close	High
SCCV312-1	SC heat exchanger bypass control valve 312 fails to open or close	High
SCCV310-1	SC heat exchanger flow control valve 310 fails to open or close	High
SCCV311-1	SC heat exchanger flow control valve 311 fails to open or close	High
SCIV341-1	Isolation valve 341 from containment spray HX fails to open or close	High
SCIV600-1	SC heat exchanger discharge line MOV 600 fails to open or close	High
SCIV610-1	SC heat exchanger discharge line MOV 610 fails to open or close	High
SCIV651-1	Suction line isolation valve 651 fails to open or close	High
SCIV343-1	Isolation valve 343 from containment spray HX fails to open or close	High
SCIV342-1	Containment spray system isolation valve 342 fails to open or close	High

Table II: The criticality class

Class Range	Measure of Criticality	Criteria	Unit	Weight
E	4.0-3.0	Effect on Safety	S	50%
F	3.0-2.0	Effect on Availability	A	30%
G	2.0-1.5	Effect on Maintenance costs	C	20%
H	1.5-1.0	No effect	-	-

2.9 Task Selection & Implementation

The RCM uses Logic Tree Analysis (LTA) as illustrated in Fig.6. LTA is used to determine the optimum maintenance tasks with respect to the failures modes. 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, and
- Run to failure: is applied on less safety and economical failure modes.

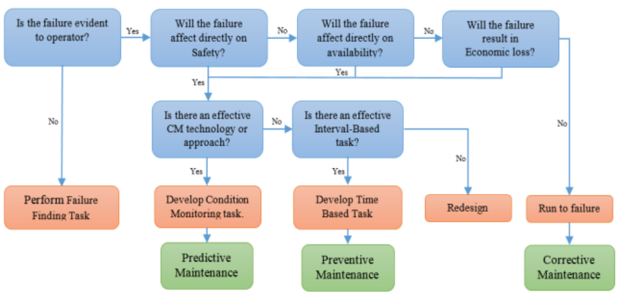

Fig. 6. RCM Logic Tree Analysis (LTA).

Table III, summarizes the selected task for the critical items.

Table. III Results of RCM Process for SCS

Component Type	CBM	TBM	Redesign	Failure Finding
SCP	31	10	1	3
	68.9 %	22.2 %	2.2 %	6.7 %
MOV	11	7	1	1
	55 %	35 %	5 %	5 %
CV	14	4	0	0
	77.8 %	22.2 %	0 %	0 %
SCHX	8	3	0	0
	72.7 %	27.3 %	0 %	0 %
Total Tasks	64	24	2	4
	68.1 %	25.5 %	2.1 %	4.3 %

After applying the RCM process for SCS around 68.1% from the potential failures we can prevent it by CBM, 25.5% of failure prevented by time based maintenance, 2.1% needs to redesign and 4.3 % for failure finding and there is no run to fail tasks. The increasing of the CBM task will reduce components failure rates, improve reliability and reduce the maintenance activities. For the SCP which is the main component in the SCS most of the failure modes can be monitored using condition based techniques. These tools detect and trend the degradation indicators before the potential failure occurs and around 68.9 % from its potential failures can be prevented by CBM. An increase in CBM processes will improve the availability of the SCP and then reduce the number of periodic maintenance activities.

For motor operator valves some effective preventive maintenance tasks proposed for consideration and enhancement are the measurement and fingerprint monitoring of motor power and torque switch tripping and in specific cases measurement of stem forces during functional testing of MOVs in the plants and workshops. The factors such as abnormal environmental stress, wrong adjustment ,drifting, dirt, ware, and oxidation have been identified as the root cause for most of the failure mode and therefore condition monitoring like vibration monitoring and Infrared-thermography are recommended.

For Check Valves the main cause of failure mode associated with check valves is that of reverse leakage. Task of functional test is recommended for SCS-related check valves. Ensure that the valves will be routinely stroked from fully open to fully close during the periodic test with the results formally recorded.

For heat exchanger the Plugged Tubes/ Flow Blockage and Inadequate Heat Transfer are the dominant failures and mainly occur due to corrosion. It is recommended that the Condition directed Infrared - Thermograph monitoring techniques be implemented.

2.10 Treatment of non-critical items

Non-critical items are not analyzed. Plants already having a maintenance program, should be carried out on the noncritical component.

3. CONCLUSIONS

The RCM methodology is useful for improving the equipment reliability by strengthening the management of equipment condition, and leads to a significant decrease in the number of periodical maintenance, extended maintenance cycle, longer useful life of equipment, and decrease in overall maintenance cost. It also focuses on the safety of the system by assigning criticality index to the various components and further selecting maintenance activities based on the risk of failure involved. Therefore, it can be said that RCM introduces a maintenance plan designed for maximum safety in an economical manner and making the system more reliable. For the SCP, increasing the number of condition monitoring tasks will improve the availability of the SCP. It is recommended to reduce the number of periodic maintenance activities. Future studies will be done on the cost benefit analysis for RCM application to the SCS.

ACKNOWLEDGEMENTS

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