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Safety related maintenance in the framework of the reliability centered maintenance concept

INTERNATIONAL ATOMIC ENERGY AGENCY

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FOREWORD

Maintenance of systems, structures and components at a nuclear power plant is one of the most important programmes aiming at achieving safe and reliable power production throughout the lifetime of the plant. Historically, the maintenance of the equipment at NPPs was done in accordance to the specification of the designer. However, by analyzing experience, it was recognized that the nuclear industry could benefit significantly from optimizing maintenance. Since being adopted from the aerospace industry, the concept of Reliability Centered Maintenance (RCM) received substantial interest in the nuclear industry, primarily because of its potential benefits in plant reliability and safety through optimizing a plant's maintenance programme.

In order to discuss the status of RCM and other approaches for optimization of maintenance, and the safety benefits of those approaches, the IAEA convened a Technical Committee Meeting on "Safety Related Maintenance in the Framework of the Reliability Centered Maintenance Concept" in Vienna from 27 to 30 May 1991. The meeting was attended by more than 70 experts from 21 countries and international organizations. In addition to a number of papers which were presented, extensive plenary and panel discussions took place during the meeting, where a variety of maintenance related topics were clarified.

This TECDOC summarizes the status of the RCM methods and its applications in nuclear industry in USA and France today, with a variety of examples of application of RCM from several countries, as presented during the meeting. The papers presented at the meeting are reproduced in the Annex.

EDITORIAL NOTE

CONTENTS

ANNEX. PAPERS PRESENTED AT THE TECHNICAL COMMITTEE MEETING

1. INTRODUCTION

1.1. PURPOSE AND STRUCTURE OF THE REPORT

Elevated safety requirements and ever increasing costs of maintenance of nuclear power plants stimulate the interest in different methods and approaches to optimize maintenance activities. Among different concepts, the Reliability Centered Maintenance (RCM) as an approach to improve Preventive Maintenance (PM) programmes is being widely discussed and applied in several IAEA Member States. In order to summarize basic principles and current implementation of the RCM, the IAEA organized a Consultants Meeting in November 1990. The report prepared during that meeting was discussed during the Technical Committee Meeting (TCM) held in May 1991. Numerous technical presentations as well as panel and plenary discussions took place at the TCM. This document contains the report of the Consultants Meeting (modified to include comments of the TCM), a summary of the most important discussions as well as all the papers presented at the TCM.

The aim of the document is to provide rather extensive review of concept, methods, and tools for the RCM, but also review of current status in maintenance optimization approaches in Member States. The document is targeted to experts involved in maintenance at NPPs, but also for those involved in analytical aspects of maintenance optimization. The document should fulfill the needs of both beginners in the area, by providing the basics of the RCM approaches, and advanced users of the methodology, by providing information on different ways of its implementation.

The document is structured in a way, firstly, to provide the general overview of the methodology, and secondly, to discuss different approaches which are being utilized in Member States. Chapter 2 provides basic discussion of the RCM concept, together with its limitation and historical development. Analytical methods used within the RCM concept are detailed in Chapter 3, where the differences in approaches by two major users (USA and France) are highlighted. Chapter 4 discusses different aspects of RCM implementation, from the single system concept to the overall, living RCM programme. Chapter 5 introduces actual and potential benefits of the RCM concepts, and Chapter 6 details status of selected RCM programmes in the USA and France. Possible future developments of the RCM methods and an example of a computer code to support RCM investigation are provided in Chapter 7. Chapter 8 summarizes the discussions at the TCM.

The papers presented at the meeting review a variety of topics related to the development and implementation of the RCM. Highlights of some of these are as follows: Specific aspects of implementing RCM or similar preventive maintenance optimization programmes have been reviewed. Significant results in applying the modified RCM approach adjusted to local conditions have been achieved at the San Onofre Nuclear Power Plant. Electricité de France (EDF), thanks to the high standardization of its plants, was able to simultaneously implement the pilot RCM programme at 30 plants. The significance of that is obvious, since a single analysis was performed and the same PM optimization implemented at every plant. Although RCM methods are, in general, well matured, there is still room for improvements. A specific degradation mode analysis approach is discussed as a tool for optimizing the RCM programme. This approach could streamline standard RCM methodology. Recently developed RCM computer codes also greatly improve the efficiency of the RCM analysis by allowing on-screen choice of options and, in addition, comprehensive record keeping. The RCM is generally considered to be an approach to optimize preventive maintenance on a component/system level. If, in addition to the RCM, the overall plant PSA model is used, preventive maintenance may be optimized at a plant level. The pioneering research work in that area which may ultimately lead to the optimized plant maintenance, taking into account safety aspects, is under way in the USA.

1.2. RELATIONSHIP OF RCM TO NUCLEAR SAFETY

Public and personnel safety is of primary priority in nuclear plant design, operation and maintenance. RCM is applied at nuclear plants in a way that is completely in accordance with this safety objective.

RCM is a process for specifying applicable and effective PM tasks which prevent failure or optimally control the failure modes for important system functions. For all systems, RCM will explicitly evaluate the failure modes and effects for system safety functions. For component failure modes that are determined by RCM to be critical, the RCM logic tree analysis requires a consideration of scheduled maintenance to reduce the risk of function unavailability for (1) all hidden failures, and (2) all evident failures that have a direct and adverse effect on operating safety.

Furthermore, RCM task implementation requires that PM task changes undergo a thorough safety review, and that they are consistent with technical specifications, environmental qualifications and other regulatory commitments.

Thus, RCM will optimize PM with respect to safety functions, and all RCM recommendations will undergo scrutiny for consistency with other safety programmes before implementation.

1.3. TERMINOLOGY OF MAINTENANCE

The primary purpose of maintenance is to allow nuclear operators to use all functions necessary for safe and economic power production by keeping those functions available. In order to keep these functions provided by the systems available, the maintenance tasks have to be achieved on components related to the systems that are achieving the necessary functions.

In this report, *"Equipment"* means a complete functional assembly of a given make and model (e.g. a pump). *"Component"* is used to describe an internal subassembly of an item of equipment.

> Equipment failure can be defined as either an interruption of functional capability of the equipment (through breakdown or shutdown by an internal protection feature) or a degradation below a defined level of performance

when such a minimum is contained in the functional technical specifications. Equipment has failed if it is declared inoperable by operating personnel using single evidence criteria.

A degradation is a loss of performance of characteristics within the limits of the specifications.

The maintenance activities can be split into two categories: corrective maintenance (CM) and preventive maintenance (PM).

Corrective maintenance is a maintenance task which is performed after the failure of an item of equipment.

Preventive maintenance includes time directed tasks and condition directed maintenance.

Time directed tasks are performed according to a given schedule or after a given amount of use.

Condition directed tasks are performed after identification and diagnosis reflecting the actual status of the degradation of the equipment at the present time.

Predictive maintenance can be defined as a continuous or periodic monitoring and diagnosis in order to give the condition or status of a component degradation evolution prior to equipment failure. Predictive maintenance is a part of preventive maintenance (PM).

A "successful" maintenance programme for each piece of equipment consists of addressing each of its significant failure mechanisms by one of three options:

-- Use preventive maintenance to control or to eliminate the failure;

-- Correct the design to eliminate the degradation or to reduce further the PM (this is the modification option);

-- Run to failure, applying only corrective maintenance.

An optimized preventive maintenance programme will include only applicable and effective tasks.

A preventive maintenance task is applicable if it can control a given type of equipment failure.

A preventive maintenance task is effective when it is practical and it can be performed under satisfactory economic conditions.

The maintenance activities and associated tasks and events are summarized in Fig. 1-1.

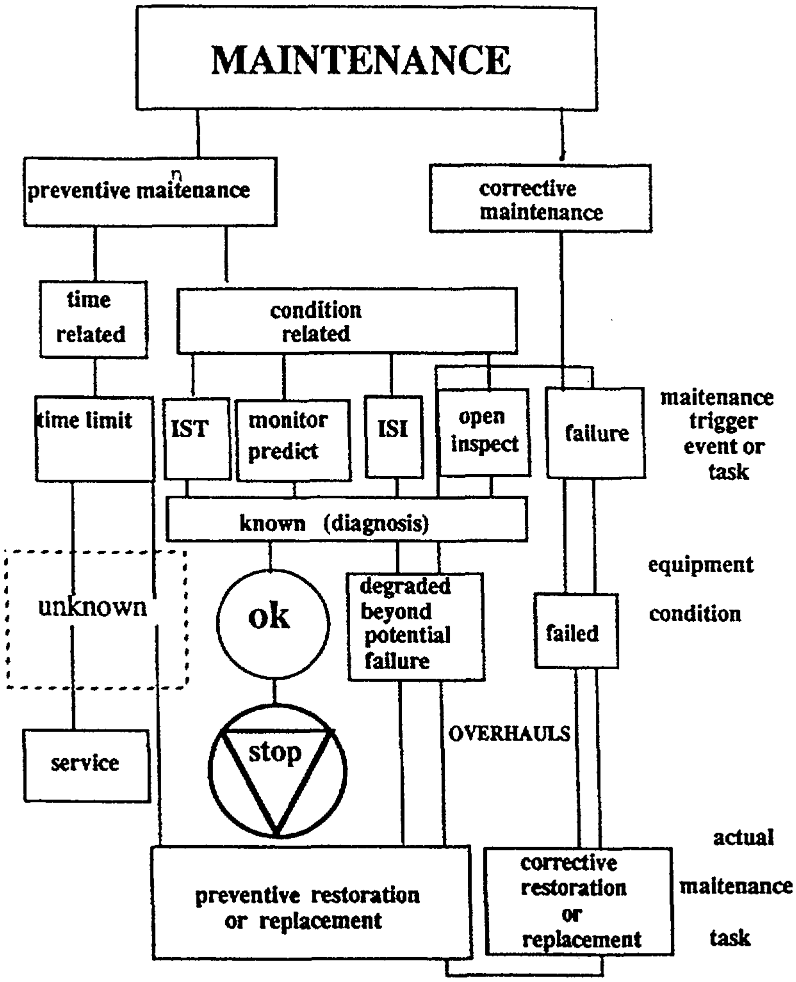


Fig. 1-1. Terminology of maintenance.

A sound understanding and applications of these maintenance concepts will lead to a given level of intrinsic reliability of equipment with a normal amount of preventive maintenance by preventing failures and by monitoring degradations.

2. WHAT IS RCM

2.1. OVERVIEW OF RCM IN THE NUCLEAR INDUSTRY

Strictly speaking, RCM is an evaluation method for selecting PM activities for a plant system. The utilities which comprise the Electric Power Research Institute (EPRI) RCM Users Group have accepted the following definition for their use:

> "Reliability centered maintenance (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 or equipment according to the safety and operational consequences of each failure and the degradation mechanism responsible for the failures.
>
> The requirements of an RCM analysis include:
>
> -- defining the system boundaries;
>
> -- defining the important functions of the system;
>
> -- identifying the dominant failure modes and the effects of these failures;
>
> -- determining the criticality of these failure modes and the associated critical components;
>
> -- based on actual or potential equipment failure mechanisms, identifying applicable and effective tasks that can prevent the failures or reduce their likelihood.
>
> The RCM analysis must incorporate specific plant experience and should also identify potential failure modes. These failures can be identified based on related industry experience and by use of analytical tools such as FMEA, logic models, or other methods. The analysis considers condition directed tasks and time directed tasks as well as testing and modifications. RCM can call for accepting failures after the consequences are well understood".

As a practical matter, an RCM programme must include those activities that are required to implement the RCM analysis results; that is, at least the processes of system selection for RCM analysis, RCM results evaluation and implementation by the maintenance staff, and an ongoing RCM results evaluation and implementation by the maintenance staff, and an ongoing RCM living programme to assess effectiveness and update the RCM results.

In addition, an RCM Programme provides a flexible frame to introduce new PM tasks necessary to control new degradation modes (ageing) that will be discovered during the life of the plant.

Finally, an RCM maintenance philosophy is one which bases all maintenance activities, as far as practicable, on selecting applicable and effective tasks for addressing critical failure modes for important system functions. This philosophy transcends the RCM analyses and the RCM Programme for selected systems.

Figures 2-1 and 2-2 depict this hierarchical nature of RCM. Figure 2-1 shows the relationship of the method of RCM analysis to a utility RCM programme. Figure 2-2 shows the broader influence of an RCM maintenance philosophy on the elements of the overall plant maintenance philosophy on the elements of the overall plant maintenance effort.

2.2. THE LIMITS TO RCM

RCM as a tool has significant potential benefits to a utility in developing a preventive maintenance programme or for optimizing an existing programme. The potential benefits of RCM include assistance in improving an inadequate PM programme, eliminating unnecessary PMs and surveillance, improving the reliability and safety of the system and the plant, optimizing maintenance resources, providing a well documented technical basis for the PM programme, and identifying design changes that improve system reliability. The actual benefits realized depend on the specific objectives of the utility.

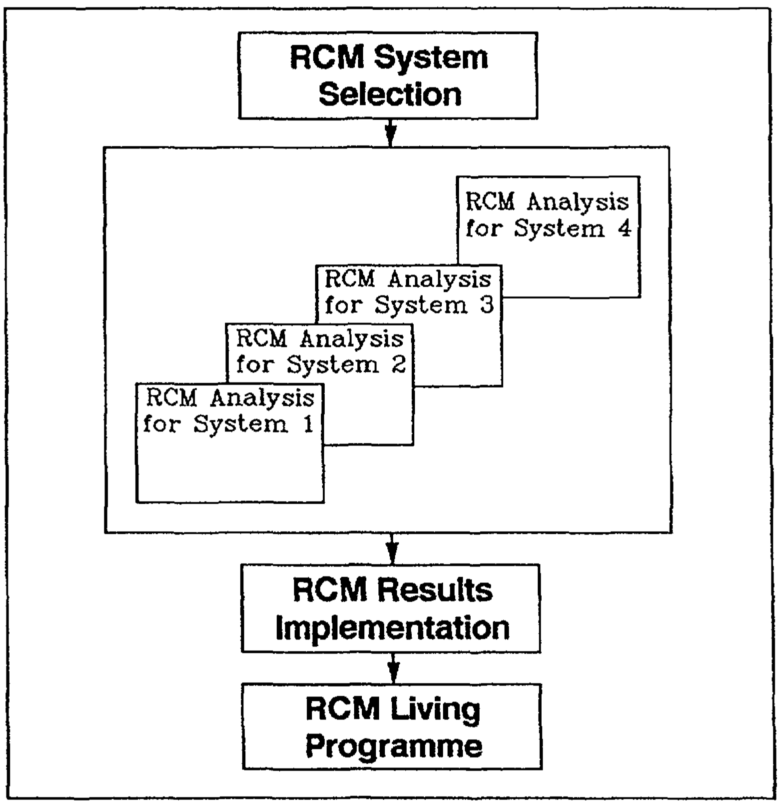


Fig. 2-1. RCM programme.

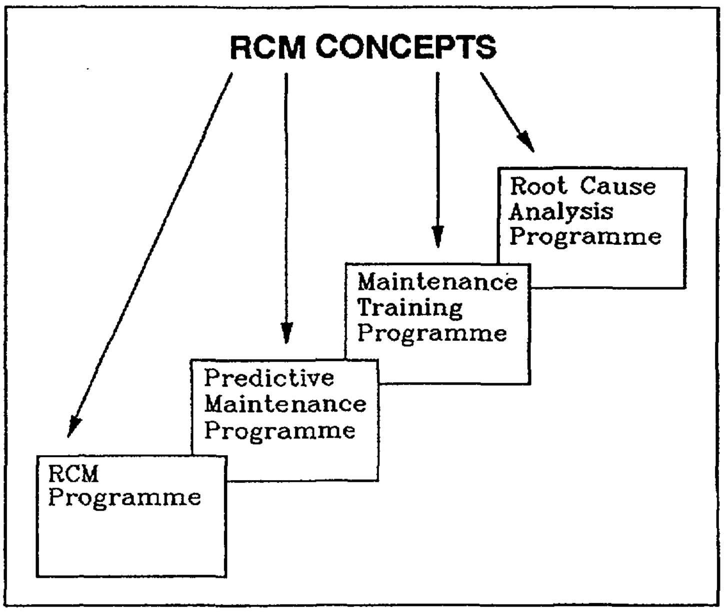


Fig. 2-2. RCM maintenance philosophy.

However, there are some issues that cannot be addressed by RCM. Other programmes would be necessary to address these issues. Specifically, RCM cannot compensate for inadequacies in maintenance training or root cause analysis programmes or deficiencies in other programmes at the utility. RCM cannot reduce the occurrence of maintenance errors. Although RCM can recommend PM that might compensate for weak design features, its purpose is not to be a substitute for necessary design changes. RCM cannot specify the PM task details. The maintenance staff must still provide the necessary procedures and specifications.

In summary, then, RCM is one component of a utility's total effort to enhance the availability, reliability and safety of the plant. Its potential can be realized only if other components of the total maintenance programme are sound.

2.3. HISTORY OF RCM

2.3.1. Use of RCM in commercial aviation and by the military

The RCM method has its origins in the commercial aviation industry in the late 1960s. With the advent of wide bodied aircraft, beginning with the Boeing 747, it was financially imperative to optimize PM; that is to perform just the correct amount of PM to achieve high safety, availability and reliability.

The method was designed to make use of two concepts that were usually not adequately considered in PM programme: (1) complex equipment does not generally experience an abrupt wearout indicated by increasing failure rates; and (2) the emphasis in PM should be on maintaining important system functions.

Out of a 1969 meeting of airline engineers representing the initial purchasers of the Boeing 747 aircraft came MSG-1, which included the basis for the maintenance programme. The airline industry subsequently developed MSG-2 and is currently using MSG-3 based on these same philosophies.

The US Department of Defense adopted the principles from MSG-2 in 1975. It named the process RCM and directed that the method by broadly applied to military hardware. It published an RCM textbook in 1978.

In 1981, the US Naval Sea Systems Command completed its RCM handbook. In the same year, the US Navy published a Military Standard for application of RCM to naval aircraft. By then RCM was being employed by the US Army Air Force and Navy for several classes or aircraft and ships.

2.3.2. Pilot applications of nuclear plant RCM

In 1984, the Electric Power Research Institute (EPRI), USA, and its utility advisory boards recommended that the usefulness of RCM be evaluated in trial applications to single systems at selected nuclear power plants. The first EPRI application of RCM was on the component cooling water systems of Florida Power and Light's Turkey Point Units 3 and 4. The study recommended 24 tasks that differed from the existing ones. A project team drafted changes to the plant procedures for the time directed and condition directed preventive maintenance tasks that were identified. This package of suggested PM changes was used in the evaluation of the plant PM programme at Turkey Point.

The application of RCM to the main feedwater system at Duke Power's McGuire station began shortly before the end of the Turkey Point pilot study. The RCM pilot study team investigated the system as it was before modifications were made in response to operational problems and corrective maintenance early in the plant's life. The RCM study verified the appropriateness of major elements of the current PM programme. It developed desirable candidate condition directed tasks as replacements for existing time directed tasks and verified the need for modifications which the plant had identified by other means.

The third pilot application was conducted on the auxiliary feedwater system (AFWS) at Southern California Edison's (SCE) San Onofre Station. Unlike the normally operating systems that had been studied in the first two applications, the standby AFWS has functional redundancy, constraints on allowable outage time, infrequent operation, and frequent testing. Also, system failures are often not obvious until a demand for the system occurs. Therefore, this study offered a further test of the applicability of the RCM for a nuclear plant. The study recommended a net decrease in PM effort on the system with many PM tasks to be deleted, reduced in scope or changed from time directed to condition directed.

2.3.3. Large multi system nuclear plant RCM demonstrations

As the next step in developing RCM for potential wide use in the nuclear industry, EPRI selected two host utilities for large scale RCM demonstrations. One demonstration was conducted at the Ginna nuclear power station. The other demonstration was conducted at San Onofre nuclear generating station, Units 2 and 3.

A principal objective of these projects was to implement RCM on a large number of plant systems at each plant as part of a PM evaluation programme. The projects showed both the cost-effectiveness and the feasibility of the integration of RCM into the operating environment and organization of each power plant. They demonstrated acceptance of the RCM programme by utility personnel. These objectives were met concurrently with the utilities' own objectives, such as (1) quantifiable reductions in maintenance cost; (2) realignment of maintenance resources to improve overall plant availability and safety; (3) producing a more favourable PM-to-CM cost ratio; (4) optimization of technical specification testing requirements; and (5) providing a partial basis for plant life extension and license renewal.

Both utilities viewed their RCM projects as one element of a larger maintenance improvement programme without clear boundaries. At Rochester Gas and Electricity Corporation's Ginna Plant, the following additional activities were underway:

-- restructuring of the maintenance organization;

-- upgrading of the work control system;

-- upgrading of procedures;

-- development of a maintenance information system;

At SCE the plant had the following additional activities underway:

-- PM audit task force for all systems;

-- of technical optimization specifications;

-- maintenance basis documentation.

At both utilities RCM team members participated in the total maintenance improvement effort, and RCM became the maintenance philosophy that bound these diverse activities together.

Both the Ginna and the San Onofre demonstrations began in the Spring of 1988. All of the analyses on 12 to 20 systems were complete at each plant within two years.

Significant steps in each demonstration included: (1) selection and prioritization of systems for RCM evaluation; (2) performance of the RCM analysis steps on the selected systems; (3) evaluation of the RCM recommendations by a multi disciplinary team or task force; (4) implementation of the RCM recommendations; (5) establishment of a system to rank and verify the RCM benefits; and (6) establishment of procedures to update the RCM bases and recommendations with time.

Differences in the demonstrations were partly imposed by very real differences in the two utilities and their respective plants. Ginna is run by a small utility, and is a small, single unit plant with many operating years of experience. The unit has had high availability and reliability. Its PM programme was less formal and procedural than for new plants Ginna is run by a small utility, and is a small, single unit plant with many operating years of experience. The unit has had high availability and reliability. Its PM programme was less formal and procedural than for new plants. Its utility was interested in maintaining this good performance in the second half of the plant's license period and in laying the basis for a possible license renewal. San Onofre is a large utility and Units 2 and 3 are large, relatively new units with scope for improvements in availability and reliability. The utility was interested in justifying optimization of their extensive PM programme and technical specification testing requirements.

The demonstration projects at San Onofre and Ginna are now complete. Most of the objectives have been met, and the lessons learned are now available for the benefit of other utilities undertaking RCM activities.

2.4. RCM AND NUCLEAR PLANT REGULATION

RCM has been developed by the nuclear power industry for the optimization of its PM programme. There was no involvement of nuclear regulatory agencies (such as the USNRC or rate setting commissions) or industry sponsored support organizations (such as the Institute of Nuclear Power Operations (INPO)).

Since RCM has been successfully demonstrated for use by the nuclear power industry and has been applied by an increasing number of facility operators, these regulatory and other organizations have taken a greater interest in understanding the benefits of RCM. The USNRC has proposed the use of reliability based PM evaluation methods (including RCM) as an effective basis for a nuclear plant PM programme INPO has published a Good Practice document which describes the use of reliability based techniques for PM programme improvement (including the use of RCM).

Regulatory and other organizations are thus recognizing the safety and operational benefits of RCM. However, there has been no regulatory pressure or motivation either for the development of RCM in the nuclear industry or for its rapid acceptance and application by utilities.

3. ANALYTICAL METHOD

3.1. BASIC STEPS

The methodology to perform the RCM analysis varies somewhat among the utilities around the world. This situation can be explained by the internal organization of a utility, the available resources and the nature of the feedback experience, taking into account the past history of equipment failures and the nature of reliability analysis methods.

The basic RCM steps, however, are quite common to all applications. The RCM analysis method comprises the following steps:

(a) Plant partitioning into systems

The partitioning of the plant into systems for a given type of nuclear power plant is either specific to the utility or generic for a given type of nuclear reactor (PWR, BWR). It may also be influenced by the vendor.

(b) System selection

The system selection aims to define which systems are most eligible for RCM activities. Several approaches can be taken for system selection:

-- Use of qualitative criteria based on the plant personnel's expertise and maintenance activities over the past years.

-- Use of quantitative criteria taking into account, for instance, costs to repair, reactive safety, lost megawatts, cost to maintain, manpower and resource requirements, ALARA, regulatory concerns, needs for training.

-- Use of both qualitative and quantitative criteria.

It is worth noting that after various experiences the first criteria, based on expert judgement by the operation, safety and maintenance team, is very often just as effective in prioritizing systems as the more quantitative approach.

(c) Data and information collection

The RCM analysis for a given system requires the data and information collection for the various members of the RCM team.

-- drawings, description and existing studies of the system;

-- operating procedures and technical specifications;

-- corrective maintenance data history relating to the date of the failure, the cause of the failure, the consequences of the failure and the actions taken;

-- all the existing preventivė maintenance and monitoring tasks that are current.

(d) Identification of the system boundaries

The identification of the system boundaries will delineate the physical boundaries of the system in terms of functions and identify the support systems and interfaces that are supposed to be fully operational for the analysis. This is currently achieved after discussions with plant personnel.

(e) Determination of the functional failure of systems and its subsystems

In this stage a functional failure analysis is performed to identify the functions that are important for safety, availability or maintenance. This includes a partitioning of the system into subsystems to ease the analysis and the determination of what analysis method the systems analyst is to use to study failure of the function (FMEA, fault tree, etc.).

(f) Ranking of failure criticality

Generally a ranking of the functional failures is performed by a dedicated team to validate the most important ones (this team includes experts from the operational and maintenance departments).

(g) Logic tree analysis for maintenance task selection

The logic tree analysis aims to produce recommendations for preventive maintenance for critical failure modes. (These recommendations take into account applicable and effective preventive maintenance tasks.)

The criticality of failure modes is related to their impact on:

-- safety;

-- availability;

-- maintenance costs.

RCM recommendations can call for: (1) a failure finding task for hidden failures; (2) a time directed PM task; (3) a condition directed PM task with condition monitoring (4) a design change to eliminate the failure mechanism or to enable the detection; or (5) the equipment to run to failure.

Figure 3-1 shows the overall steps of the RCM analysis.

3.2. THE FRENCH APPROACH

The standardization of the French nuclear 900 MW(e) and 1300 MW(e) units has led Electricité de France (EDF) to establish a maintenance policy and a maintenance programme at the corporate level of the Nuclear and Fossil Generation

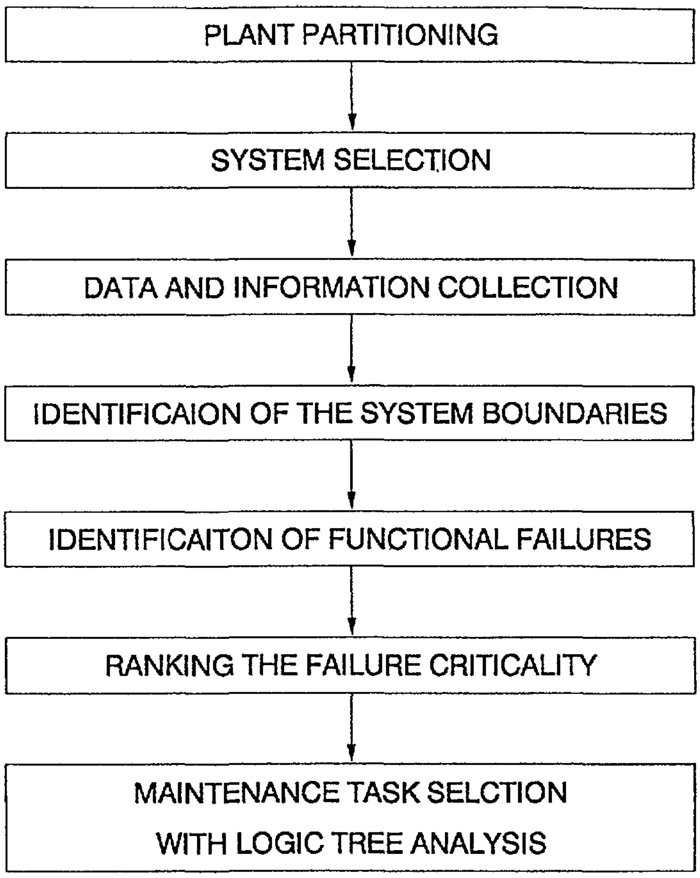


Fig. 3-1. Flow diagram for an RCM analysis.

Division. These maintenance policies and maintenance programmes aim to keep the intrinsic reliability of each component at the appropriate level.

The implementation at the plant level is under the responsibility of the plant manager in compliance with:

-- the technical specifications;

-- the periodic testing which guarantees that various functional sets are able to perform their function;

-- the qualification testing after each maintenance activity for each of the large components of the initial programme. This is established through the vendor's recommendations and is upgraded taking into account the operating experience feedback.

The objectives of the maintenance programme are the following:

-- assess the intrinsic reliability level of each component;

-- restore the reliability to its intrinsic level after a failure;

-- identify the components having an inappropriate intrinsic reliability;

-- realize all these objectives at a minimal cost, taking into account the costs of residual failures.

The annual expenditure for maintenance represents 2.5% of the construction costs of a nuclear power plant. Consequently, even a slight reduction in maintenance costs will produce important savings. At the moment, the percentages of expenditure for scheduled maintenance and non-scheduled maintenance are equal to 60% and 40% respectively. For the 900 MO(e) units, the unavailability factor is about 16% (5.3% due to forced unavailability and 10.7% due to scheduled outages). EDF considers that the maintenance programme is not at the optimum level for corrective preventive maintenance. The optimum level is expected to be achievable. EDF is looking for ways to optimize its maintenance programme to decrease:

-- the direct costs of the maintenance;

-- the costs of unavailability;

-- the cost of the failures.

For these reasons, EDF is performing a pilot study using RCM analysis to evaluate the anticipated benefits, such as:

-- cost optimization by applying maintenance efforts to the most appropriate components;

-- visibility and traceability of actions an decisions;

-- systematic and structured processes;

-- qualitative and quantitative use of maintenance history.

The RCM analysis used by EDF comprises four major tasks (as shown in Fig. 3-2). The aim of the analysis is to define the list of the maintenance tasks to be performed on the system's equipment. The EDF approach relied on the functional consequences and on the selection of maintenance tasks necessary to avoid them. In order to identify the critical equipment eligible for RCM activities, it is necessary first to divide the plant into systems, subsystems and equipment, as shown in Fig. 3-3.

<u>Identification of critical equipment</u>

This identification is based on the analysis of functional consequences of the failure of each item of equipment. Each failure mode may have a consequence on:

-- a vital function for the safety of the plant;

-- a total or partial production loss;

-- the costs of the repairs necessitated by the failure.

This analysis is performed at the moment using FMEA. The classification of the severity of the consequences is realized using logic diagrams defined by the experts of the Nuclear and Fossil Generation Division.

Critical equipment definition

A piece of equipment will be declared critical if at least one of its failure modes is important for safety, production or maintenance.

Classification of failure mode severity

A failure mode of a piece of equipment is:

S.S: severe for safety if it induces a loss of vital safety functions.

S.P.: severe for production if its induces a shutdown or a reduced power generation when the plant is connected to the grid or if it will lead to a delay in the connection to the grid.

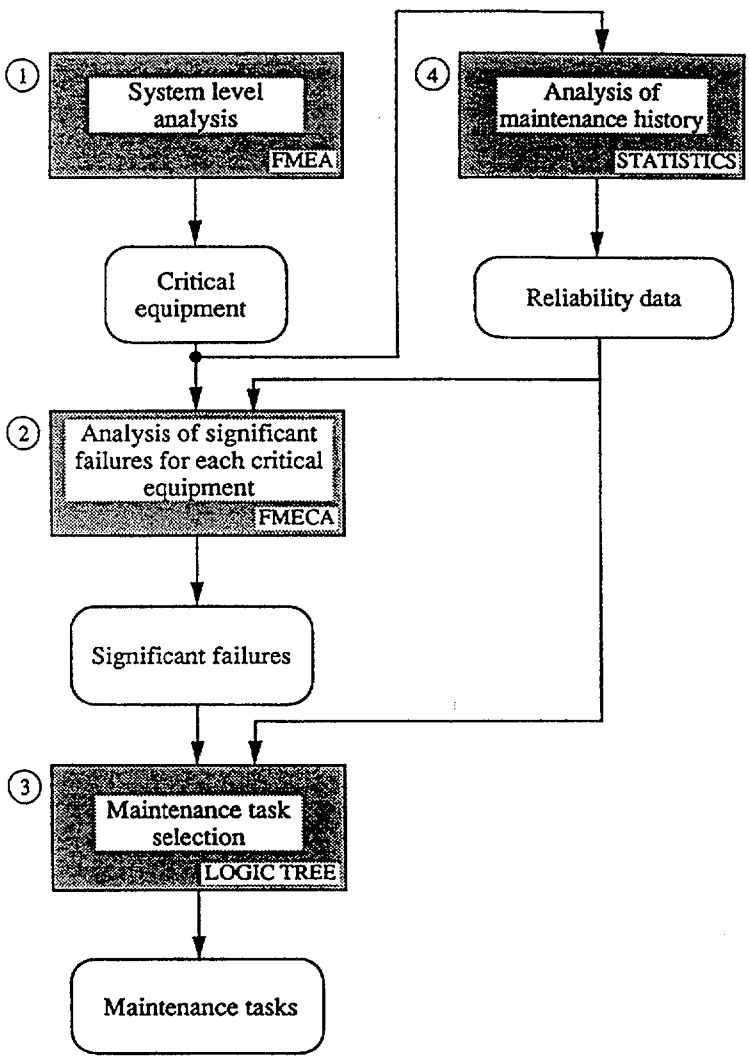


Fig. 3-2. RCM process.

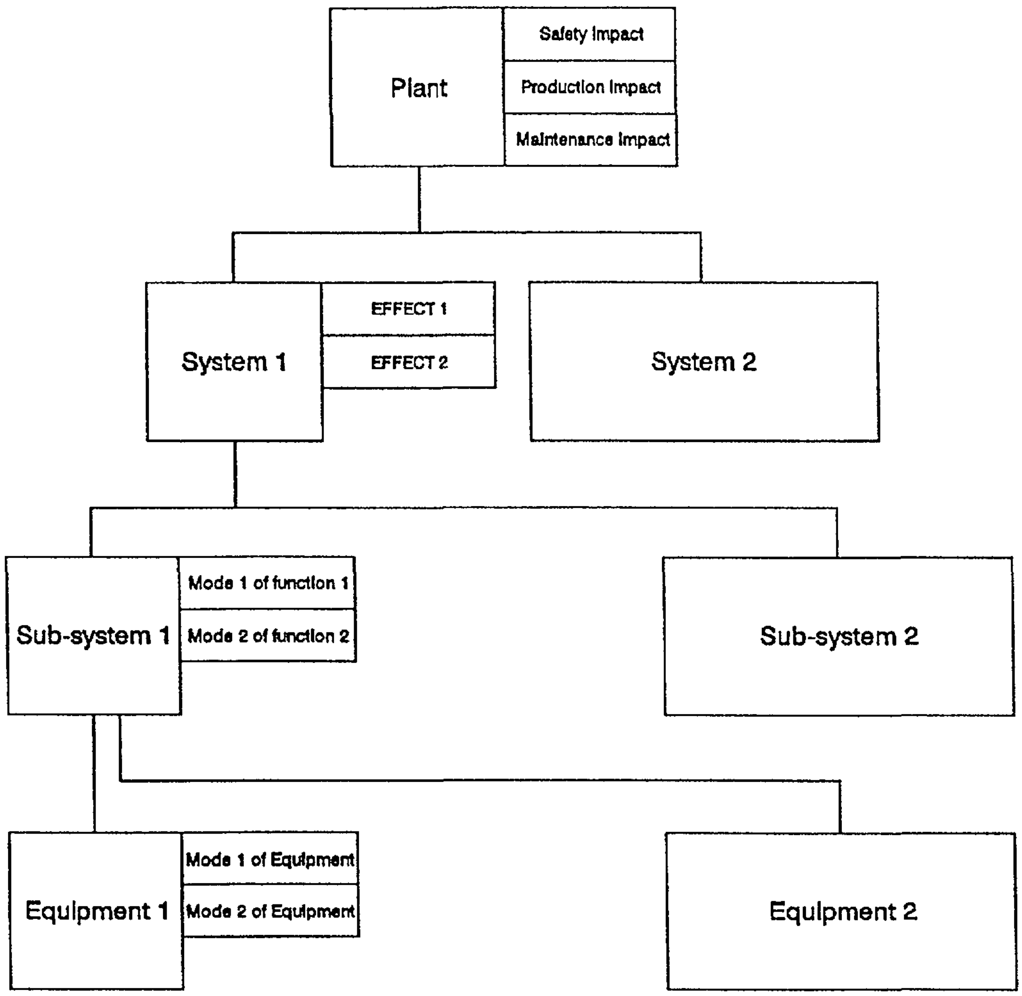


Fig. 3-3. Plant breakdown.

S.M: severe for maintenance if the failure leads to expensive repairs.

N.S: not severe if it is not severe for safety, production or maintenance.

The system selection performed by EDF takes into account the systems that are important for safety, production and maintenance. This selection is based on interviews and evaluation by the operations, safety and maintenance teams, taking into account the functions realized by the systems and also the operational experience feedback.

In all cases the boundaries of the systems excluded the support systems (air, electricity) and, to ease the analysis, the system was split into subsystems. Each subsystem must perform at lease one of its specific functions. For each subsystem the boundaries are clearly defined, and an exhaustive list of all the functions performed is established.

The definitions of these functions performed are very detailed in order to evaluate the effects of the failure modes on the system and on the plant. For instance, the functions that are considered essential for safety are those which are necessary to:

-- to realize the missions of the system clearly identified in the probabilistic safety analysis of the 900 MW(e) nuclear power plant;

-- to maintain the integrity of the second barrier (NSSS vessel);

-- to maintain the integrity of the third barrier (containment vessel).

In order to identify the critical equipment eligible for RCM activities, it is necessary first to break down the plant into systems, subsystems and equipment, as shown in Fig. 3-3.

The analysis of the failure of each subsystem is performed by FMEA. With the functional decomposition described in Fig. 3-3 for each subsystem, all the equipment is listed and for each item of equipment the modes of taken into account failures are defined.

As a result of the partition of the plant into the systems, subsystems and equipment, it is possible to deduce the effects of the failure modes at the system level and then at the plant level. The effects of the failure modes (i.e. severe for safety, severe for production, severe for maintenance) are derived from dedicated logic trees taking into account the status of the plant (full power, shutdown). Thanks to the FMEA, the raw list of critical equipment is as shown in Fig. 3-4.

For each piece of critical item of equipment, the following details are given:

-- the modes of failure;

-- for each failure mode, the severity;

-- whether the failure is evident or hidden;

-- the occurrence rate.

After this exhaustive analysis experts, taking into account quantitative data or making their own judgement, will establish the final list of critical items of equipment to be analyzed in more detail.

Once this list of critical components has been completed, the next step is the identification of the equipment failures. The selection of the equipment failures requires:

-- definition of the equipment boundaries;

-- the detailed list of the functions performed by the equipment that support the system functions;

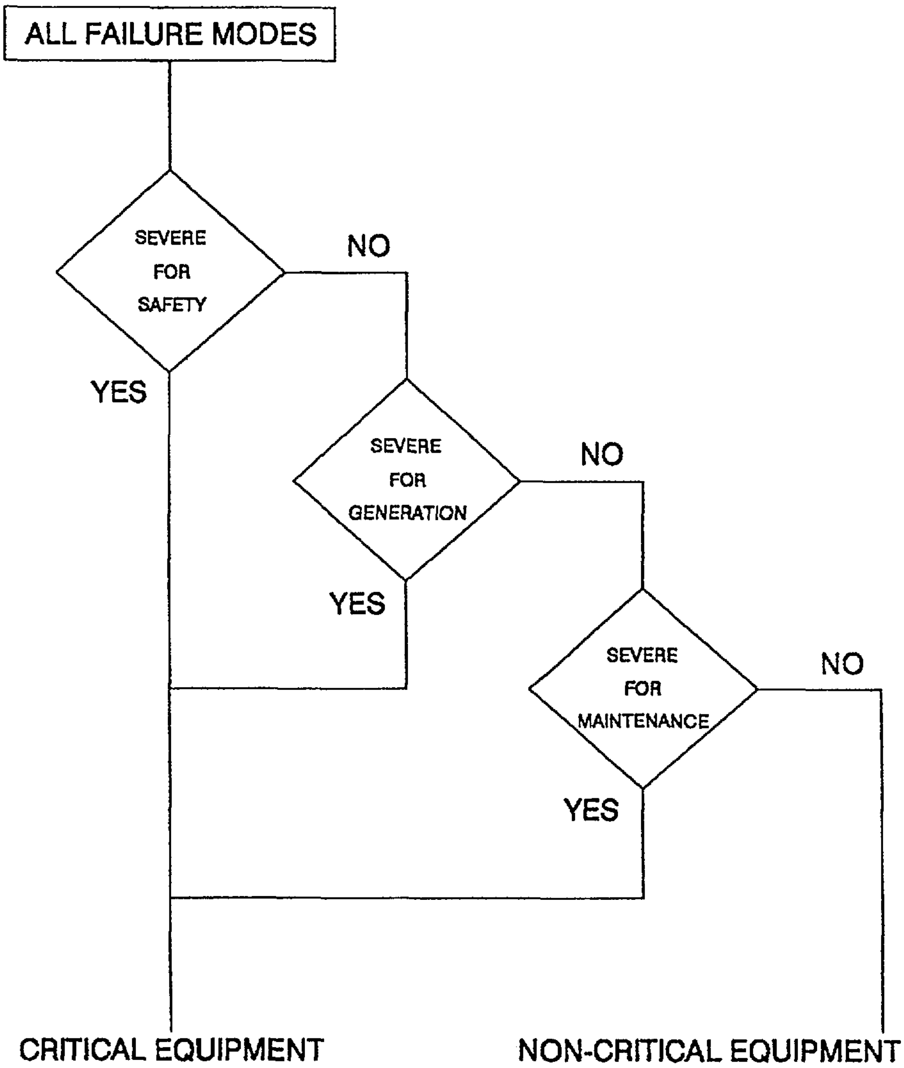


Fig. 3-4. Logic diagram for critical equipment identification.

-- a functional decomposition of the equipment.

The equipment is decomposed into functional subsets; each functional subset may be further decomposed into subsets according to the complexity of the components, as shown in Fig. 3-5.

Figure 3-6 gives an example of a functional decomposition for a gear reducer.

The identification of the significant failures is performed using failure modes, effects and criticality of the function failure rate and the impact of the failure.

The criticality gives a classification of the functional failure in three categories:

-- a negligible functional failure means that the failure effects are negligible and the failure rate is acceptable;

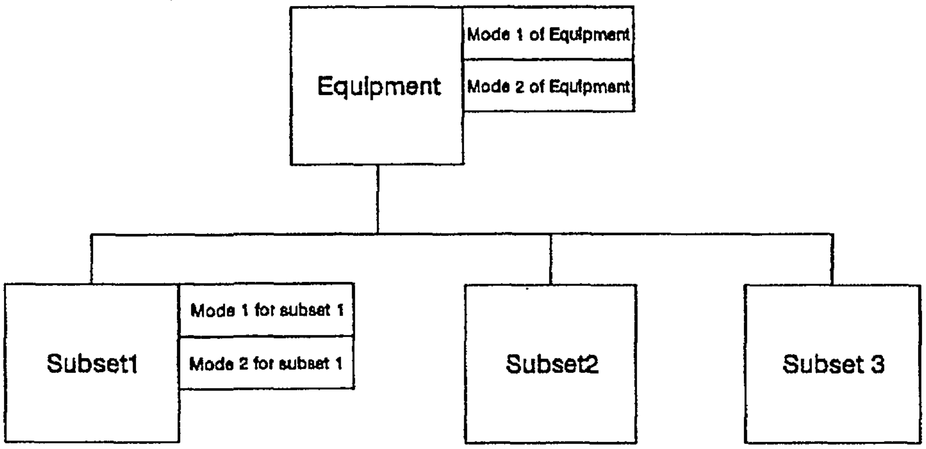


Fig. 3-5. Functional partitioning of an item of equipment.

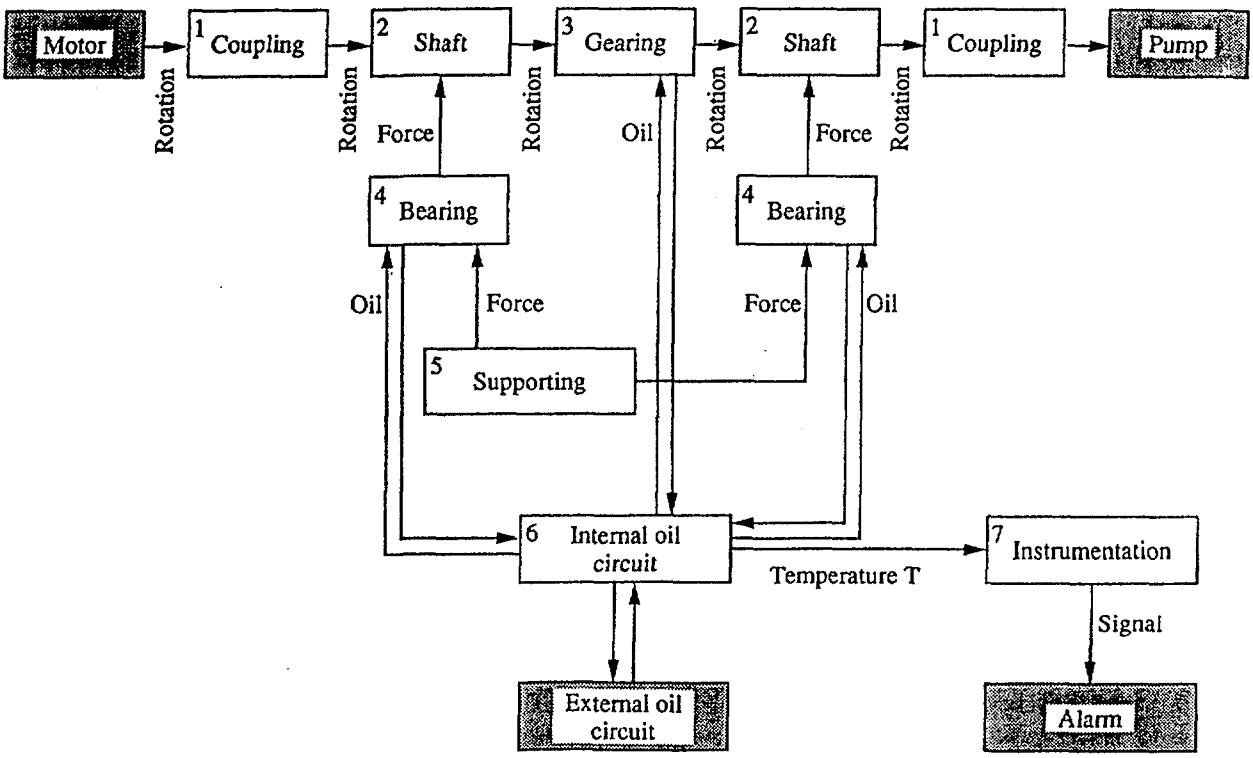


Fig. 3-6. Functional diagram of a gear reducer.

-- an acceptable functional failure has to be controlled and the failure rate must be under a given threshold;

-- a non-acceptable failure rate must be prevented.

An example of the FMCEA is shown in Fig. 3-7.

System : CVCS	Equipment : Gear reducer						Failure rate :		
Item	Item functional failure	Equipment effect	Causes	% failure rate	Source	Severity	Criticality	Degradation	Detection method
Bearing	Loss of guiding	Fails in run	* Failure of ball bearing		SRDF	S.P. if >14 D	Acceptable	Wearing	Vibrations Overheating
			* Failure of journal bearing		SRDF	S.P. if>14 D	Acceptable	Scratch	Vibrations Overheating
			*						

S. P. : Severe for Production

Fig. 3-7. Example of an FMCEA.

Maintenance Task Selection

The nature of the maintenance activities is defined directly by the results of the FMCEA, together with a logic tree.

-- For a negligible functional failure, the only applicable preventive maintenance costs that are considered are those that are less costly than the repair or replacement that is a consequence of failure. Other considerations such as ALARA may preclude use of even a cost effective PM. For example, the only task applicable, efficient and cost effective PM which can be implemented may be greasing. According to the result of the logic tree, the greasing task will be applied or the equipment will run to failure.

-- For an acceptable functional failure, the equipment has to be maintained to reduce to an acceptable level the risk of a failure. All the applicable PM activities are investigated according to the logic decision tree shown in Fig. 3-8. According to the results of the logic tree, only the most cost effective task is retained. If there is no PM task available, a redesign has to be considered.

-- For a non-acceptable functional failure, all the applicable PM tasks are evaluated. A special logic tree is used to perform the analysis which will give two alternative choices: implementation of the task or a set of tasks that are the most efficient and cost effective or a compulsory redesign.

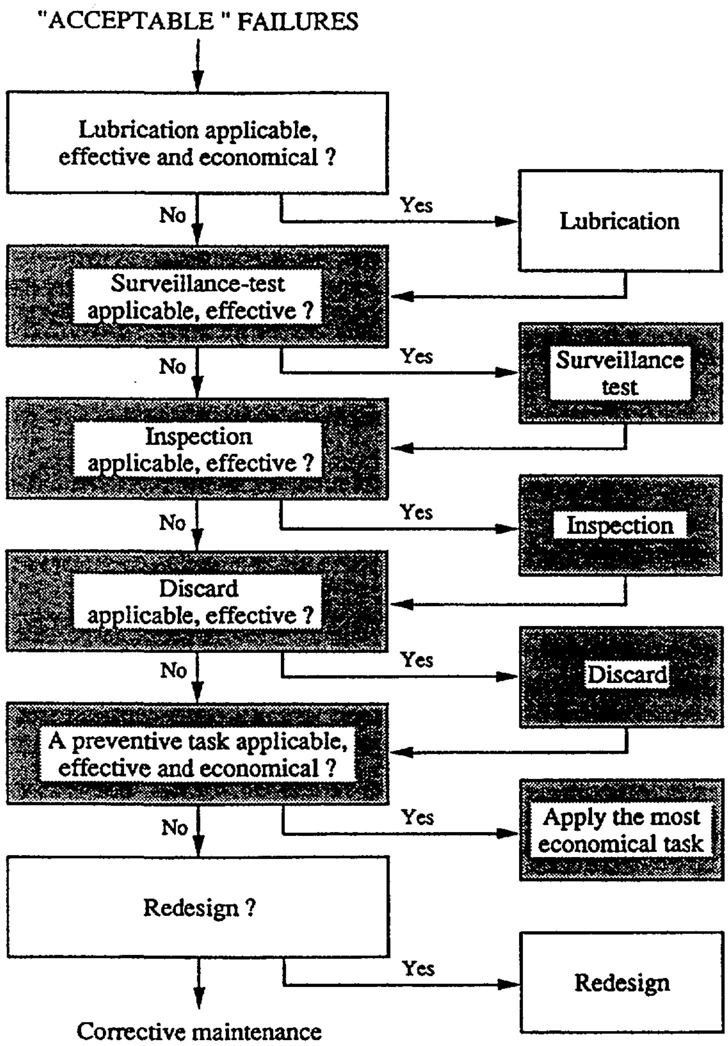


Fig. 3-8. Example of a logic decision tree for acceptable failure.

3.3. THE US APPROACH

3.3.1. A case study from San Onofre Nuclear Generating Station

It is instructive to compare the RCM analysis steps for one specific RCM programme with the basic steps given in Section 3.1. The San Onofre RCM demonstration project is considered below for that purpose.

The major actions taken during the RCM analysis process at San Onofre are listed below:

(1) Define system boundary, partition into subsystems;
(2) Determine subsystem interfaces;
(3) Determine subsystem functions and out-interfaces;
(4) Provide functional failure modes;
(5) Review I;
(6) Collect data;

(7) Generate component listing, instrument matrix;
(8) Complete FMEA analysis;
(9) Complete instrument matrix;
(10) Complete CM history and design history reviews;
(11) Determine critical and non-critical components;
(12) Complete LTA analysis;
(13) Review II;
(14) Conduct interviews/PM and bases review;
(15) Evaluate non-critical components and PM recommendations;
(16) Finalize documentation.

These sections are consistent with the basic steps in Fig. 3-1, but there are several refinements and additions. The San Onofre actions explicitly identify reviews and interviews with plant personnel. This emphasizes the extreme importance of obtaining input from operations, maintenance and system engineers.

The San Onofre actions also include two additional items in the system analysis: a complete component listing and an instrument matrix. These items are included because the San Onofre RCM project critically reviews the current maintenance for all equipment, even if it does not support an important function or if it is not critical equipment. The component listing assures completeness. The instrument matrix is a table that clearly presents each instrument in a system and all of its functions. The instrument matrix expedites the analysis. An example instrument matrix is presented in Fig. 3-9.

Finally, the San Onofre actions emphasize the production of final documentation as the basis for the maintenance programme and as a starting point for the RCM living programme.

3.3.2. Other programmes in the USA

RCM methods in the nuclear industry have developed in an environment of open communications and technology transfer. As a result, most applications of RCM have conformed closely to the industry definition of RCM. They have employed the same analytical steps and have used the same terminology for the most parts. Some of the very early work done prior to the EPRI Users Group and demonstration projects was inappropriately labelled as RCM.

Nonetheless, there are some variations in the RCM analytical methods employed by different utilities. For the most part, the differences are attributable to differences in the objectives that utilities have for their RCM studies, by the external organization of the utility or the amount of failure experience available and resources committed to the project. Some utilities tend to favour the selection of normally running production systems; others favour the selection of standby safety systems. Although originally developed for application to normally running systems, there is nothing inherent in the RCM methods which would limit their application to one type system or another.

EQUIPMENT	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
2FCL6840						X					
2FCL6845						X					
2FGJ971								X			
2FGJ979								X			
2FI992[illegible]						X					
2FSL9926						X					
2LG9934						X					
2LGJ938						X					
2LGJ939						X					
2LGJ969						X					
2LGJ977						X					
2LIJ973											X
2LIJ981											X
2PCHJ964	X										
2PCHJ965	X										
2PDI9940B								X			
2PDI9940C								X			
2PDI9940D								X			
2PDI9940E								X			
2PDI9940F								X			
2PDI9941B					X						
2PDI9941BB					X						

F1. Provides trip function (component, system, plant).
F2. Provides automatic control/interlock.
F3. Safety related display instrumentation.
F4. Supports tech.spec. surveillances.
F5. Provides alarm/indication to the control room.
F6. Instrument monitored on operator rounds.
F7. Computer input.
F8. Used to perform system or component design basis evaluation.
F9. Used during system manual operation.
F10. Needs to be operable but accuracy of indication is not essential.
F11. Not required function.

Fig. 3-9. Instrumentation matrix for normal containment ventilation (GND).

Some utilities focus their investigation of dominant failure modes on operating and maintenance data and experience. Others develop their dominant failure modes primarily from an engineering evaluation of the system through FMEA or fault tree modelling. Either approach can be justified depending on the age of the plant, the quality of historical data and the availability of existing fault tree models and qualified personnel to use them.

Some utilities have deliberately excluded instrumentation from the system boundaries for RCM. They have elected to use other evaluation methods for these components. Others have developed an instrument matrix to replace the FMEA for instruments. This matrix enables the RCM analyst to determine and document all the functions of instruments in the system more efficiently and thoroughly.

RCM has recently been applied generically to a particular model of reactor coolant pump. This application of RCM to a single equipment type having multiple applications is consistent with the use of RCM for evaluating individual systems. The equipment is a complex assembly with several components and multiple functions. It can be treated effectively as a system with subsystems, in-interfaces and out-interfaces. Even if the pump is considered as part of a larger system, it would certainly qualify as a functionally significant item in RCM terminology. The pump also has a very narrow range of applications with similar environments and service life. Therefore, RCM can be generically applied to this item of equipment.

Finally, some variations in RCM methods are attributable to intentional links between the RCM programme and other plant programmes. One utility has an ambitious programme to reduce Tech.Specs required testing. Therefore, the RCM evaluation is careful not to consider Tech.Spec. action statements with the existing requirements. One utility has linked its RCM programme to their plant life extension programme. They explicitly seek PM activities to detect aging. Another RCM application is specifically designed to make optimal use of an extensive new predictive maintenance programme. This utility will aggressively seek condition-directed tasks to replace its current time-directed activities. One utility has performed an RCM study on a system which has quantitative reliability goals. This RCM project will focus on identifying applicable and effective tasks to achieve these reliability goals. One result of this variation in RCM applications is a wide range of costs per system within the industry. This wide range of costs is explainable by comparing the level of detail that is necessary to satisfy the wide range of utility objectives.

3.4. CRITICAL AREAS

Industry experience has demonstrated that the success of an RCM programme is particularly dependent on dealing effectively with several critical areas.

These areas are:

-- Availability of a team incorporating experts from the safety, operation and maintenance departments.

-- Support at the corporate level.

-- Reliable maintenance history relating precisely the cause and the consequences of the failures including loss of production and, cost of repair.

-- Good knowledge of predictive maintenance techniques to diagnose and monitor degradation.

- Proper resources to document the RCM analysis for further improvements. (This should include a computerized RCM work-station or customized database software.)

- The desired depth of the analysis must be consistent with resources and objectives. Among various approaches of RCMs performed around the world in nuclear power plants, the main differences exist at the level of the final analysis. The analysis can stop at the equipment level or go deeper to components of the equipment. Consequently the costs and time necessary may vary by a factor or 1 to 10 between two different implementations.

4. IMPLEMENTATION

4.1. INTRODUCTION

The RCM analysis method has been described in detail in Chapter 3. The relationship between the RCM analysis, a larger RCM programme and an RCM maintenance philosophy has been discussed in Chapter 2. This chapter considers those elements of an RCM programme that are necessary to evaluate and implement the RCM analysis results at the plant. Specifically, these elements are:

(1) RCM project organization and staffing;
(2) evaluation and implementation of RCM recommendations by plant staff;
(3) the RCM living programme.

Not explicitly included in this report is a discussion of the interface of the RCM analysis with other plant programmes, such as optimization of spare parts, plant life extension and ageing, root cause analysis programme, maintenance personnel training, plant information systems and others. These interfaces can be, on a project specific basis, desirable or necessary. They are, however, beyond the scope of this report.

4.2. PROJECT ORGANIZATION

The successful achievement and implementation of an RCM project requires the co-operative efforts from both the management and from a multidisciplinary team. The project organization differs depending upon the size of the utility, the resources available and the maintenance history. There are no fixed rules to define a project organization.

However, in all existing and living project organizations a multidisciplinary team includes the following staff:

- maintenance experts;
- operations experts;
- system engineering experts;
- reliability engineering experts;
- I&C experts;
- computer services expert.

Experienced personnel are required to perform accurate and complete RCM analysis. Having experienced personnel of each discipline will:

- allow concurrence of analysis;
- ensure completeness of analysis;
- document the collective knowledge of plant staff;
- increase the chance to implement changes by providing strong justification.

Co-ordination of the RCM has to be handled by a project manager with extensive experience with the maintenance programme, who is knowledgeable about the history and operation and who has authority within the plant. The project manager will have to co-ordinate either the internal or external resources to be sure of the coherence of all individual tasks with the overall project. On average, the project manager will have to co-ordinate between ten and twenty people full time or part time.

The project manager during the RCM analysis will also have to draw on expertise from skilled personnel when expert judgement is necessary.

The project manager has to keep to the schedule and the allocated budget. He will be assisted by support personnel for the documentation of the project. In many project organizations an RCM review group or steering committee has been set up. It generally includes the senior manager and all the managers concerned. The scope of activity and responsibility of the RCM review group is found in three areas: technical, interface and implementation.

The purpose of the technical review is to provide guidance and perspective based on the diversity and depth of experience of group members.

The purpose of the interface review is to achieve and promote internal communication of the project's scope and objectives.

The implementation review acts as a facilitator to ensure that changes made as a result of the RCM project are implemented as intended within the organization. It will issue recommendations for training for new PM technologies.

Figure 4-1 shows the RCM project organization for the San Onofre station and Fig. 4-2 shows the organization of the Ginna RCM project team.

4.3. TASK IMPLEMENTATION

The RCM analysis leads to **implementation of new or deletion** of existing PM and monitoring activities. The modifications of the existing maintenance programme may lead to various situations.

-- Duplication of existing PM to similar equipment
  This would imply incorporation of this additional task into the plant's maintenance programme.

-- Change of design
  This ultimate situation will lead to the qualification of the new design, to writing new operating or maintenance procedures and eventually to changing the technical specifications.

-- Implementation of new PM
  The implementation of new PM such as predictive maintenance based on vibration analysis, infrared thermography, or lube oil analysis, for instance, will have several impacts for the plant.

  First, monitoring systems must be acquired if they are not available at the plant, or contracts have to be signed at servicing companies.

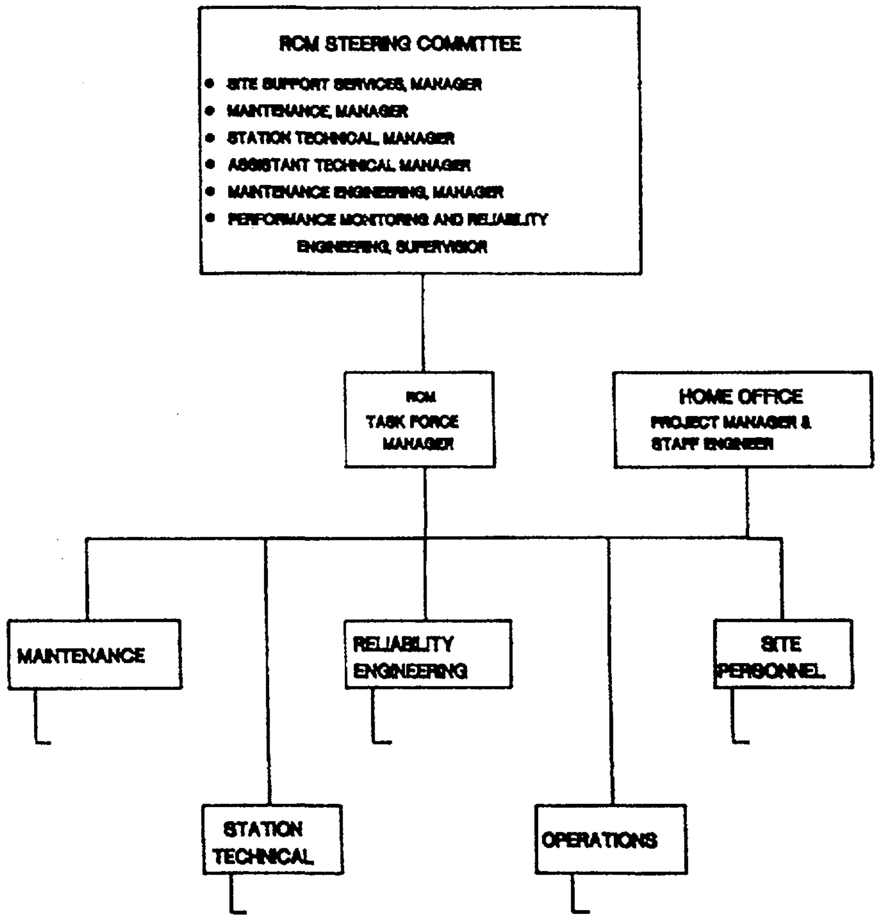


Fig. 4-1. San Onofre RCM project organization.

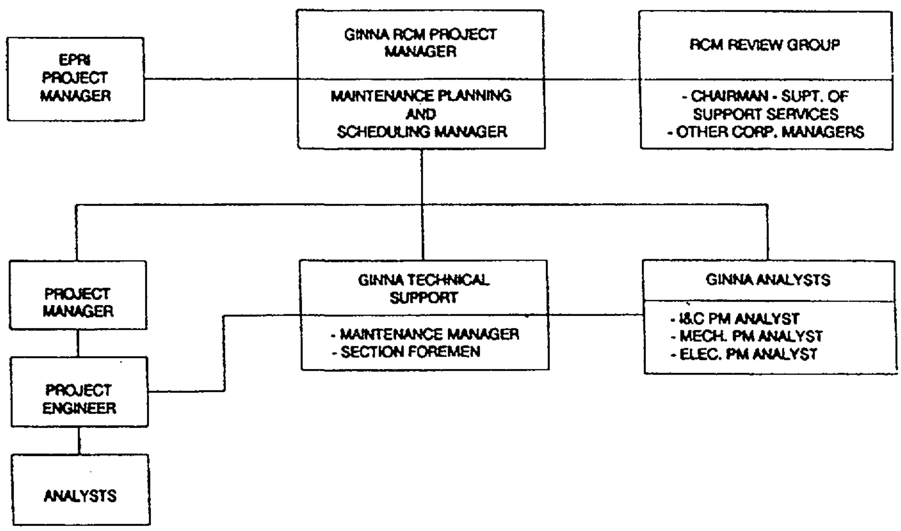


Fig. 4-2. Ginna RCM project organization.

Secondly, the maintenance personnel must be trained to be able to diagnose a degradation of the equipment condition by parameter trending.

Trending will permit a change in the current maintenance philosophy. The data trending requires a database which will integrate all the data available on each component, including the baseline date. When the current data indicate unacceptable trends or abnormal values, the condition reflected by the deviation will dictate the maintenance actions. This situation implies a change in plant culture.

-- Environment Qualification (EQ)
This can be in conflict with the RCM recommendations and these conflicts will require additional review needing extra measures and time.

The key to a successful implementation of the RCM programme relies on the perfect knowledge of the final goals of the RCM, whatever the position of the plant personnel in the organizational chart.

-- Implementation of maintenance history database
In order to measure the effectiveness of RCM, data collection related to maintenance activities will be organized to fit with the RCM analysis. This implies a modification of the structure of the maintenance sheet, a dedicated computerized database to derive performance indicators and also a special training of maintenance personnel which will ease the integration and the acceptance of the new maintenance philosophy.

4.4. RCM LIVING PROGRAMME

The RCM living programme is the structured set of methods and requirements for maintaining the PM programme and the RCM analysis current after the recommendations of the RCM process are implemented.

The objectives of the living programme are:

(1) to monitor indicators of RCM effectiveness;
(2) to ensure that design changes, operating procedure changes and other plant changes are reflected as appropriate in PM programme changes;
(3) to track corrective maintenance experience to confirm that the bases for the RCM recommendations remain valid;
(4) to evaluate the impact on PM activities of new maintenance technologies;
(5) to maintain the RCM documentation current.

Achieving living programme objectives is essential to a successful RCM application. Without them, the PM programme is static and its effectiveness has not been confirmed. Without information feedback and RCM programme updates, the plant staff will lack confidence in the appropriateness of the PM programme activities, and the PM programme will eventually become obsolete.

Although no RCM living programme has yet been fully implemented and demonstrated to be effective, several programmes have been specified and are slated for implementation. Attributes of a potentially successful living programme are as follows:

-- RCM analysis documentation must be thorough and consistent among systems. Computerized databases and an analysis work station are highly desirable to facilitate updates and to ensure accuracy, consistency and completeness.

-- Responsibility and control of the programme must be clearly defined.

-- Reviews and updates must be timely and regularly scheduled.

-- Data on plant changes, procedure changes and operating experience must be easily retrievable and accessible to the persons responsible for the living programme.

-- Open items regarding RCM task implementation must be tracked and closed out through the living programme.

The task of monitoring and measuring RCM effectiveness presents a special challenge. Quantitative measures include trends or absolute values of such parameters as:

(1) maintenance labour and material costs saved;
(2) change in total number of corrective maintenance tasks performed;
(3) change in forced outage rate due to maintenance;
(4) change in safety system unavailabilities.

These measures are not directly tied to RCM effectiveness, so considerable judgement is required to assess RCM effectiveness from these and any other indicators.

5. THE BENEFITS OF RCM

There are many anticipated benefits of RCM to utilities which implement an RCM programme. Some of these benefits can be expressed as or directly related to deferred costs to the utility. Of these benefits, some can be accurately and quickly assessed, while others will be difficult to assess or will take many years to ascertain accurately.

One easily quantifiable benefit that can be quickly ascertained is the savings in personnel, labour and materials cost that can be directly realized by the implementation of the RCM recommendations. This benefit has been estimated by several utilities after implementation of RCM on one or several systems. The average payback period to recoup the cost of the RCM analysis and implementation, considering only the direct savings above, has been three years. Figure 5-1 provides an example of this direct benefit for one RCM system analysis.

Other quantifiable benefits that are anticipated from RCM include improvements in plant availability and scram frequency. They also include improvement in safety system availability. These benefits can be measured only after several years of operation with the RCM recommendations in place. Unfortunately, the relationship between these benefits and RCM will be difficult to establish since many programmes are in progress simultaneously at a plant, and the effects of these other programmes can offset or enhance these benefits of RCM in an unknown way.

Another quantifiable benefit of RCM can be the achievement of some numerical objective which, although not directly related to cost savings, is nonetheless a tangible objective of the utility. An example of such an objective is the achievement of a CM to PM ratio.

Of perhaps more importance to utilities are the qualitative benefits of RCM. RCM provides detailed and accessible documentation of the basis for the PM programme. This documentation is of value to the utility not only because it justifies the current activities, but also because it enables the utility efficiently to update the PM programme over time. Another important intangible benefit is the establishment of an RCM philosophy among the plant staff; that is, the entire maintenance programme will be influenced by the need to perform applicable and effective activities that protect important system functions.

Finally, RCM can help utilities to meet certain programmatic and management objectives. An important example is the optimization of a plant predictive maintenance programme. RCM can provide the rationale for applying predictive maintenance technology to address the most important functional failure modes, thus optimizing the use of this important resource.

Table 5-I is an example of an RCM application which adjusted an existing programme away from a time directed PM basis and towards a condition directed (predictive maintenance) basis.

System Function: **To supply chilled water to containment coolers and maintain normal containment temperatures**

- **500 system components**
- **150 preventive maintenance tasks reviewed**
- **20% of the tasks were changed**
  - **4 preventive maintenance tasks added**
  - **8 preventive maintenance tasks eliminated**
  - **24 preventive maintenance tasks modified**
- **Redirects 325 Mhrs annually**

Fig. 5-1. Sample system results: containment normal ventilation analysis.

Table 5-I. RESULTS FROM RCM STUDIES FOR ONE NUCLEAR PLANT

SYSTEM	RCM RECOMMENDATIONS COMPARED TO EXISTING PM PROGRAMS			
	PMs ADDED	CONDITION-MONITORED TASK IDENTIFIED OR MODIFIED	EXISTING PMs DELETED	EXISTING PMs MODIFIED
- Safety Injection	235	26	392	129
- Salt Water	71	29	260	53
- Service Water	37	6	253	48
- Aux. Feedwater	69	14	355	18
- 125 V DC	58	107	49	55
- Reactor Protection System	131	6	304	16
- Main Feedwater (U-1)	120	55	192	28
- Main Feedwater (U-2)	157	47	155	15

6. STATUS OF SELECTED INDUSTRY PROGRAMMES

6.1. APPLICATION OF THE RCM AT EDF, FRANCE

The existing EDF maintenance programme takes into account the feedback experiences from its standardized units.

The motivations of EDF to evaluate the benefits of the RCM approach are the following:

-- PM/CM ratio improvement;
-- systematic and structured process;
-- cost optimization;
-- qualitative and quantitative use of maintenance history;
-- visibility and traceability of actions and decisions.

To evaluate the benefits of the RCM approach, as described in Section 3.1, the CVCS was selected as a pilot study for the following reason:

-- The CVCS is operating continuously.
-- The CVCS is safety and availability related.
-- The CVCS has a large number of various equipment including valves, pumps, heat exchanges, and sensors.
-- Several parts of the CVCS analysis will be used again for other systems.

The pilot study of the CVCS started at the beginning of 1990. The CVCS was decomposed into eight subsystems:

-- volume control tank;
-- the charging pump;
-- the charging line;
-- injection of the Seal no. 1 of the primary pumps;
-- let down line (demineralization excluded);
-- outlet water from Seal no. 2 of the primary pumps;
-- water supply for the RHR.

For each subsystem, the functions important for safety, production and maintenance were identified, taking into account in particular the results of the probabilistic safety analysis of the 900 MW units.

By using FMEA, the critical functional failure list was completed by July 1990. The final list ranked by the experts from the generation division will be completed by the end of 1990.

The functional partitioning of the critical items of equipment will be completed by the end of 1990 after their validation. Taking into account the various feedback experience (event database, reliability database, Blayais unit maintenance history, and special reports), it was possible to identify the equipment failure rate, the component failure rate, the modes and the causes of the failures of the component and the degradation modes.

This task requires the manual screening of several hundred documents related to the maintenance history. The analysis of the significant failures of each critical equipment item is done by FMECA pump gear reducer.

The maintenance task selection, using logic tree analysis will be completed also by the end of 1990. Figure 6-1 provides a draft of a maintenance task selection sheet for a CVCS pump gear reducer.

The final study for the CVCS was completed during 1991.

A detailed project organization was set to perform the study and is described in Fig. 6-2.

Once the final maintenance tasks provided by the RCM have been validated by experts and compared with the existing maintenance programme, the final decision will be taken by mid-1991 on whether to undertake the analysis of other systems.

An implementation of living programme would induce modifications of the national maintenance programme and, as appropriate, restructuring of the maintenance history inside the plant information management system to measure the effectiveness of the RCM. In addition, according to the EDF experience, the benefits of RCM would be tangible only after a three year period of experimentation at the plant.

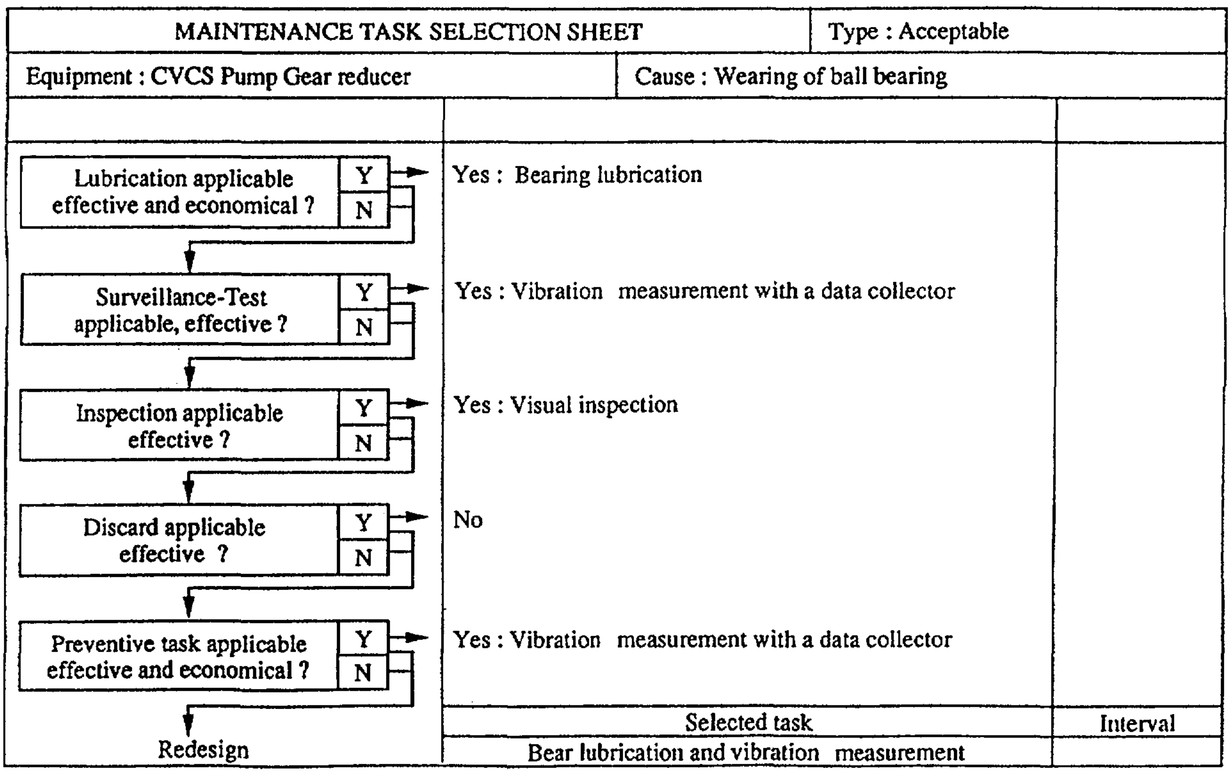


Fig. 6-1. Draft of a maintenance task selection sheet.

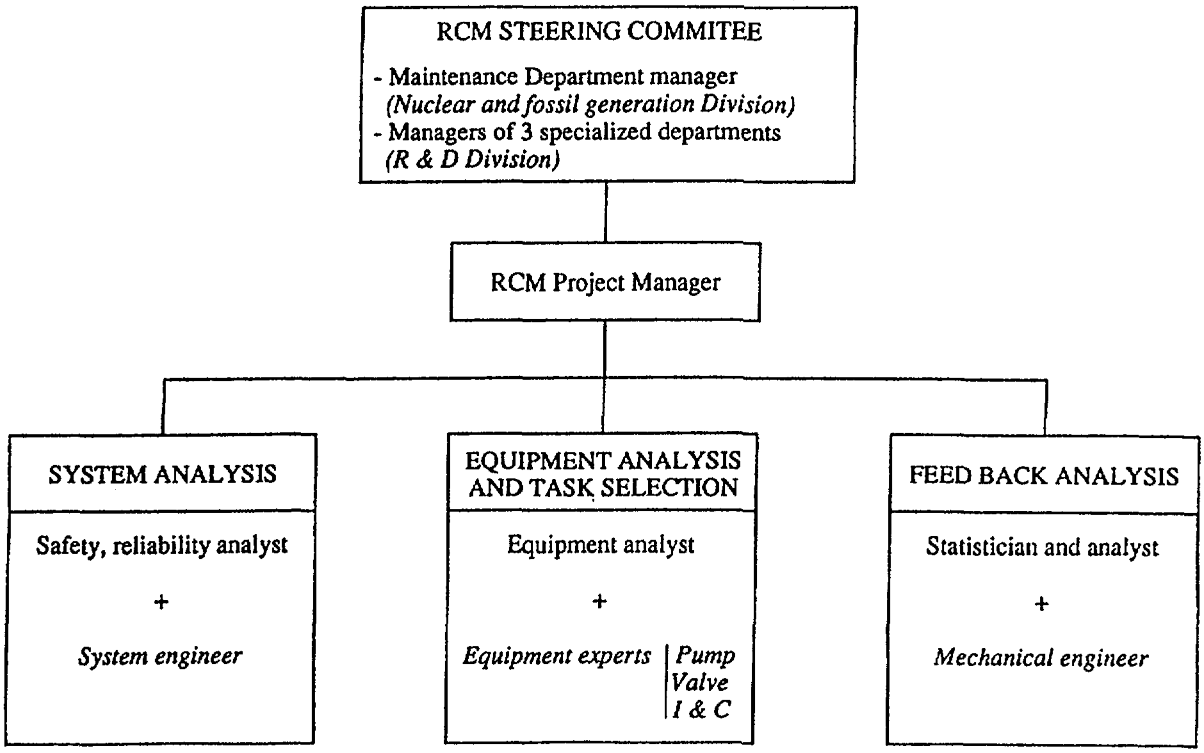


Fig. 6-2. RCM project organization.

6.2. APPLICATIONS OF RCM BY SEVERAL UTILITIES IN THE USA

Immediately following the publication of the RCM pilot study reports for the single system applications of RCM at Turkey Point Station, the McGuire Station and San Onofre Nuclear Generating Station, several utilities in the USA undertook pilot studies of their own.

At the time of this writing, approximately 12 nuclear plants have performed pilot studies on one or several plant systems for the purpose of evaluating the RCM method or for the purpose of addressing a specific maintenance concern for those systems. These applications are generally useful RCM studies, but they do not indicate the commitment on the part of these utilities to an RCM programme or to an RCM philosophy of maintenance.

Some of the utilities in this category are now developing more extensive RCM programmes as a result of their limited studies.

In addition, approximately six nuclear plants are committed to performing RCM analyses on a large number of plant systems. These systems were selected on the basis of their importance to plant operations and safety. The number of systems varies from 8 to more than 20. Each of these plants has implemented or plans to implement the RCM recommendations. Several of these plants have definite plans for an RCM living programme. These plants can be considered to have an RCM programme in place.

Two of the plants in this category are the EPRI demonstration plants - Ginna and San Onofre. Their RCM programmes are clearly documented in their respective EPRI published reports.

Most recently, several utilities have chosen to institute full plant PM Programme Improvement Projects (PMPIP) with RCM as an important element of the PM evaluations. These projects differ in principle from the RCM programme described, because they encompass all significant plant systems and major components.

In most cases, the projects take a hierarchical approach to PM evaluation. That is, detailed RCM analysis is planned for the most significant systems (typically 20 to 30), a reduced scope RCM evaluation is planned for less significant systems, and a traditional PM evaluation using only RCM insights is planned for the least functionally significant systems or component types. These RCM based projects point to an RCM based maintenance philosophy that will influence all activities in the maintenance programme.

Indications are that PMPIP projects are under consideration by a growing number of utilities in the USA at this time.

6.3. THE RCM PROGRAMME OF EPRI

The leadership role played by EPRI has already been referred to in the discussion of the three pilot studies and the two large scale demonstration projects. In addition, EPRI has sponsored the EPRI RCM Users Group (ERUG), an informal group of EPRI utility members who regularly meet for the duration of the large scale demonstration projects to exchange information on RCM technology and to help steer the research efforts of EPRI in the RCM area. This organization was influential in the transfer of RCM technology to a large group of utilities.

In response to the needs of the ERUG members, EPRI has produced several other RCM related products and activities. A database of information from utility sponsored RCM system studies has been assembled by EPRI for use by other utilities to assist in their own RCM studies or to glean RCM insights for limited scope studies. EPRI has also developed a software specification for a microcomputer workstation to assist utilities in performing RCM analysis workshops, at which about 100 utility personnel have received training in the RCM analysis method.

7. STATUS OF RCM TECHNOLOGY

7.1. DEMONSTRATED AREAS

As with any technology, the value of RCM can be stated with certainty only after it has been validated at several levels. First, the analytical steps must yield results that have potential value. Second, the plant staff must be willing and able to perform the analysis and to implement the results. Third, the process must be demonstrated to be cost effective or to have a positive benefit-to-cost ratio.

According to these criteria, RCM has been conclusively demonstrated to yield results that have potential value, and a significant number of utilities have been willing and able to perform the analyses. At this time, however, only a small number of utilities have successfully implemented a large number of RCM recommendations at their facilities. Furthermore, the cost effectiveness and benefit-to-cost ratio are still largely unverified.

With respect to implementation, only several of the more recent programmes have had the plant involvement and management commitment necessary to support substantial changes in the existing PM programmes. This criteria, therefore, is only now ripe for testing. With respect to cost effectiveness, indications are that RCM analysis has had an approximate three year payback period from considerations of savings in working time of personnel and materials costs alone. The more substantial cost savings from improved plant performance can be documented only after several years. Even then, it will be difficult or impossible to link cost changes directly to RCM. Considering intangible benefits, on the other hand, utilities have elected to undertake and continue RCM programmes to get PM basis documentation, a rationale for applying predictive maintenance, a basis for prioritizing PM expenditures and similar benefits.

In summary, the final value of RCM to the industry cannot be determined at this time. There is sufficient evidence to believe, however, that a well focused RCM programme will have a positive benefit to cost ratio for the sponsoring utility.

7.2. AREAS UNDER DEVELOPMENT

Some areas of RCM technology are still under development, and advances in those areas are anticipated over the near term. No mature RCM living programme has been demonstrated, although several are currently beginning or being planned. RCM analysis workstations exist, but a comprehensive workstation employing expert system technology is as yet only on the drawing boards, as described in the next section.

Methods to perform limited scope RCM analyses for less significant systems are being investigated. With strong emphasis on more extensive use of predictive maintenance technologies and rapidly evolving information management capabilities, additional effort to customize the RCM method to better optimize the selection of condition directed PM tasks is anticipated. Finally, as RCM becomes more widely used in the industry, it is anticipated that databases of failure information will be developed which more directly meet the needs for RCM. Specifically, failure and repair information for components (as opposed to items of equipment) will be needed for the selection applicable and effective tasks.

7.3. RCM ANALYSIS WORKSTATION

The RCM experience to date has demonstrated the value of an integrated RCM computer workstation. Such a workstation can help the RCM analyst through all steps of the RCM analysis, would help in documenting the analysis and results, and would support the RCM living programme. The workstation can reduce the labour in (and therefore the cost of) RCM analysis, ensure consistency in format and level of detail among analysts, provide enduring and easily referenced documentation and facilitate later updates and reviews.

Workstations that have been developed so far are database management programmes. Typically, they do not interface directly with plant information systems except through the ability to read files from these systems or write files to these systems. They also contain no artificial intelligence or expert system capability.

EPRI has developed a specification for a more sophisticated workstation code that will support many aspects of an RCM programme, including system selection, living programme, and generic application of RCM results to other plant equipment and systems. The workstation would have some expert system capabilities to assist the analyst at each step.

8. SUMMARY OF DISCUSSIONS AT THE TECHNICAL COMMITTEE MEETING

1. Following the presentations on the application of RCM by EDF and the GINNA RCM programmes in the USA, there was general agreement that the systematic approach prescribed by RCM was a useful tool in determining an optimum maintenance programme.

2. The extent to which Failure Mode and Effect Analysis was performed and the method used prompted much discussion. Participants commented on the comprehensive two stage analytical approach used by EDF for both equipment and component analysis and noted that PSA studies were used together with component reliability data in order to determine critical components and failure modes.

   This was in contrast with a more qualitative approach used at Ginna and San Onofre in the USA. Here there was more reliance placed on local knowledge and existing plant maintenance records in the identification of critical components an failure modes.

   It was noted that the option chosen seemed to have a major influence on an RCM project time and cost. This was evident from the costs outlined by EDF compared with the two USA projects. It was concluded that the difference in benefit arising from these two approaches could not be quantified as no projects had yet accrued sufficient experience. It was generally concluded that the more analytical approach could be more justified for large components and in particular where many similar components are in service as in EDF.

3. Many of the questions raised in the discussion were directed to the justification for embarking on an RCM programme, particularly when compared with examples of successful classical maintenance programmes with good experience feedback and ongoing reviews which resulted in high plant availability factors and falling maintenance costs. Some participants were of the opinion that RCM should be directed to improving nuclear safety and that this should be linked to PSA studies if they have been carried out.

   All of the principle users of the RCM approach represented at the Committee had commercial benefit as the basic objective, i.e. maintenance cost reduction and improvement in availability. However, the projects were conditioned to ensure that existing safety related tasks required by Technical Specifications or other regulatory requirements would be maintained. It was also established by users that as a result of the RCM analysis additional safety critical tasks were identified, these were in addition to improvements to existing safety related tasks and hence improvements to nuclear safety was claimed as a result of embarking on a commercially directed programme.

4. The selection of safety critical components was discussed and in particular the treatment of components that provide a diversity function. It was stated by some users that provided the failure on such equipment was visible to the operator, then this would not necessarily be classified as "critical" unless the failure has a direct effect on safety. IN cases where the failure was "hidden" then in these cases the component would be deemed critical. There was some disagreement over this concept and some participants expressed a view that all safety related items should be critical. The EDF approach used PSA to assess the contribution of each component to the avoidance of the event in order to rank critical components.

5. The estimates given by presenters on the expected return on investment following implementation of an RCM programme prompted much debate. It was considered that general benefits were accruing from other factors e.g. quality assurance programmes, improved training and operational feedback arrangements which would make benefits from an RCM programme difficult to isolate, particularly in the area of improved plant availability.

   It was considered by presenters with an experience of RCM implementation programmes that there were some spin off benefit arising from a general improvement in maintenance work control and increased awareness and interest of staff leading to higher quality work.

   It was generally accepted that the RCM approach could produce a well documented maintenance policy with a clearly stated basis. There were questions relating to the maintenance of such a policy on a "living" programme and in response certain software developments were outlined which would form the basis of a direct interface with work control systems. These would operate to trigger and facilitate further analysis/changes to the maintenance programme as a result of events that were not previously incorporated or when higher than expected levels of component/system failure occurred.

   It was the opinion of all presenters that RCM could be a most useful tool to support Plant Life Extension proposals, proposals to extend intervals between plant shutdowns or used to support proposals for relaxation in statutory maintenance workloads, e.g. Technical Specifications and Maintenance Schedules.

6. One of the discussion points related to the means by which effective maintenance is measured. The ratio of planned maintenance tasks to corrective maintenance tasks (PM/CM) was commonly used as a general indicator and was thought to be useful if used to relate to a particular system or component. It was suggested that perhaps more comprehensive measures should be developed in order that international comparisons could be made. It wa also stated that maintenance should be given a much higher profile and receive more attention at an international level.

7. The use of RCM in the design of nuclear related plant was identified as a useful benefit. The EDF project had not yet been developed to the stage where it could be incorporated into the current construction programme. It

wa stated that this would be the ultimate aim. It was stated that a more immediate benefit could be obtained if the RCM approach was included into the specification of new equipment on existing plants. One particular USA utility has already requested that vendors must carry out RCM analysis on equipment as part of the contractual requirements. This would then require the supplier of equipment to provide an RCM justification for the specified maintenance and spares requirements.

BIBLIOGRAPHY

CRELLIN, G.L. et al, "Use of RCM for McGuire Nuclear Station Feedwater System", EPRI Report NP-4795, September 1986.

HOOK, T.G. et al, "Application of RCM to San Onofre Units 2 and 3 Auxiliary Feedwater System", EPRI Report NP-5430, September 1987.

GAERTNER, J.P., "Demonstration of Reliability Centered Maintenance, Volume 1: Project Plan", EPRI Report NP-6152 Vol. 1, January 1989.

ANDERSON, J.G. et al, "Demonstration of Reliability Centered Maintenance, Volume 2: First Annual Progress Report From San Onofre Nuclear Generating Station", EPRI Report NP-6152, Vol. 2, September 1989.

EDGAR, E.C. et al, "Demonstration of Reliability Centered Maintenance, Volume 3: First Annual Progress Report From Ginna Nuclear Power Station", EPRI Report NP-6152, Vol. 3, September 1989.

NOWLAN, F.S. et al, "Reliability Centered Maintenance", prepared by United Airlines, Report No. A066-579, December 1978.

TAYLOR, G.M., "San Onofre: Using RCM to Optimize Preventive Maintenance", Nuclear News, November 1989.

MATTESON, T. et al, "Reliability-Centered Maintenance Presentations", Sixth International Maintenance Conference, Institute of Industrial Engineers, 1989.

INSTITUTE OF NUCLEAR POWER OPERATIONS, Good Practice MA-319. "Reliability-Based Preventive Maintenance Methodology", March 1990.

NICHOLAS, J.R., "Applying Predictive Maintenance Techniques in a Reliability Centered Maintenance Program", 16th Inter RAM Conference, Hershey PA, USA, May 1990.

Annex

PAPERS PRESENTED AT THE TECHNICAL COMMITTEE MEETING

RELIABILITY CENTERED MAINTENANCE (RCM)
AT SOUTHERN CALIFORNIA EDISON

N.B. BLOOM
Southern California Edison Company,
San Clemente, California,
United States of America

Abstract

The paper discuss the fundamentals of the RCM programme at Southern California Edison Co. San Onofre NPP. Different steps in the implementation of RCM are described, together with the review of information (documentation and data) needed for the analysis. The RCM decision logic and performance of FEMA is described in detail. Implementation of the RCM recommendation is discussed. Direct as well as indirect benefits of the RCM programme implementation are detailed.

The objective of a preventive maintenance program is to maintain equipment in a satisfactory condition for normal or emergency use based on predetermined criteria. It is important to recognize that a maintenance program cannot correct deficiencies in the inherent safety and reliability levels of the equipment. The maintenance program can only prevent deterioration of such inherent levels. If the inherent levels are found to be unsatisfactory, design modification is necessary to obtain improvement.

The RCM philosophy was first developed in the airline industry in the early 1960's and was called Maintenance Steering Group (MSG) Logic. The concept established a systematic evaluation approach for developing or optimizing a maintenance program.

This paper describes the fundamentals of the RCM program being implemented at Southern California Edison's San Onofre Nuclear Generating Station. The RCM program outline as

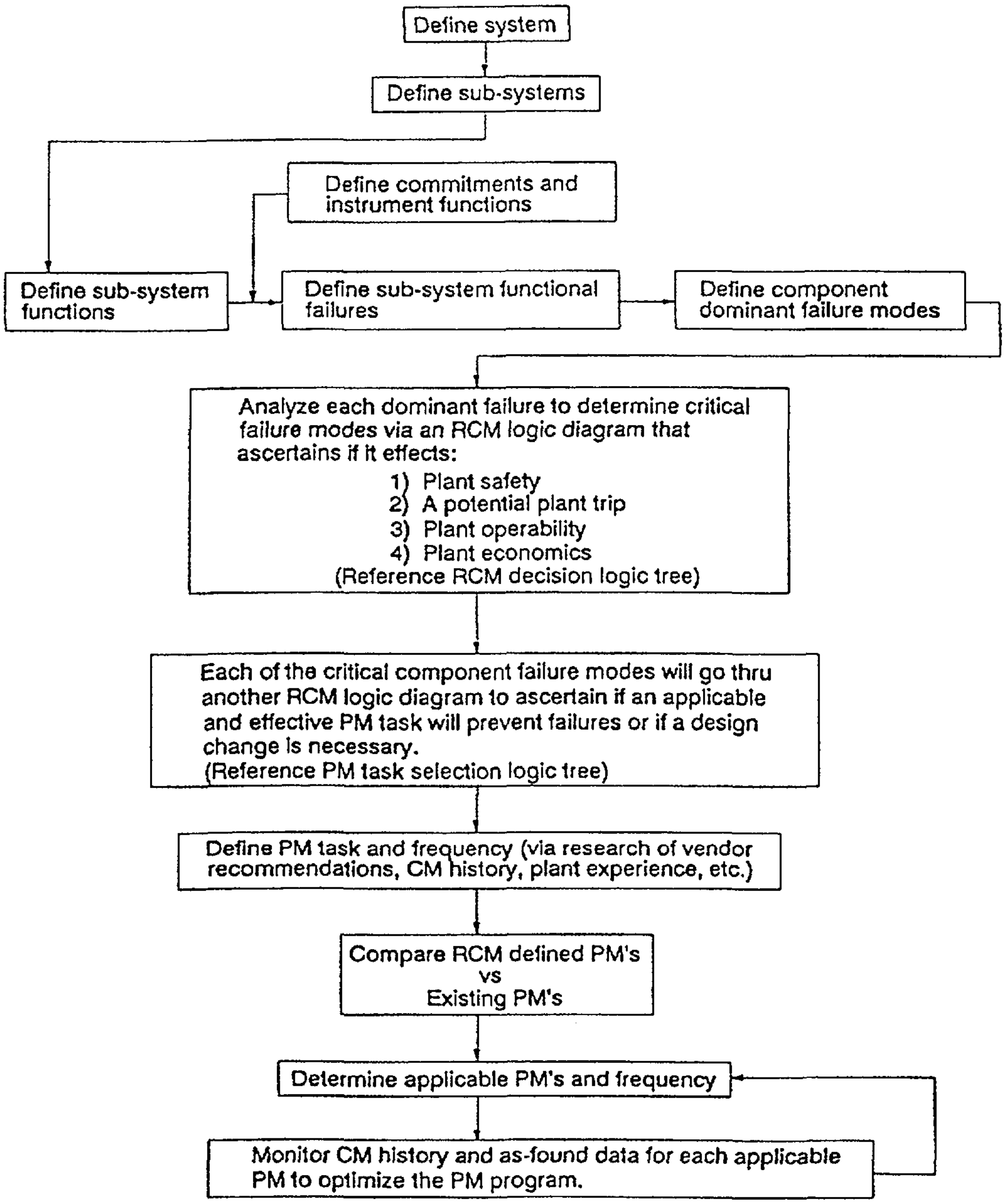


FIG. 1. RCM flowchart.

shown in fig 1, provides the basis for an RCM analysis that maximizes station productivity by applying a rational basis for deciding how to utilize limited maintenance and operations resources.

The RCM analysis allows the maintenance program at San Onofre to evolve from a concept based primarily on "Vendor

Recommendations" to one based on more prudent fundamentals of system and function analysis and the subsequent operability effects on the plant.

The San Onofre approach to RCM enhances its implementation through the methodology of the program, the selection of task force personnel, and the straightforward approach of the analysis. The program provides greater comprehension by incorporating a higher degree of objective decision making and less subjective decision making. A finite distinction of PM's is identified according to economics, commitments, or functional criticality. As such, should implementing programs require a reduction of the workload, a more prudent decision can be made of deferrable vs. non-deferrable PM's as a result of having their basis readily at hand.

The final PM program is defined as an overall San Onofre plant PM program recognizing and documenting the work of other disciplines such as Operations and Engineering rather than being a "Maintenance Only" PM program.

A primary goal of this RCM program is also targeted at minimizing the amount of mitigating actions or other activity disruptions incurred by control room operating personnel.

The work is performed by in-house personnel with actual "hands on" experience such as journeymen, I & C technicians, planners with PM experience, and cognizant systems engineers for review and approval authority.

A work plan is used for identifying and tracking specific RCM system milestones and is divided into a work flow matrix. This approach provides the ability to monitor the project status and assign project responsibilities commensurate with individual skills which is a necessity for a quality oriented and timely completed program.

Prior to commencing the RCM analysis, a review of all pertinent data relative to the respective system is conducted. It is important that appropriate documentation exists for all aspects of the program. The primary documents used are the P&ID's, FSAR's and system descriptions. Other documents such as departmental procedures, operator logs, manuals, lesson plans, EQ packages, I.E. Bulletins, etc. are also used as required.

Plant systems are frequently composed of a large number of components which serve a variety of functions to support the total operation of the system. Partitioning into subsystems refers to establishing groupings of components which are related to performing a particular function within the system. The analysis can be more readily and accurately accomplished by compartmentalizing a large system into subsystems.

Examples of subsystems defined within the Circ Water system include the following: circ water pumps, main condenser and discharge, traveling screens, screen wash, fish handling, sodium hypochlorite, amertap, intake/outfall, and TPCW heat exchanger (tube side).

Determining subsystem functions is an important step in the RCM analysis. Function definitions describe what the system or subsystem must accomplish. The functions of each system are determined by reviewing plant system descriptions, P&ID's, FSAR's, procedures, tech specs, and design basis documentation. The purpose of defining the subsystem function as part of the analysis, is to further enable the emergence of specific component failure modes and their effects on system operability.

A functional failure describes how a function may be lost. It depends only on the stated function and a knowledge of how the system works. Functional failure determination does not include any decisions based on component configuration or component failures.

Failure modes are specific to components. The failure modes are those that are "dominant" or most likely to occur. They do not include "implausible" or unrealistic failure modes. Failure modes are the types of failure or ways a component can fail.

After the dominant component failure modes are identified, each failure mode is analyzed for its plant effects in accordance with an RCM Decision Logic Tree as shown in Fig 1A. The logic will ascertain if...

- o - a hidden function exists.
- o - the failure has a direct adverse effect on operating safety.
- o - it has an adverse effect on plant operating capability.
- o - it can cause a turbine or plant trip.
- o - it is an economic consideration only.

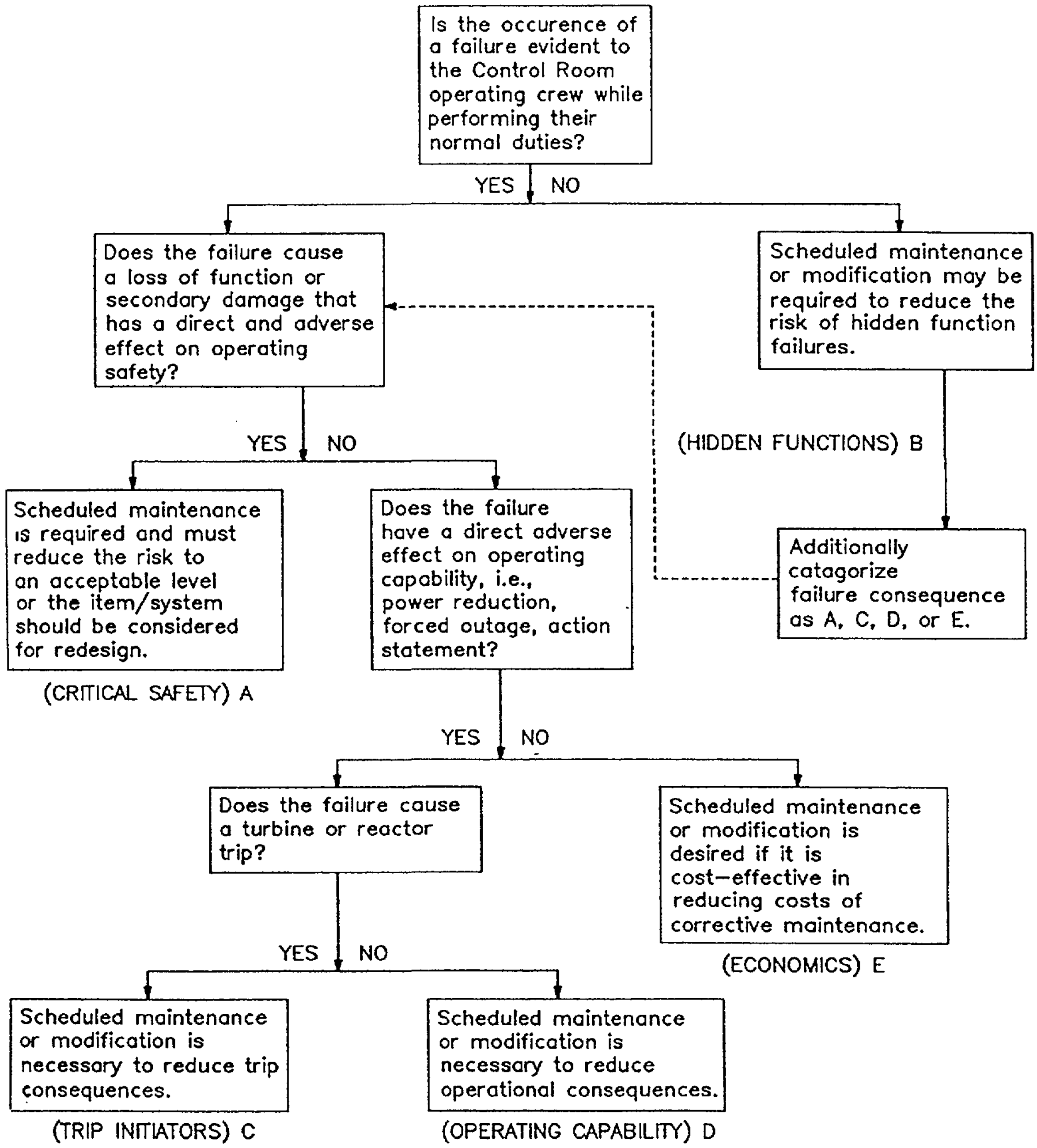


FIG. 1A. RCM decision logic tree and effects analysis.

The aforementioned analysis information is compiled into a "Failure Modes and Effects Analysis" (FMEA) worksheet as shown in fig 2.

Hidden functions are defined to circumvent system problems if the failure of a component is not readily evident to the

System Description: ______________ Date: ________ Analyst: ______________

Sub-System Description: ______________ Sheet __ of __ Cog. Engineer: ______________

Sub-System Function	Sub-System Functional Failures	Dominant Component Failure Modes (Incl. Comp. Desc.)	Component I.D.	Define System Effects	Define Plant Effects from the Logic Tree & Effects Diagram (ie.. Category= A,C,D or E) Describe all A, C or D Effect Categories	Critical Yes/No Yes = A, C or D
1. xxxxxxxxx xxxxxxxxx xxxxxxxxx.	1.1 xxxxxxxxx xxxxxxxxx xxxxxxx.	1.1.1 xxxxxxx xxxxxxx xxxxxxx xxxxxxx	xxxxx xxxxx xxxxx xxxxx	xxxxxxxxxxxxx		
		1.1.2 xxxxxxx xxxxxxx	xxxxx xxxxx xxxxx xxxxx	xxxxxxxxxxxxx		
	1.2 xxxxxxxxx xxxxxxxxx	1.2.1 xxxxxxx xxxxxxx xxxxxxx	xxxxx xxxxx	xxxxxxxxxxxxx		
		1.2.2 xxxxxxx xxxxxxx xxxxxxx	xxxxx xxxxx	xxxxxxxxxxxxx		
2. xxxxxxxxxx xxxxxxxxxx xxxxxxxxxx xx.	2.1 xxxxxxxxx xxxxxxxxx	2.1.1 xxxxxxx xxxxxxx	xxxxx xxxxx xxxxx xxxxx	xxxxxxxxxxxxx		
		2.1.2 xxxxxxx xxxxxxx	xxxxx xxxxx	xxxxxxxxxxxxx		
	2.2 xxxxxxxxx xxxxxxxxx xxxxxxxxx	2.2.1 xxxxxxx xxxxxxx xxxxxxx	xxxxx xxxxx	xxxxxxxxxxxxx		
		2.2.2 xxxxxxx xxxxxxx	xxxxx xxxxx xxxxx	xxxxxxxxxxxxx		

FIG. 2. Failure modes and effects analysis (FMEA) worksheet.

operating crew. Either a PM or potential design change may be required to mitigate failures of components with "hidden functions". The PM Task Selection Logic Tree provides a decision process for handling hidden functions when no applicable or effective PM exists. Also included in the analysis is a hidden function summary sheet which highlights either economic or plant effecting conditions involving components which do not employ any means of indicating failures to the operating crew.

Components that are determined to have an effect on plant operability as determined from the FMEA and the Logic Tree and Effects Analysis are categorized as "critical" components. Those components included in the FMEA but not determined to be "critical" are reviewed for being economically significant. Those components that have other commitments associated with them as shown in fig 3, are classified as commitment components. They may also be categorized as "critical" based on the FMEA.

	Criteria	Code
1.	Component is tested under a Technical Specification Surveillance (SV).	= TS
2.	Component is Tested under the EQ program.	= EQ
3.	Component is required to be tested by the IN-Service Testing Program.	= IT
4.	Component is insured by NML / NEIL and is required to be tested by Maintenance under the Station Insurance Procedure.	= IN
5.	Component has other External / Internal requirements for a PM to be performed (ex..SOCR, State, OSHA, NRC, IE Bulletin, NUREGS, ANSI, etc..).	= OT
6.	Component operation may have an Environmental Impact associated with Fluid or Gaseous releases.	= EI

FIG. 3. Commitments.

Components not economically justified, i.e., those that are economically insignificant are candidates for "Run-to-Failure". Fig. 4 shows the component PM prioritization hierarchy. Fig's. 4A and 4B respectively show the PM initiators and PM program composition.

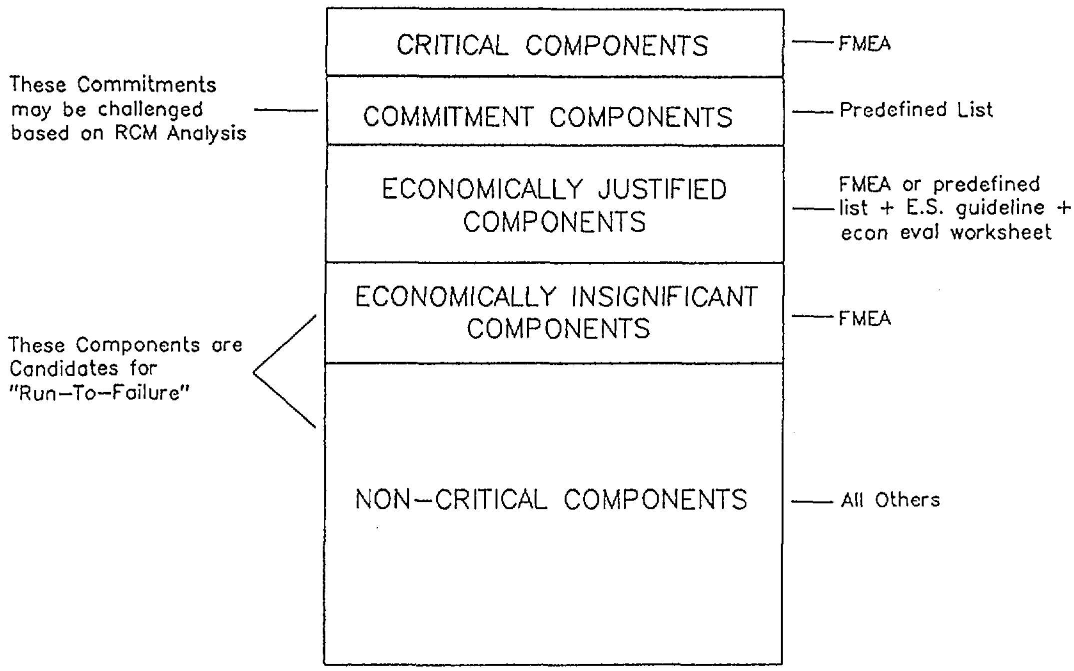


FIG. 4. Component PM prioritization.

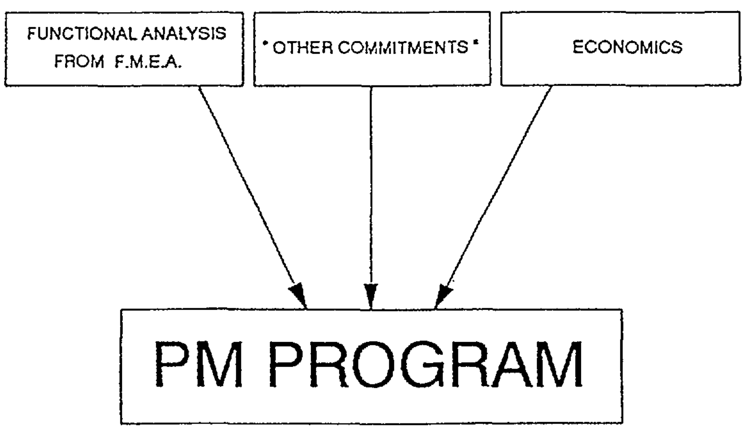


FIG. 4A. PM initiators.

The Maintenance Program will consist of PM's that are either added, retained, modified, or deleted as determined by the RCM analysis and based on one or more of the following three criteria:

I) PM's that ensure the operational viability of the plant, i.e. "Critical" components.

II) PM's that are economically justified.

III) PM's for "Commitments" such as EQ, Tech Specs, I.E. Bulletins, etc.

FIG. 4B. PM program composition.

All component PM's including those in the current maintenance program (other than commitments or those reconfirmed per the RCM analysis as being critical components) will be reviewed for classification as "Economically Significant". If they do not fit the E.S. guideline or if they do fit the guideline but are not justified IAW the Economic Evaluation Worksheet, they will be considered for Run-to-Failure status.

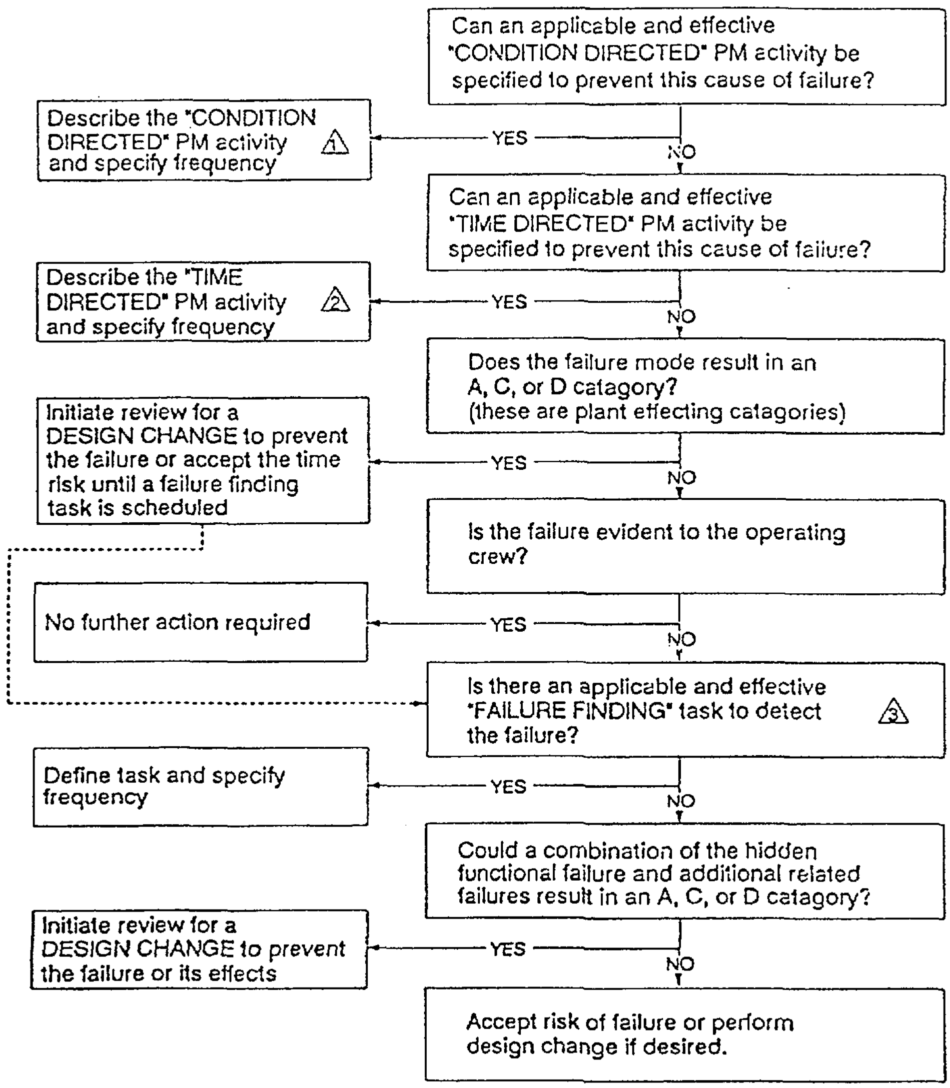
All of the previous work efforts in the RCM analysis process were accomplished to highlight functionally critical components and economically justified components so that applicable and effective PM's could be specified for them. This eliminated all other components for PM consideration (except commitment components). In fact, all others are candidates for Run-to-Failure status.

The PM Worksheet analyzes each credible cause of the respective dominant failure mode for an applicable and effective PM. Only critical and economically significant components are analyzed. Economically significant components are further evaluated IAW the Economic Evaluation Worksheet. It is important to understand that only credible failure causes are defined. One can come up with a list of dozens of postulated causes which for the most part are not relevant. A thorough understanding of the equipment by production knowledgeable personnel is necessary to determine credible failure causes.

If a component is deemed to be economically significant, based on CM history, then those credible failure causes as researched from CM history are specified. It is important to keep in mind that the economic evaluation is based on an analysis of the costs which may be incurred by not including the component in the PM program versus the cost of performing a PM task. It does not necessarily include all postulated failures. A tangible savings should be evident in order to include a PM task based on economics.

Critical components as defined per the FMEA, and Economically Significant components identified per the E.S. guideline as having a high restoration cost, excessive downtime, or a potential "A, C, or D" category, need to be analyzed for all credible failure causes applicable to preventing the specific consequences of failure.

After the credible causes are defined, the PM Task Selection Logic Tree per fig 5 directs the analyst to specify a "condition directed" task as the first choice of option for a PM. In the absence of a "condition directed" task or if an age-relationship to failure is evident, a "time directed" task is specified. Depending on whether or not a preventive task (condition or time directed) is applicable and effective, a possible design change may be required if the component is classified as A, C, or D. The PM Logic Tree also analyzes for failures that are not evident to the operating crew and defines "failure finding" tasks as appropriate.



1 typical "condition directed" PM tasks include vibration monitoring, and oil sampling.
2 typical "time directed" PM tasks include inspections, calibrations, overhauls, and replacements.
3 typical "failure finding" tasks include operability or surveillance tests which in fact are time directed but are not preventive in nature.

FIG. 5. PM task selection logic tree.

Perhaps one of the most important aspects of the program is the identification of applicable and effective PM tasks. In order to be applicable and effective, the proposed preventive task must be such that it can be appropriately applied to the component. It must be appropriate for addressing the credible failure cause. The preventive task must offer some degree of assurance that it will minimize the exposure to failure of the component. The selected task, based on a principle of prudent judgement by knowledgeable individuals, should have a relative degree of pertinence and likelihood that it will prevent the occurrence of the failure mechanism.

Some of the means by which credible failure causes and appropriate PM tasks are identified include a review of vendor manuals, CM histories, current work tasks, and first hand experience by knowledgeable individuals. In some instances it is appropriate to accept the fact that an applicable and effective preventive task cannot be identified in which case a failure finding task may be specified.

When establishing appropriate task frequencies, the respective operating environments must be taken into consideration. Components operating in harsh environments such as heat, humidity, dust, dirt, salt spray, etc., may require more frequent preventive maintenance activities. CM histories will provide insight on components which may be adversely effected as a result of their environment.

To ensure a comprehensive review of the task selection phase of the program, Station Technical approval and signoff is required for all final PM recommendations.

The RCM analysis of instruments is handled with a separate logic since many instruments do not have specific system functions. Consideration must also be given to the fact that the program is a "living" program and is subject to change as experience dictates. New CM history trends, newly identified failure modes, new technical data, etc., may invoke changes to the program at any time.

Once the PM's are defined, they are compared to tasks in the current PM program. The final PM program will show which tasks were deleted, added, modified in scope, or changed in frequency. While certain "hard" commitments cannot be changed without a formalized approach, the RCM analysis will nevertheless provide the justification to pursue a formal request for deleting, modifying, or escalating the frequency of PM's associated with those components.

The final PM summary as shown in fig 6, will specify all tasks required for the preventive maintenance program of the respective system regardless of which department is responsible for the task. For example, the entire preventive maintenance program for the Circ water system will be identified which includes tasks performed by Station Technical such as vibration monitoring analysis, and tasks performed by Operations such as monitoring motor bearing oil levels on a daily basis.

The second general phase of the PM program after initial definition of the specific PM task and frequency is to monitor that frequency for potential escalation or de-escalation if

PERFORMED BY: ______________________ APPROVED BY: ______________________

########- TSKPRN -################ - INFORMATION FROM RCM FILE - FOR: CIRC / PUMP - #######

EQUIPMENT ID / FUNCTIONAL DESCRIP.	WL TASK NUMBER / PROBLEM DESCRIPTION	TYPE	FREQ/INTVAL	HARD COMMIT (TS/EQ ETC..) LIST CODES:	RCM REQUIREMENTS TYPE FREQ/INT	TASK CHANGES ? MARK WITH AN X: ADD	DEL	FREQ	RESPONSIBLE DEPARTMENT: STT/MAD ETC..	FINAL FREQ / INTVAL
S21401MP115 "NML" CIRCULATING WATER PUMP (E)	37 INTERNAL INSPECTION	PM			D R 1	C			MAD	R 1
	10005058000 OVERHAUL PUMP (NML INSPECTION REQUIREMENT)	PM	R 3	NML AR	D R 4			X	MAD	R 4
	* 10050657000 (LIST) COMPONENT OIL SAMPLE. THIS RM IS PART OF THE PREDICTIVE	PM	Q 1	NML Q 1	D Q 1				MAD	Q 1
	30000652000 INSPECT ANODES AND REFERENCE ELECTRODES FOR THE OUTLET AND INLET	PM	R 1		D R 1				MAD	R 1
	30044009000 MOTOR OVERHAUL AND INSPECTION	PM	R 3	NML AR	D R 4			X	MAD	R 4
	* 30349001000 (LIST) CLEAN AND INSPECT MOTOR FILTERS	PM	M 1		D M 1	M			MAD	M 1
	57 MONITOR MOTOR BEARING OIL LEVEL				D D 1				OPS	D 1
	17 VIBRATION ANALYSIS OF MOTOR & PUMP				D Q 1				STT	Q 1
	10001711200 THERMOGRAPHIC INSPECTION OF MOTORS	PM	AR	NML A 1	D A 1	M			STT	A 1
S21401MP116 "NML" CIRCULATING WATER PUMP (W)	38 INTERNAL INSPECTION	PM			D R 1	C			MAD	R 1
	10015058000 OVERHAUL PUMP (NML INSPECTION REQUIREMENT)	PM	R 3	NML AR	D R 4			X	MAD	R 4
	* 10050657000 (LIST) COMPONENT OIL SAMPLE. THIS RM IS PART OF THE PREDICTIVE	PM	Q 1	NML Q 1	D Q 1				MAD	Q 1
	30010652000 INSPECT ANODES AND REFERENCE ELECTRODES FOR THE OUTLET AND INLET	PM	R 1		D R 1				MAD	R 1

* * The final program not only captures the required Maintenance division tasks but also captures those tasks performed by other departments which were identified by the RCM functional analysis to be important for ensuring a thorough maintenance program. * *

FIG. 6. San Onofre Nuclear Generating Station Units 1, 2 and 3: RCM summary report by system/subsystem.

experience warrants it. A five point rating system will be used which requires the craft to observe the equipment's function as it pertains to the PM's objective. The evaluation is directed toward the condition of the equipment function directly effected by the performance of the PM. This feedback mechanism will be used to direct maintenance to perform an analysis of the component for determination of an optimum frequency.

In summary, RCM is an organized and documented common sense approach for optimizing a maintenance program based on system functionality. It incorporates specific plant experience and identifies potential failure modes based on the use of a Failure Modes and Effects Analysis. RCM provides the justification for accepting non-critical failures after the consequences of the failures are well understood. As a result of RCM, a more efficient, economical, and plant effective PM program will be realized.

RCM is the focal point for numerous peripheral programs. In addition to the obvious benefits the RCM program affords, several other significant benefits are as follows:

- o - The RCM analysis will provide justification for challenging specific commitments.
- o - A spare parts optimization program can be formulated.
- o - RCM provides an integration of the overall preventive maintenance program on a plant basis rather than on a department basis.
- o - A viable plant specific reliability program can be established based on the RCM database.

- A more prudent approach for handling "across the board" PM's can be evaluated. For example, when an I.E. Bulletin specifies establishing a task for all similar valve types, a process of selectivity may be possible for excluding the task on the non-critical valves as determined by the RCM analysis.
- The necessity for plant/component design changes will become more evident as a result of the RCM analysis.
- The RCM program provides the cornerstone for a PM program basis document.

PROCEDURE FOR THE ARRANGEMENT OF THE RELIABILITY CENTERED MAINTENANCE (RCM) ACTIVITY AT THE PAKS NUCLEAR POWER PLANT

Z. KISS, K. TIMAR
Paks Nuclear Power Plant,
Paks, Hungary

Abstract

The use of the RCM approach for optimizing maintenance of technological systems is proposed. Details for the supervision of the system, as well as the evaluation of the system elements are described. The evaluation of the state of the system as a whole was performed to determine influence of individual elements. For each of the individual elements, positive or negative influence to the system capability is detected.

1. INTRODUCTION

We decided here that we spread RCM methods and apply them to the supervision of the state of technological systems.
It has several advantages. This way we can obtain information about the following:

- the elements of the system
- each section of the system
- the whole system

So far we have done the supervision of the cooling system of condenser.
We are starting the supervision of the emergency cooling system and have prepared the programme for checking the fire fighting water system and district heating system.
Preparations for supervising the secondary systems are in process.
We came to the conclusion that the state of all the technological systems can be checked on basis of the block diagram shown in figure 1.
This way a supervision takes quite a long time (1 - 1,5 years) but the profit gained makes it worthy.
We founded a separate department named "State supervision Department" which is in charge of steering the supervisions and controlling the utilisation of them in order to ensure the economicalness and security of the supervisions.

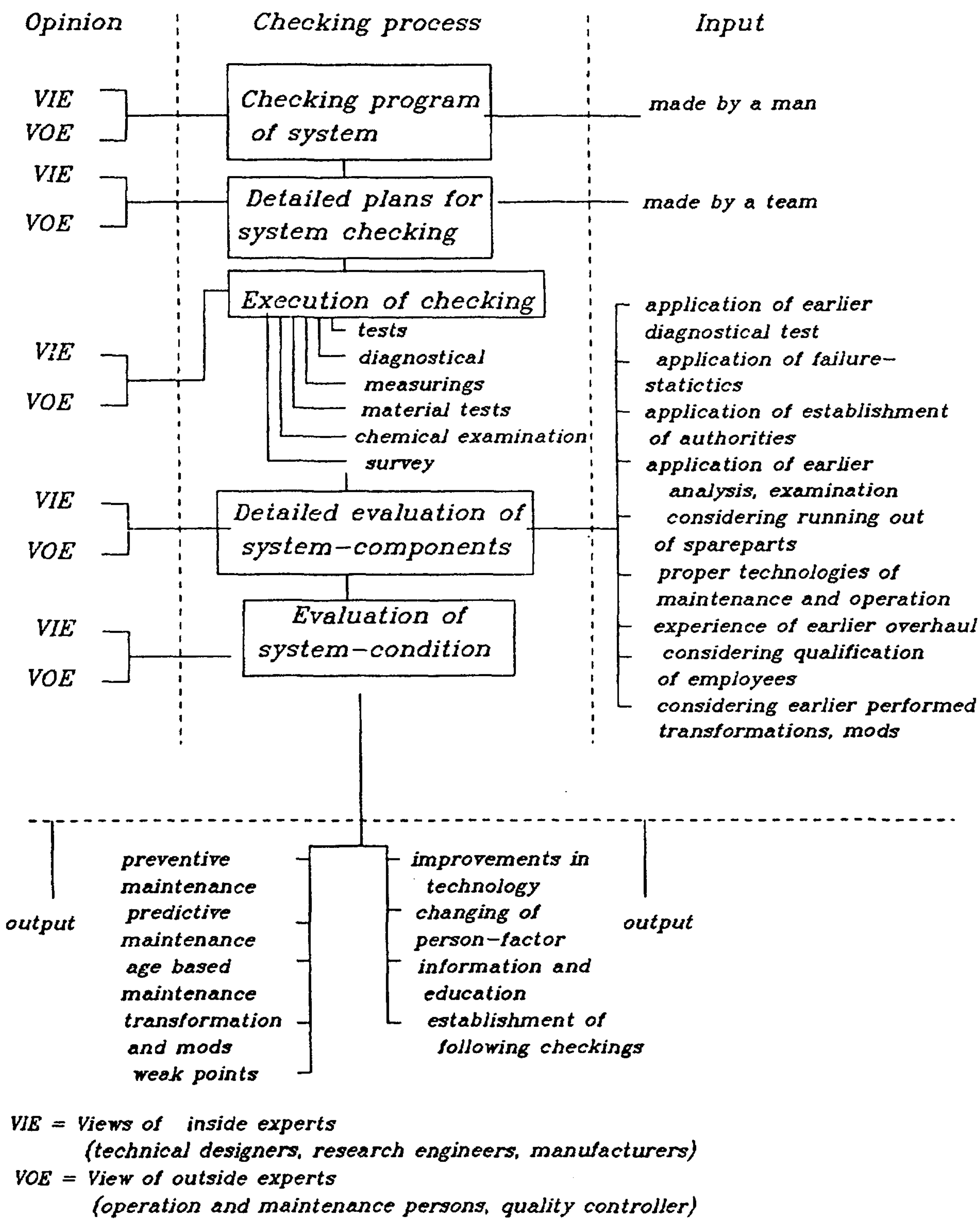


FIG. 1. System checking in the Paks Nuclear Power Plant.

Further we intend to demonstrate the supervision of the condenser's cooling system which has already been accomplished. It is going to be done on basis of figure 1. and emphasising the general conclusions.

2. PROGRAMME FOR SUPERVISION OF THE SYSTEM

The programme was written by a person working in operation and having an extensive comprehension of NPP processes.
The programme contained the following:
- the investigations concerning all elements of the cooling water system
- some special investigations to be done on some elements

The programme is not an actual plan, it only outlines the tasks to be done.
The supervision did not cover the duly-regulated system elements as a rule (e.g. coolant pumps) but the data available concerning these elements and the results of earlier tests have been integrated into the evaluation.

The programme has been revised by experts inside and outside the NPP. On the basis of the report made by these experts the final programme has been made. It is approved by the chief engineer in charge of maintenance.

3. DETAILED PLANS FOR SUPERVISION

On the basis of the programme a group of max. 5 persons made the detailed plans for the supervision. In this plan the tasks to be done were determined very exactly for each element:
- what to do
- what tools to use
- how
- who is supposed to be there (persons from outside and inside)
- how to record the results
- miscellaneous

E.g. concerning an element of the cooling water system, the 36oo mm diameter pipeline which is not covered type:

a, determining the degree of incurvation between two supporters:
- for two supported pipe sections
- at general overhaul; in case of empty and full pipelines
- by geodetic methods
- at the middle between two supports, measuring the distance between the ground level and the underside of the pipe

- the following persons are supposed to be present: designer from outside, delegates from operation and maintenance, own QA expert
- recording the results: filling in a table prepared in advance
- certifying: official minutes

b, measuring the wall thickness

- at determined places chosen on the basis of fluid mechanical aspects or other aspects also unfavourable: at four points of the cross-section
- done by outer testers, at general overhauls, with empty pipes
- with ultrasonic testing device
- prepared for surface testing
- the following persons are supposed to be present: own tester, own QA expert
- recording the results: input of the measured values belonging to the points indicated on the cross sectional drawing
- cerfification: official minutes about material testing

c, ocular inspection from the outside and inside

d, investigation of the corrosion state

e, investigation of the expansion elements

f, chemical and biological analises of the crust

other

We planned investigations made by video-cameras or endoscopes for small diameter pipes. We planned insulation tests for pipes under the ground to be done by devices operated on the surface. Where we found the insulation faulty we ordered the opening up. We made a similarly detailed plan for all the system elements (armatures, devices, reinforced concrete hot water channels, locks, etc.),
The detailed plans were modified according to the opinions given by outside and inside experts.
The final plans were approved by the head of the State Inspection Department.

4. ACCOMPLISHMENT OF SUPERVISION

Executing the tasks described in the detailed plans was scheduled to be done during the general overhaul or to periods not belonging to it but in a way which would hamper the operation and other normal activities in the least degree.
(Certainly we did not always manage)

The opinions of outside experts were taken into consideration at each test - because they have different aspects and attitudes.

The planned tests concerning the cooling system were executed only 95 % - owing to objective circumstances. There were cases, however, when the newly emerged conditions necessitated a wider range of tests.

5. DETAILED EVALUATION OF THE SYSTEM ELEMENTS

For the evaluation of the state of the particular elements the data and experience gained during the tests and the data indicated as INPUT on figure 1. were used.
The largest problem during the evaluation was the appropriate systematization of the many and different data. For the condernser's cooling water system this was done manually. On the basis of the experience accumulated here there is a computer system being elaborated, which will be employed with the other systems.

We arrived at new and important conclusions from the evaluation of the state of the particular elements for the condenser's cooling water system. Some of them are listed herebelow:

- the diagnostic methods used so far for the cooling water pumps proved to be satisfactory for the long term to handle the state of the pumps and to execute the necessary interventions.
- shaping the ground-water and seepage observing wells for handling the state of the reinforced concrete hot water channel

- on the basis of the evaluation of statistics concerning failures and relying upon maintenance technology we could determine e.g. for armatures:

- which armatures are to be checked every year or even more frequently

- which armatures are to be left without any intervention, but here it is necessary to replace them each 5 or lo years without repairing (it reduces the costs of maintenance)

- For the 36oo mm diameter pipeline mentioned in point 2 the test showed that the ageing of expansion elements will occur faster than planned and that the emptying of the pipeline in summer should be given full attention and that the rollers for the movable supports are to be re-adjusted.
- As regards the spare parts here there are two interests which contradict to each other. The manufacturer tries to sell as many spare parts as they can (stipulations in the user's manual) but the operator tries to minimize the quantity of work to be done. This way there can be spare parts accumulated for elementes which did not need any repair but it can also happen that there are not enough spare parts where it was not stipulated in the user's manual.
- The test also showed that the operational manuals need modifications in connection with some system elements and that the information and training given to the operational and maintenance staff should be improved.
- The test also showed that there is no appropriate maintenance technology for some system elements - owing to their construction. Here there is a need to modify the construction.
- Miscellaneous

6. EVALUATION OF THE SYSTEM'S STATUS

We consider the evaluation at system level very important because here the individual system elements are subordinated to the function of the system.
It determines what interventions are needed for a system to make it able to operate in the same good state as the orginal or at least approximately well for the long run.
When examining the system it is highly important to know its weak points and to handle them accordingly.

The evaluation at system level was done in a way that we determined how the individual elements influence the whole cooling water system (in positive or negative way).

This test is 9o % objective as it is based on actual inspections on the individual elements, however, it is subjective lo % owing to lack of knowledge at the present level of technical knowledge. We think the following things can be answered only on basis of a system level evaluation (output indications on figure 1.):

- preventive maintenance
- predictive maintenance
- maintenance dependent on lifetime
- necessary modifications, changes
- weak points
- technical development
- changes in human factors
- information, training
- determining the following supervisions
- yearly correction of the determined trend

a, Preventive maintenance

Eliminating the deficiencies discovered during the tests in the following order:

- first the deficiencies influencing the whole system
- secondly the ones influencing the individual elements

Further more attention should be given to them to avoid repeated occurence.

b, Predictive maintenance

It is suitable where some changes can be determined in measuring numbers or in case of determinable quality changes. E.g. for the pipelines the trend of the annual wall thinning can be determined on basis of wall thickness measurements. This way we can schedule the time of pipeline replacement - before the failure could occur. Or e.g. there is experience gained during several years concerning the time of deterioration of seals. This way we can change the seal before it actually deteriorates.

The fault prevention is done in the following way here, too:

- first the things influencing the whole system
- secondly the ones influencing the individual elements

Further the cycles of replacements are to be given more attention.

c, Maintenance depending on lifetime

Preventive maintenance includes both predictive and lifetime-dependent maintenance. Why I included them into different points is that they both have different significance in the system-level tests.

Lifetime dependent maintenance means that we take the fact into consideration that the equipments are ageing and there is more and more need to maintain them. It has to be taken into account when we determine the range of maintenance and the spare parts .
It is also taken into consideration according to the following:
- first the ones influencing the whole system
- secondly the ones influencing the individual elements

Further we aim at observing the increments of these and and their planning.

d, Technical development
With the system tests the technical development work always aims at decreasing the quantity of work spent on the things named in points b, and c,.
E.g. replacing the pipelines with ones made of different material, using coatings, other seal-types; to avoid growing the quantity of the work for maintenance.
e, Necessary modifications, changes
It is aimed at eliminating the weak points in the whole system and the weak points at the individual elements on the basis of the supervision.
Certainly there may be a need to modify operational instructions or maintenance technologies as well.

The basis for a modification or change can be the shaping of a better observation or test method.

f, Weak points
These are the faults or deficiencies which can be eliminated only with large costs or they repeatedly happen in case of the greatest care too. They can happen owing to designing, manufacturing or operational, maintenance deficiencies or because of changing conditions.

The weak points of a system influence the goodness of a system basically and in the long run.

g, Changing the human factors

The investigation finds it out if the maintenance and repair is done by persons who have the necessary professional knowledge and knowledge of systems. It also covers the facilities and conditions judjing if they are suitable. These factors all play quite an important role in the state of a system.

h, Information, training

The operational and maintenance personnel has to be given appropriate information about the tests which were done and about their findings. If it is necessary, training has to be provided. It cannot be avoided even in the case of highly qualified persons either in order to ensure the success of the interventions done on the basis of the tests.

i, Determining the dates of next tests

On the basis of the tests it has to be determined when the repeated supervision of the elements and systems becomes necessary and what the time intervals are to repeat them.
The majority of the nuclear power plant systems allow - in our opinion - to perform one single comprehensive and full scope supervision during the whole lifetime or to do it every 10 -15 years. As concerns the system elements it can be necessary to perform supervisions every 1 - 5 years. Here we have to bear in mind that the evaluation should be done from a system-specific aspect.

j, Correction of the determined trend

After a full-scope supervision of a system the measures taken have to be reviewed annually in order to define if the trend was correct or if the changes in conditions necessitate a correction of the trend.

The condenser's cooling water system was tested and the evaluation was done according to points a, - j. Further we give some of the statements done on the basis of the evaluation.

- we discovered quite a few faults which were not known before and which can be eliminated in an easy way (e.g. deficiencies in corrosion prevention, cracks in the structures, deposits, insufficiencies in pipe supports, cracks in armatures etc.)

- the weak points of the system became known (end catches, rubber compensators, cables of closed air cooler, level maintaining spillover, etc.)
- we decided to make some modifications in maintenance technologies as well as in equipment (usage of different type compensators, changing the cables of closed air cooler and laying it on a different track)
- we determined the lifetime for the individual elements and of the system

	during deficiencies	after eliminating deficiencies
elements	1 - 5 years	1o - 3o years
system	1o - 15 years	about 3o years

The next supervision will be in 1 - 5 years time for elements and in 10 years for the system.

7. CONCLUSIONS

- The above all concerns the investigation of the physical state. The system-level supervisions can be supplemented by operational-technological tests. Combining both can give full-scope conclusions and could create a new basis for cooperation between the different committees of IAEA.

GLOSSARY

System: a given technological system (e.g. cooling water system for the condenser)

System elements: /elements of a system/ equipment, facilities belonging to a given technological system (e.g. taking the cooling system of condenser these are: pumps, filters, pipes, armatures, hot water channel etc.)

PRESENT STATUS OF RELIABILITY CENTERED MAINTENANCE (RCM) IN JAPAN

K. OHTA
Nuclear Power Engineering Test Centre (NUPEC),
Tokyo, Japan

Abstract

The nuclear industries in Japan have incessantly accumulated experience more than 25 years and made every effort in a variety of fields to enhance the reliability and availability.

The philosophy of the maintenance policy has centered on looking for perfect preventive maintenance based on the actual operating results and experience.

On the other hand, the western RCM method has focussed general attention on the past experience and expertise in the systematic selection of systems and components to be subjected to preventive maintenance.
In that meaning, the Japanese way currently assumed when drafting maintenance programs can be also said to aim at an RCM of the kind.

Since most of the maintenance activities in Japan have been performed during the periodic inspection, the paper will explain the present status of the Japanese periodic inspection and the reliability evaluation activities using FTA developed by NUPEC, and also will comment on RCM.

1. INTRODUCTION

Total 40 nuclear power plants are commercially operating in Japan which are 39 units of LWRs (21 BWRs and 18 PWRs) and one unit of GCR.

Their total power generating capacity is 32,059 MW and the share of generating electricity is about 26%. The nuclear industries in Japan including the electric power companies, manufacturers and other related companies have incessantly accumulated experience more than twentyfive years and made every effort in a variety of fields, to enhance the reliability and availability of the NPPs without making any sacrifice of the safety.

The philosophy of the maintenance policy in the domestic NPPs has centered on looking for perfect preventive maintenance and repair activities based on the actual operating results and experience.

As the result, the operating performance of the domestic NPPs has been very successful, as shown in Fig. 1.

In spite of such satisfactory past performance, the nuclear industries believed that a further sophistication of the maintenance should have been performed to aim at more enhanced reliability and availability of NPPs in the future, so the Japan Power Engineering and Inspection Corporation along with the electric power companies and the manufacturers has proceeded the investigation into the reliability centered maintenance (RCM) for the past four years.

The western RCM method has focussed general attention on past experience and expertise in the systematic selection of systems and components for preventive maintenance. In that meaning, the Japanese way currently implemented when drafting maintenance programs can be also said to aim at an RCM of the kind.

Since most of the maintenance activities have been performed during the periodic inspection period, Chapter one will deal with the present status of the periodic inspection performed in Japan, and then Chapter two will describe the evaluation activities of the FTA method developed by NUSIRC. We believe that the results of quantitative reliability evaluation may help us to make up the present experience-based preventive maintenance program.

2. PRESENT STATUS OF PERIODIC INSPECTION OF NPPs IN JAPAN

(1) Purpose of Periodic Inspection

The domestic electric power companies are obliged by law to make inspections for the important facilities to secure plant safety and smooth supply of electricity, for every predetermined interval (24 months ± one month for steam turbines, and 12 months ± one month for other facilities). Table 1 shows examples of these facilities.

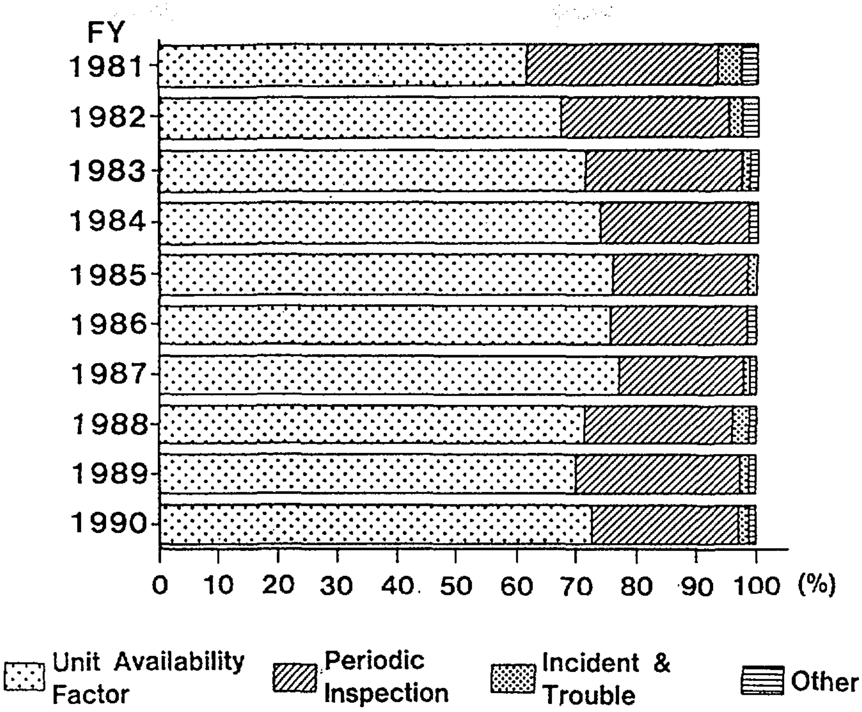
During periodic inspection, domestic electric power companies perform inspections and maintenance of the safety-related and other important systems and maintain the plant integrity. At the same time they perform refuelling and also thoroughgoing preventive maintenance activities considering that an everlasting safe and stable operation of NPPs can directly lead to the reliance and support by the public for the NPPs.

(2) Inspection on Law

The most important items in maintaining plant safety should be subject to witness inspections by inspectors dispatched from the authority. These inspection items are about 70 in total, which are compulsory inspected during every periodic inspection, that is, almost every year. Table 2 shows the examples of the witness inspections.

(3) Voluntary Inspection and Maintenance

During the above compulsory periodic inspection period, voluntary inspections and maintenance are performed by the electric power companies.



Breakdown List

	Unit Availability Factor	Periodic Inspection	Incident & Trouble	Other
FY	%	%	%	%
1981	61.7	32.6	3.2	2.5
1982	67.6	28.3	1.6	2.4
1983	71.5	26.0	1.2	1.3
1984	73.9	25.0	0.4	0.7
1985	76.0	22.7	0.9	0.4
1986	75.7	23.3	0.5	0.5
1987	77.1	20.9	1.2	0.9
1988	71.4	24.7	2.9	0.9
1989	70.0	27.6	1.3	1.1
1990	72.7	24.7	1.4	1.1

FIG. 1. History of operating status.

They are combined into their own long term (about 10 years) inspection program, in which inspection items and their intervals are planned for the whole plant facilities based on their working conditions, and also referring to the past operating and maintenance experience including the one of other power companies.

In preparing the long term inspection program the following factors shown by Table 3 are considered.

When potential aging of any piece of equipment is recognized referring to the data obtained from inspection and repair results, proper actions such as repair or replacement have been taken for the would-be-affected equipment on the principle of preventive maintenance.

Table 1 Object Systems for Periodic Inepection by MITI

- Reactor (Pressure Vessel and Core Facilities)
- Reactor Cooling System
- Instrumentation and Control System
- Fuel Facilities
- Radiation Monitoring System
- Waste Disposal System
- Reactor Containment Vessel
- Auxiliary Boiler Facilities
- Emergency Power Generating System
- Main Steam Turbine Facilities

Table 2 Example of MITI Test
(Total about 70 Items)

BWR	· In-Service Inspection of Reactor Coolant Pressure Boundary
	· Fuel Assembly Sipping Test
	· Reactor Shutdown Margin Test
	· PLR Pump Disassembly
	· Main Steam Safety Valve Disassembly, Leakage and Functional Test
	· ECCS Functional Test
	· Feedwater Pump Functional Test
	· CRD Functional Test
	· Fuel Handling Equipment Functional Test
	· Liquid Radwaste Disposal System Functional Test
PWR	· In-Service Inspection of Reactor Coolant Pressure Boundary
	· Fuel Assembly Sipping Test
	· Primary Coolant Pump Disassembly
	· SG Tube Eddy Current Examination Test
	· Pressurizer Safety Valve Functional and Leakage Test
	· ECCS Functional Test
	· CRD Functional Test
	· Reactor Protection Interlock Functional Test
	· Fuel Handling Facility Functional Test
	· Area Monitoring System Functional Test
	· Reactor Containment Vessel Leak Rate Test

Table 3 Decision making Points for PM Selection

• Normal Use or Emergency Use
• Whether Supported by Auxiliary Equipment or not
• Possibility of Maintenance or Surveillance Test without Plant Shutdown
• The Term of Guarantee of the Equipment
• Operating Hours
• Failure History of the Equipment
• Operating Environment of the Equipment (sea water high temperature etc.)
• Experience from the Other Nuclear Power Plant or Fossil Power Plant.

(4) Modification of Facilities

On the other hand, lessons obtained from the collection and analysis of incident and failure informations in other domestic and foreign NPPs have also been positively reflected into the facility modification and maintenance plans.

Facility modification and the application of new technology including the above have been performed in the domestic NPPs during their periodic inspection period to enhance the safety, reliability, operability and maintenability. Normally such modifications are planned and designed four years earlier than the actual modification, and before one to two years detailed design is completed to obtain necessary review and approval from the authority.

(5) Management Organization of Maintenance Activities

In Japan, normally maintenance and modification activities made during the periodic inspection period are not performed by the personnel of the power company but by technicians and workers of related manufacturers and their subcontractors.

The personnel of the power company mainly takes care of the establishment of work plans, the review of engineering design, the supervision of the works, the control of scheduling, the supervision of quality assurance, the control of radiation exposure and group coordination.

The number of the employee of a power station which has three to four units normally ranges 400 to 500 and periodic inspections are sequentially performed one by one. The number of subcontractor's workers to be mobilized are about 2000 per day per unit.

(1) Reliability Evaluation Using FTA for Domestic Typical LWR

To perform reliability evaluation of NPPs, the Nuclear Power Safety Information Research Center (NUSIRC) introduced the FTA code system and performed various analyses on the main systems with automatic plant shutdown as the top event for typical LWR. (900MW 3-loop PWR, 1100MW Type-V BWR) Fig. 2 shows the basic procedures.

First of all, for the system to be selected for the evaluation, interfaces of the related systems were specified, and automatic or manual plant shutdown was selected as the top event. Next, identification was made for failure modes of system components dominating the evaluation. FMEA was made for the impact of the identified failure modes on plant operation and determination was made for the failure scenario leading to the top events.

Further, failures in domestic and foreign NPPs were surveyed to identify plant scram causes, which were later incorporated into FTs. Then, the qualitative MCSs of the typical plants were calculated based on the FT data thus obtained. Using the above MCSs, quantitative analyses were made for the following items:

- Unavailability of systems at time t
- Number of system failures encountered by time t
- Point estimation and uncertainty analysis of system failure incidence probability
- Risk achievement worth and risk reduction worth of components
- Birnbaum severity of components
- Fussell-Vesely severity of components

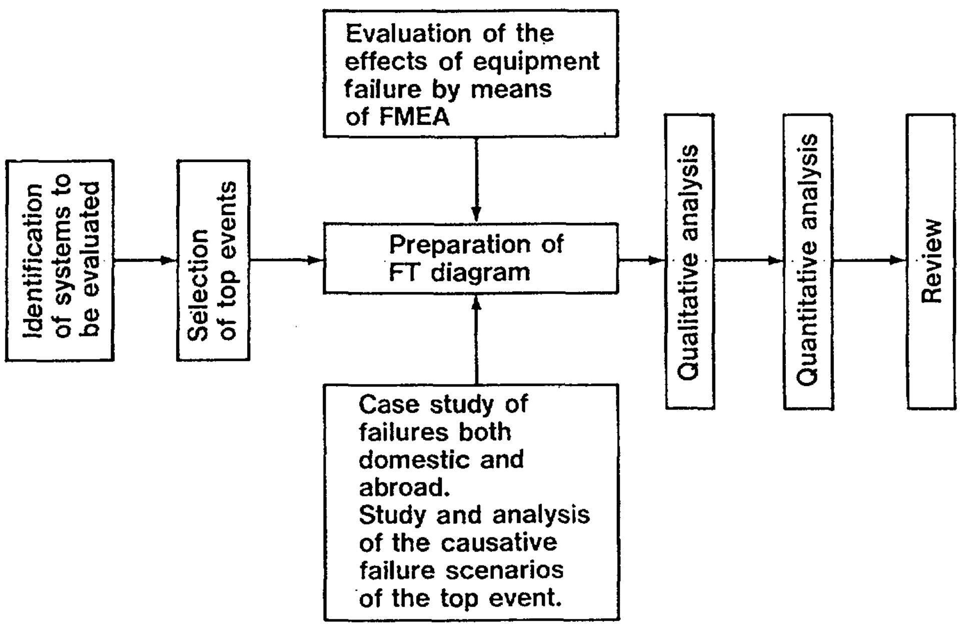


FIG. 2. FTA methodology and procedure.

(2) Evaluation Results

The quantitative analysis has been performed by using USA data which are IEEE std.500, WASH-1400 and NUREG/CR-2815. Evaluations from the USA data seems to be a little higher than the actual operational performances in the domestic NPPs. We are proceeding to calculate failure rates for main components in the domestic NPPs using the actual domestic failure data, which proved that the relation between components of failure rates showed a similar trend between Japan and USA.

Now we are in a stage of detailed review comparing the evaluation results by FTA with the operational performances in the domestic NPPs.

For example, we proposed in the PSA symposium held in Japan last December that the Fussell - Vesely severity grade would be better to use as a desirable index to reflect the FTA results into maintenance activities. As the index will well express the contribution grade to the failure, it may be helpful to make an effective maintenance plan. Fig. 3 and 4 show the examples. This February, just two months after our proposition, unexpectedly there happened the SG tube rapture in a PWR and the EHC control hydraulic oil leak failure in a BWR. The reliabilities and failure causes of these affected systems

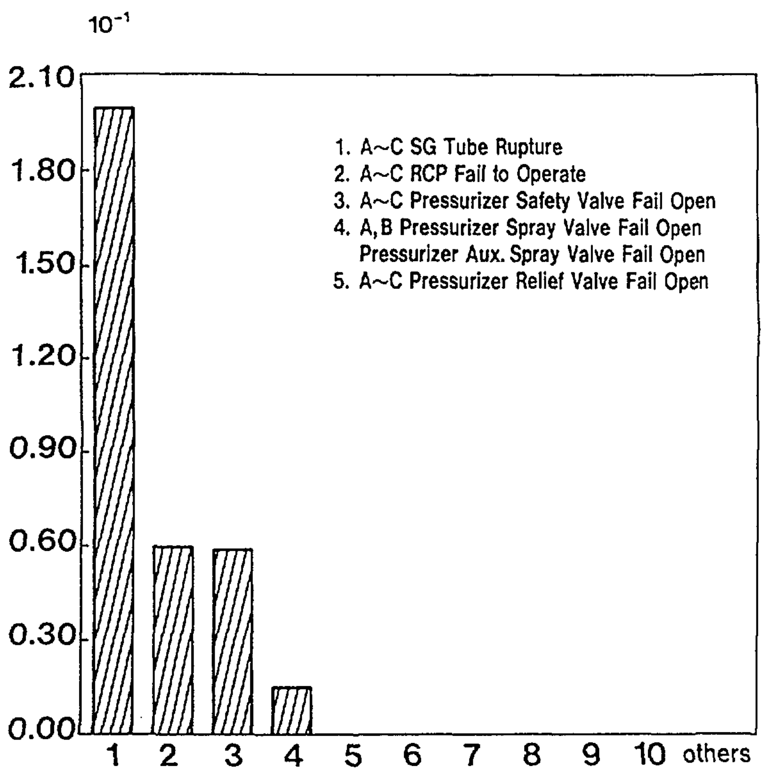


FIG. 3. Fussell-Vesely importance grade for PWR RCS component.

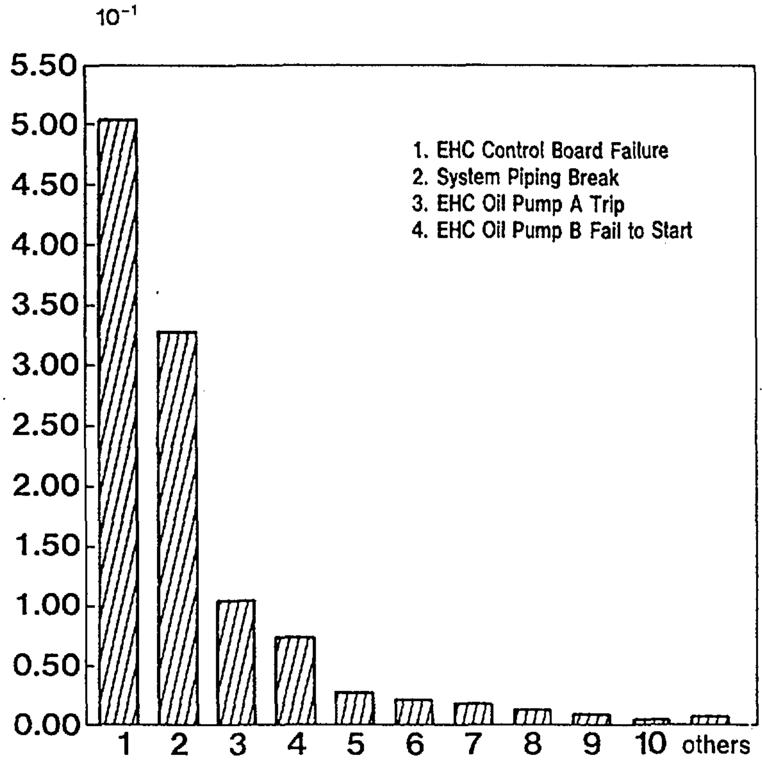


FIG. 4. Fussell-Vesely importance grade for BWR turbine control system.

showed a fairly good agreement with the reality, even though the USA data used. Therefore, we believe that the results of the quantitative reliability evaluation using FTA will be useful to classify or prioritize the severity on a system level or on a component level, and that the approach will be beneficial to support the present maintenance fundamentals in Japan, that is, the past experience, resultant data and expertise.

4. CONSIDERATIONS

(1) Collection of RCM Data

Since the domestic NPPs have performed necessary maintenance before potential failures reveal themselves, there have been very few failures which in turn made it rather difficult to establish a data base required for RCM. And, there may be an ironical contradiction that the more successful the prevention of failures is the less the failure data obtained.

(2) Necessity of Quantitative Evaluation Approach

According to the EPRI reports, the qualitative FMEA evaluation as seen in the earlier examples for the RCM analysis is being replaced by quantitative evaluations using FTA or GO method.

It is necessary to consider the introduction of these quantitative evaluation methods, which may also serve to avoid the uncertainty in the analysis.

(3) More Clarified Specification of Selection Criteria for RCM Decision Logic Tree Analysis (LTA)

The impact evaluation of each failure mode would be followed by the selection of maintenance activities to be performed using the logic tree analysis (LTA), which may necessitate the establishment of an objective and reasonable selection criteria related to the impact of failure modes on plant safety and operability, based on the data associated with technical experience, incidents, failures and inspections in each stage of operation and repair.

(4) Decision Method for Kind, Inspection Frequency and Detail of Maintenance Activities

In order to determine the kind, inspection frequency and detail of maintenance activities, LTA must be assisted by other means.

For example, to determine the kind of maintenance activities, LTA must be assisted by fully developed monitoring / diagnostic techniques.

To determine the inspection frequency and detail of maintenance activities, LTA must be assisted by the life evaluation of equipment and part, which may necessitate the analysis of parts replaced in maintenance and the evaluation of remaining life to be predicted by destructive tests, etc.

NUSIRC has set the computer code which can handle the time dependent failure rate and just began to study the optimization of test frequency for a sample case,

(5) Evaluation of RCM Effectiveness

When maintenance detail has been changed by RCM, it may not be so easy to prove how much the RCM has reduced or is reducing the maintenance cost and failure rate, that the development of evaluation method of RCM effectiveness is necessary. Buildup of technical and experience data is indispensable to assure that such reduction in preventive maintenance cost would never affect the present level of reliability.

(6) Difference of Environment for RCM Implementation

The qualitative policy that the operation of NPPs should be based on plant safety may be commonly prevalent over the world, but the quantity of the level and extent may be greatly influenced by social environment of each country and the regulatory attitude of each authority may be also affected by the social environment.

Is it conceivable to recommend a standard level of maintenance and operation control activities to govern the variety of international societies ?

As Japanese preventive maintenance policy is mainly based on the actual operating results and experience, it may be difficult to link the reduction of maintenance task with economical advantage until sufficient concrete data having been prepared.

REFERENCE

Haruyuki Kumano (Application of RCM for Nuclear Power Station in Japan) Japan Power Engineering and Inspection Corporation, May 1990.

EFFECTIVE MAINTENANCE AS A TOOL FOR NUCLEAR POWER PLANT EQUIPMENT AND SYSTEMS RELIABILITY MANAGEMENT

V. NIKOLAEV
Ministry of Atomic Energy

V. GOURINOVICH
All-Union Institute for Nuclear Power Plants

Moscow, Russian Federation

Abstract

After a short introduction to the site operating organization and importance of using of reliability based maintenance evaluation methods in improving the maintenance activities this paper first describes a point of view concerning the maintenance impact on the reliability of plant equipment. The author considers the maintenance system as an effective managerial tool to maintain the reliability of equipment.

In the third part of the paper starting with the definition of "Maintenance system" the author discusses the approaches for maintenance system optimizing. While giving an idea on some additional analytical steps of RCM analysis, he also enters into more detail concerning the features of maintenance philosophy.

1. INTRODUCTION

The importance of safe and efficient performance of nuclear power plants is clear. There are diverse approaches to improve performance, including equipment maintenance improvement practices. Reliability based techniques (including RCM) are of high interest primarily as an effective basis for maintenance philosophy. The purpose of this paper is to describe how we consider the concept of Reliability Centered Maintenance and apply it in improving the maintenance activities.

But first let me describe our organization. The responsibility for generation of electricity within our Ministry lies with three Main Departments: the Operational Main Department, the Dispatching Control Main Department and the Maintenance Main Department.

The responsibility for overall co-ordination of electricity generation lies on the USSR Deputy Minister of Nuclear Power and Industry.

The Maintenance Main Department which I represent co-ordinates maintenance activities of all the Nuclear Power Stations and supervises several maintenance enterprises.

The Operational Main Department operates 15 Nuclear Power Station which have 46 units and the declared net capability of the Stations is in excess of 36000 Megawatts which provide approximately 12% of the present annual electricity supply.

With such a large operating organization the use of reliability based maintenance evaluation methods is important. We began to develop new maintenance philosophy in 1989 but its practical aplications are still negligible. We think this meeting discussions will help us to achieve more progress in the future.

2. RELIABILITY AND MAINTENANCE — GENERAL APPROACH

The particular processes involved in the nuclear industry and the need to protect all persons from undue radiological hazards, impose strict safety requirements on the nuclear power plants operation. But operating organizations have other objectives besides those related to safety. The NPP's are due to perform with a risk to the public as low as reasonably achievable but also to obtain the highest level of energy availability at a reasonable cost. It is recognized that the NPP systems and equipment reliability contribute to both safety and high availability. The high reliability of plant systems and equipment achievement calls for systematic actions to be taken during the design, construction (manufacturing) and operation stages of the systems (equipment) themselves. An effective managerial tool to maintain the reliability of plant equipment established when designing and manufacturing during the operation stage is an adequate maintenance system. Definition of "maintenance system" will be given later.

Figure 1 shows a relative interpretation of the maintenance impact on the reliability of equipment: for simple eguipment, wich requires only servicing during lifetime - fig.1a; for complicated equipment which requires servicing and repair (running repair, medium repair, overhaul) during lifetime - fig.1b.

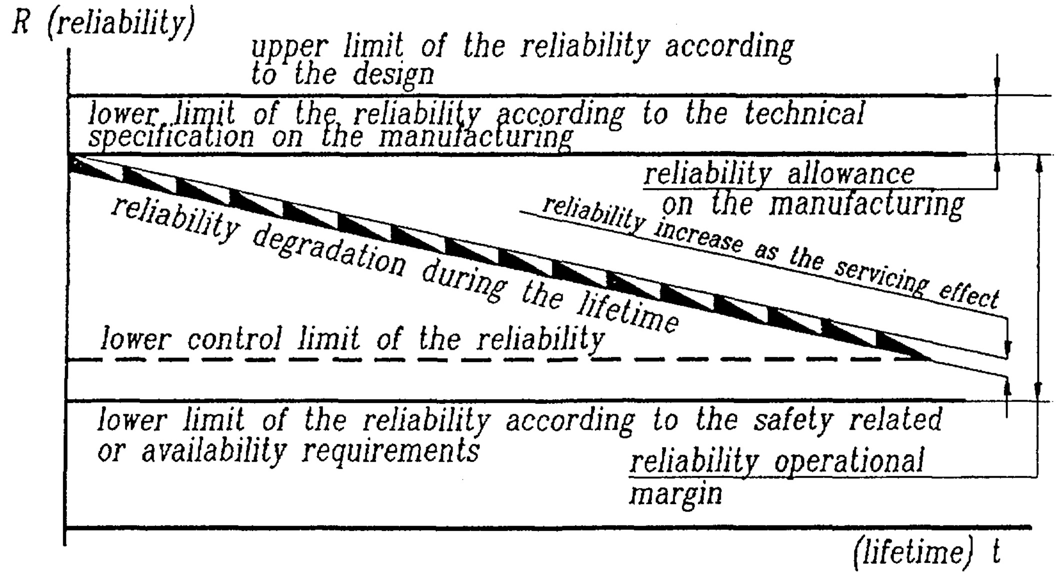


FIG. 1a.

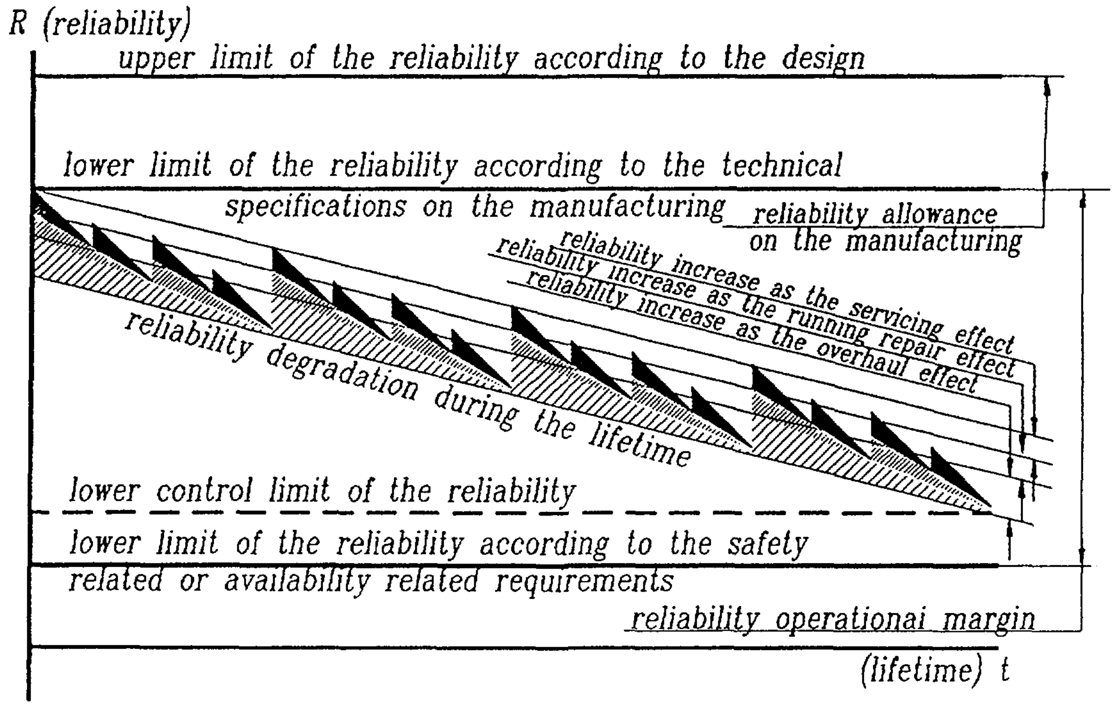


FIG. 1b.

FIG. 1. Impact of maintenance on the reliability of equipment.

Figure depicts the relationship of the maintenance activities to the reliability of eqiupment Maintenance renews condition of the eqiupment, restores its reliability for a definite time but cannot stop the general degradation of the equipment condition during lifetime. It is very important to specify characteristics determining the lower limit of degradation of the equipment condition and reliability but we do not have the plant equipment for which such characteristics are contained in the design technical specifications to the full.

3. MAINTENANCE SYSTEM OPTIMIZATION FOR EFFECTIVENESS

In this paper "Maintenance system" means taken as a whole complex:

- category of the equipment to be maintained;
- maintenance tasks defined according to Regulatory requirements, equipment design criteria and features, reliability characteristics or experience data;
- maintenance facilities;
- maintenance basis documentation defining technical specifications and necessary procedures;
- maintenance staff and organization.

The maintenance system should be based on a maintenance philosophy.

Figure 2 shows that our existing Maintenance system-1 is based on the time directed preventive maintenance philosophy which is depicted with all features. The disadvantages of the philosophy are known. I will not waste time enumerating them.

Figure 3 depicts our approach for optimizing the Maintenance system-1.

We agree to basic analytical steps of RCM analysis stated in the document "Status of Reliability Centred Maintenance (RCM) in the Nuclear Industry".

But we consider such steps of the analysis as (c) data and information collection, (e) determination of the functional failure of systems and its subsystems will be more effective if we use some additional steps:

- classification of damages revealed when equipment inspectioning (servicing, repairing);
- connecting the damages with failure modes;
- rating of damages, defects specifying and developing technical specifications for repair.

These steps ensure the formalization of damage record-keeping when servicing and repairing, allow to put in order equipment failures information feedback.

The pointed mechanism of using the feedback information for maintenance system improvement is shown in figure 3.

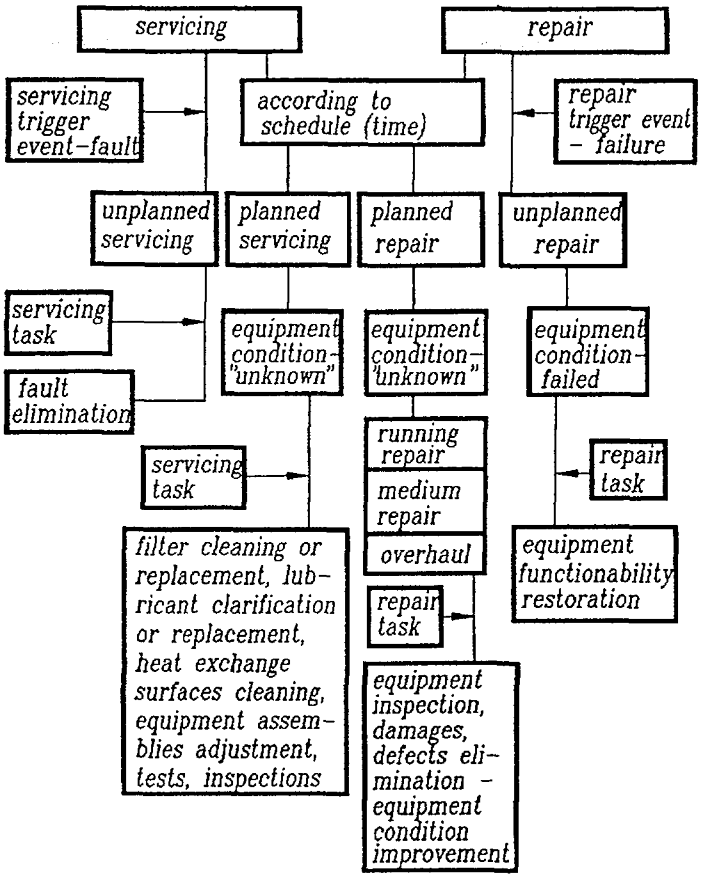


FIG. 2. Maintenance system no. 1.

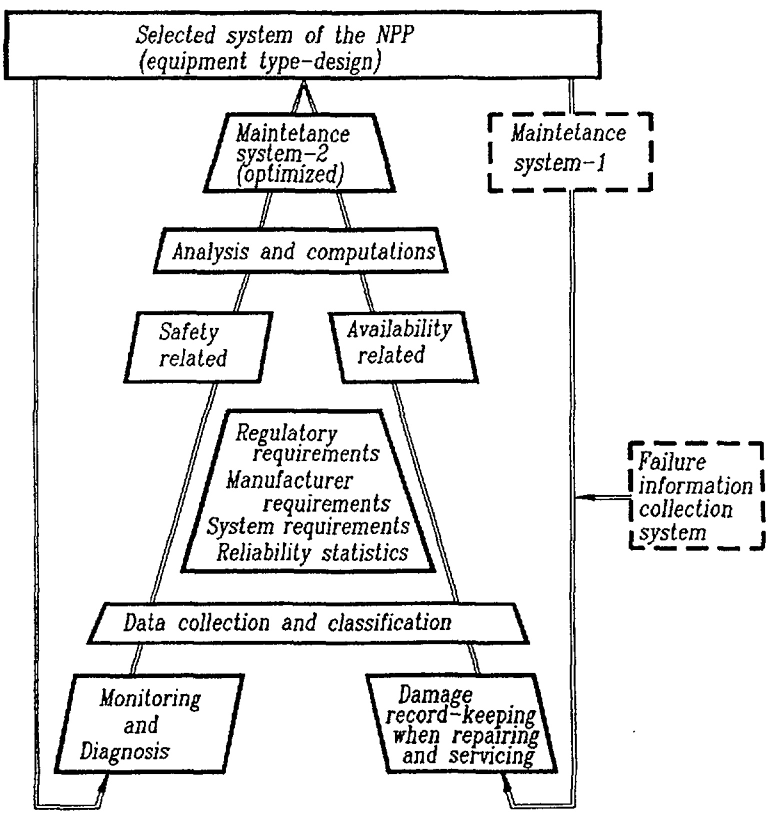


FIG. 3. Reliability based techniques for maintenance system optimization.

The maintenance system after optimizing as we can see it is shown in figure 4.

In figure 3 and 4 "Reliability statistics" means statistical data after failure and damages information processing.

We consider it is important to formalize the failures and damages information collection using the classification of equipment damages and special documentation forms for record-keeping.

As examples in figures 5 and 6 there are shown an extract from the reactor vessel technical specifications for repair and a technical condition card.

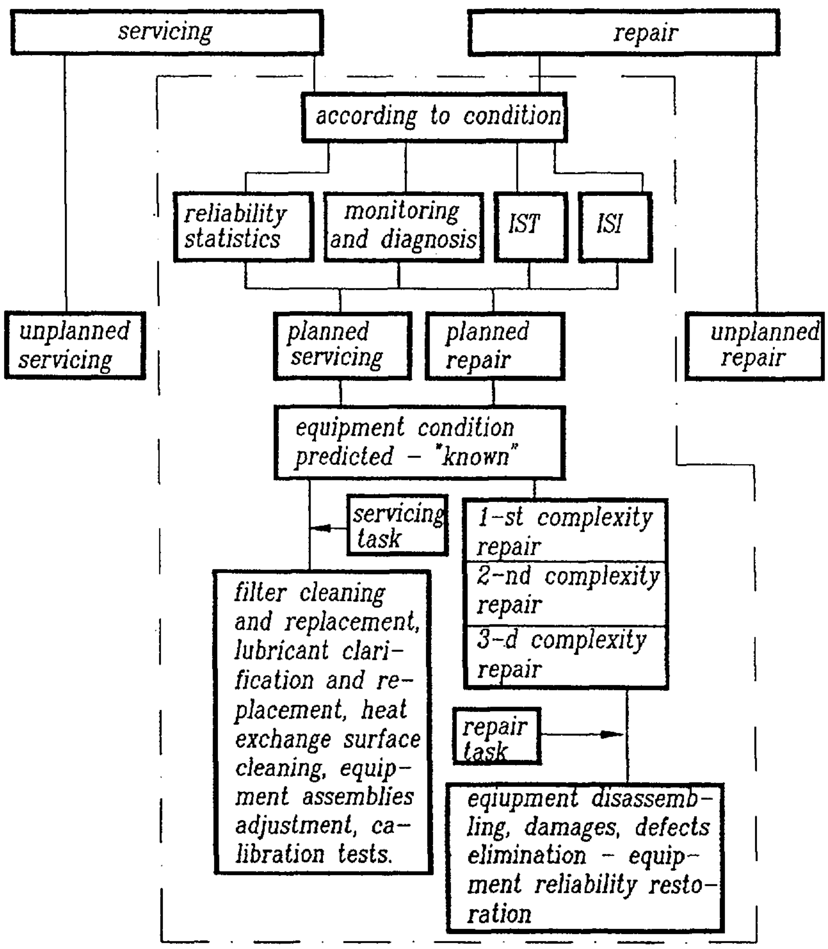


FIG. 4. Maintenance system no. 2.

REACTOR VESSEL
(component name)

Component designation (name)	Potential defect	Way of defect identification (type of testing)	Measuring tools	Conclusion and recommended way of repair	Technical requirements for repair
A1 Б1 B1 Г1	Cracks corrosive damage up to 2 mm deep	Visual inspection (VI) Measuring inspection (MI)	Cracks depth gaude ПТ-10С ShG160 depth gauge	Defect elimination without welding	Attachment 1
A1 Б1 B1* Г1*	Peeling	Ultrasonic testing(UT)	SK-187		
Д1	Cracks Dents	VI Same		Local processing of bulges	Processing with D1 surface Surface roughness no more than Ra2,5
A2 N1	Cracks up to 15 mm deep	VI UT MI	Same as above	Defect elimination without welding	S_{A2min} = 220mm in the circular zone 1600 mm diameter around the bottom pole S_{A2min} = 200mm in the remaining portion of A2 surface Attachment 1

Component designation (name)	Potential defect	Way of defect identification (type of testing)	Measuring tools	Conclusion and recommended way of repair	Technical requirements for repair
N2	Cracks up to 3 mm deep	VI UT MI	Same as above (See Fig.1)	Defect elimination without welding	Attachment 1
Б2 N3 N4	Cracks	VI UT	"	Same	Same
B2	Cracks up to 3 mm deep	VI (in accessible places) MI		"	"
Г2 Д2	Cracks up to 1.5 mm deep	VI MI	Same	"	"
N5	Same	VI UT MI	"	"	"
N6 N7	"	VI Magnetic particle UT MI			

* Note: Inspection to be performed in accessible places

FIG. 5a. Defects detection and repair card.

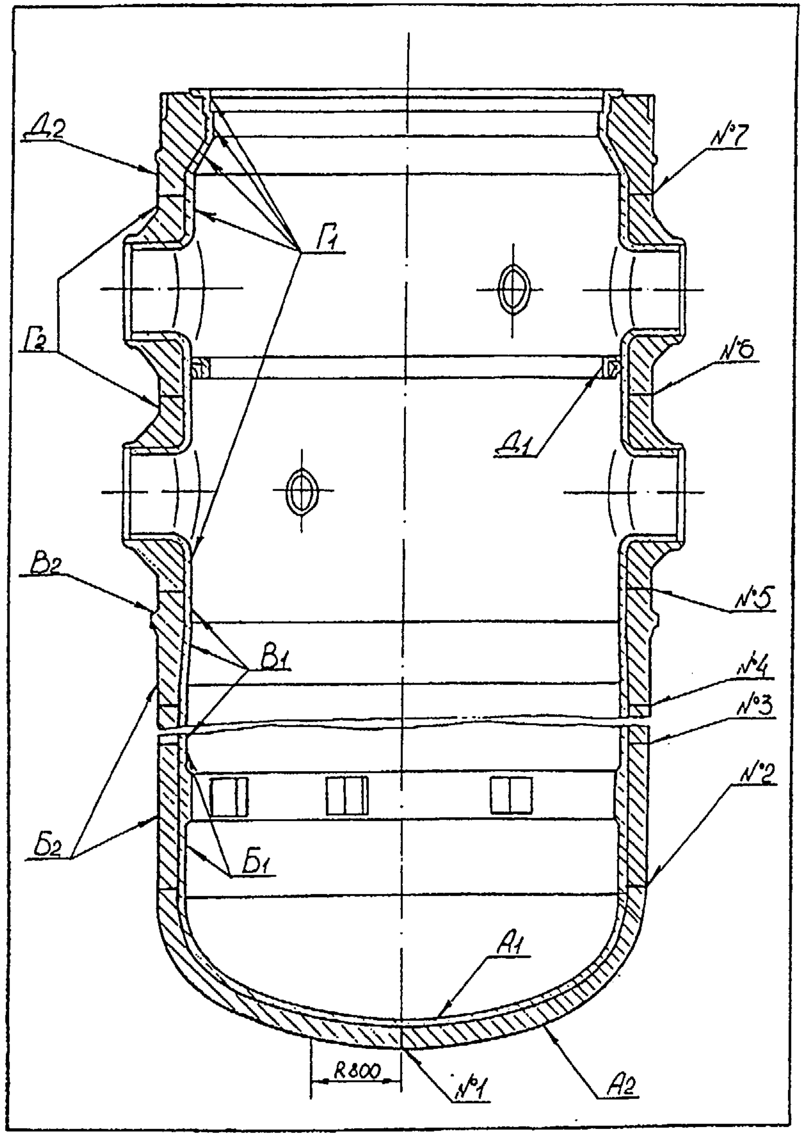


FIG. 5b. Reactor vessel.

(date of servicing/repair/)

REACTOR VESSEL
(component name)

Component designation (name)	Potential damage (defect)	While testing	While accepting for operation

FIG. 6. Technical condition card.

DEVELOPMENT OF RELIABILITY CENTERED MAINTENANCE (RCM) METHODOLOGY FOR THE ELECTRICITE DE FRANCE NUCLEAR PLANTS: A PILOT APPLICATION TO THE CVCS SYSTEM

J.P. JACQUOT
Research and Development Division

P. LEGAUD, G. ZWINGELSTEIN
Nuclear and Fossil Fuel Generation Division

Electricité de France,
Chatou, France

Abstract

Several RCM studies have recently demonstrated that RCM methodology developed in aeronautics and later adopted by the U.S. military is also applicable in the nuclear industry. Considering the first results obtained and the potential advantages of this approach, an RCM project was started in 1990 for EDF Nuclear Power Plants Maintenance.

This paper presents the objectives of the project, its organization, and the specific concepts and methods used in the RCM process. Preliminary results obtained in the pilot application as well as the potential improvements of the methods are described.

1. INTRODUCTION

Maintenance costs represent a significant part of the overall cost of electricity. Considering the potential efficiency of Reliability Centered Maintenance in aeronautics, military applications, and, more recently, in the nuclear industry [1] [2], an RCM project was started for EDF nuclear power plants maintenance.[3]

After describing the benefits that can be expected from the RCM approach, the specific objectives as well as the organization of the project are presented. Following a description of the basic concepts, the methods used in the RCM process are explained ; the preliminary results are presented as well as the potential improvements of the methods.

2. OBJECTIVES AND ORGANISATION OF THE PROJECT

A classical characteristic of the RCM approach is for it to be a systematic and structured process. The traceability of actions and decisions is a major advantage of the approach : it gives the possibility to justify, review and, later on, to readjust the components maintenance program. Through the RCM process, all qualitative and quantitative feedback data can easily be taken into account. Another benefit expected from this approach is a reduction in costs (including maintenance costs and unavailability costs). In fact, the main objective of the RCM process is to **apply the maintenance effort at the best location, with the most effective maintenance technique.**

The following EDF staff also participated in the study: J. Delbos (Nuclear and Fossil Fuel Generation Division), A. Despujols, J. Dewailly, J. Havart, C. Meuwisse (Research and Development Division).

Specific objectives of the EDF project are :

- to use the reliability data from 28 nuclear plants (identical for the nuclear island),

- to perform an analysis with an in-depth similar to that of a classical maintenance program,

- to be easy to be included in the existing maintenance organization.

Before describing the RCM project organisation it is interesting to present the existing EDF maintenance organization.

The basic structure of this organization is shown in figure 1.

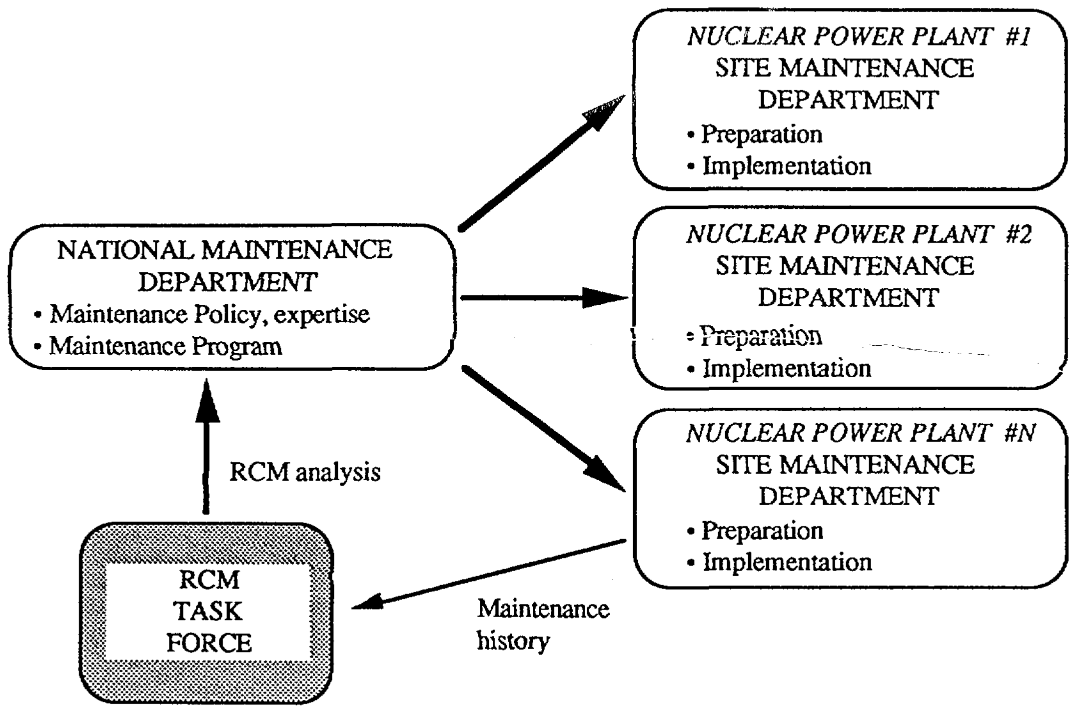


Figure 1 : The RCM project in the maintenance organization

The maintenance programs are traditionally defined by equipment experts in a central office (National Maintenance Department). This department is in charge of the nuclear plants maintenance policy.

This maintenance policy and each maintenance program <u>have to be</u> applied by each nuclear plant during the preparation and implementation phase.

The aim of the project organization is to insert the RCM task force in this existing structure. The task force is composed of engineers from both the Nuclear and Fossil Generation Division and the R & D Division.

For the pilot application, the R & D Division is in charge of the analysis whereas the Generation Division gives expertise and validates the final documents.

The RCM project is divided into 4 phases (or workpackages) as indicated in figure 2.

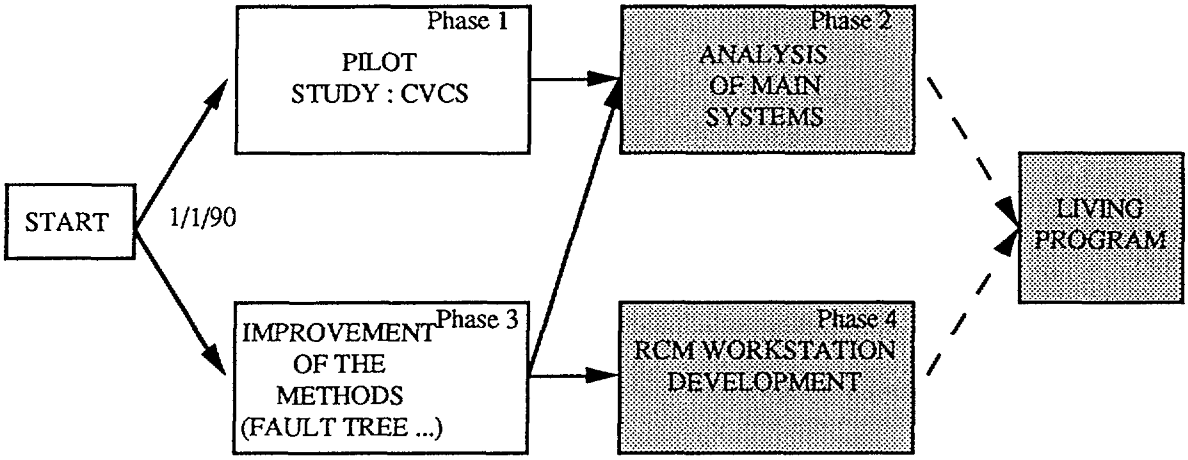


Figure 2 : Project phases

During the pilot study (phase 1) the analysis of a thermohydraulic system (Chemical, Volume, Control System) is performed. The objective is to deduce all remarks, conclusions and adjustments for a large scale analysis phase (phase 2). This phase 2 will be started, if the cost/benefit ratio of the approach appears satisfactory.

Another phase is devoted to improve the methods used in the RCM process. Several techniques are probably more efficient, such as fault trees, statistical tools, functional analysis, etc...

The last phase consists of the design of an RCM workstation with two objectives : to manage all the necessary data and to give help to the RCM analyst.

In the next section, the concepts and methods used in the pilot study will be first presented.

Afterwards, the preliminary results obtained in the CVCS pilot application will be given as well as some potential improvements to the RCM process.

3. CONCEPTS, METHODS AND EXAMPLES

The RCM process was developed in aeronautics (where it is now a standard) in the sixties and later adapted by the military industry (U.S. Navy).

Each industry including the nuclear industry made its own adaptation of the method depending on the type of the mission. Consequently, EDF has to define its own adaptation.

For the first pilot application, the methods used in the RCM process are mainly qualitative. Improvements to these methods are considered for the future analysis of other systems. They will be briefly presented in chapter 4.

3.1. CONCEPTS

The RCM process is based on a **functional** decomposition of systems and components.

Failure and degradation

A failure is defined as an interruption of the component function, creating a loss of performance, below the threshold defined in the functional specifications. A component has failed if it is declared (or considered) inoperable by the operating personnel using simple functional criteria.

A degradation is a loss of performance or characteristics within the limits of the specifications. Very few components are free of degradations. A degradation has to be analyzed very carefully ; the knowledge of the failure and degradation mechanisms often gives an indication of the basic principles of a condition directed maintenance task, which would be able to prevent the failure.

Intrinsic reliability

The intrinsic reliability is the optimum reliability of a component obtained with a "normal" amount of preventive maintenance. This concept, first introduced in aeronautics, is very useful for complex equipments. Note that a component with a low intrinsic reliability requires redesign, not maintenance. Conversely, a high intrinsic reliability generally results in minimum maintenance needs.

3.2. THE RCM PROCESS

For a given system in a nuclear plant, the RCM process is divided into four steps as indicated in figure 3.

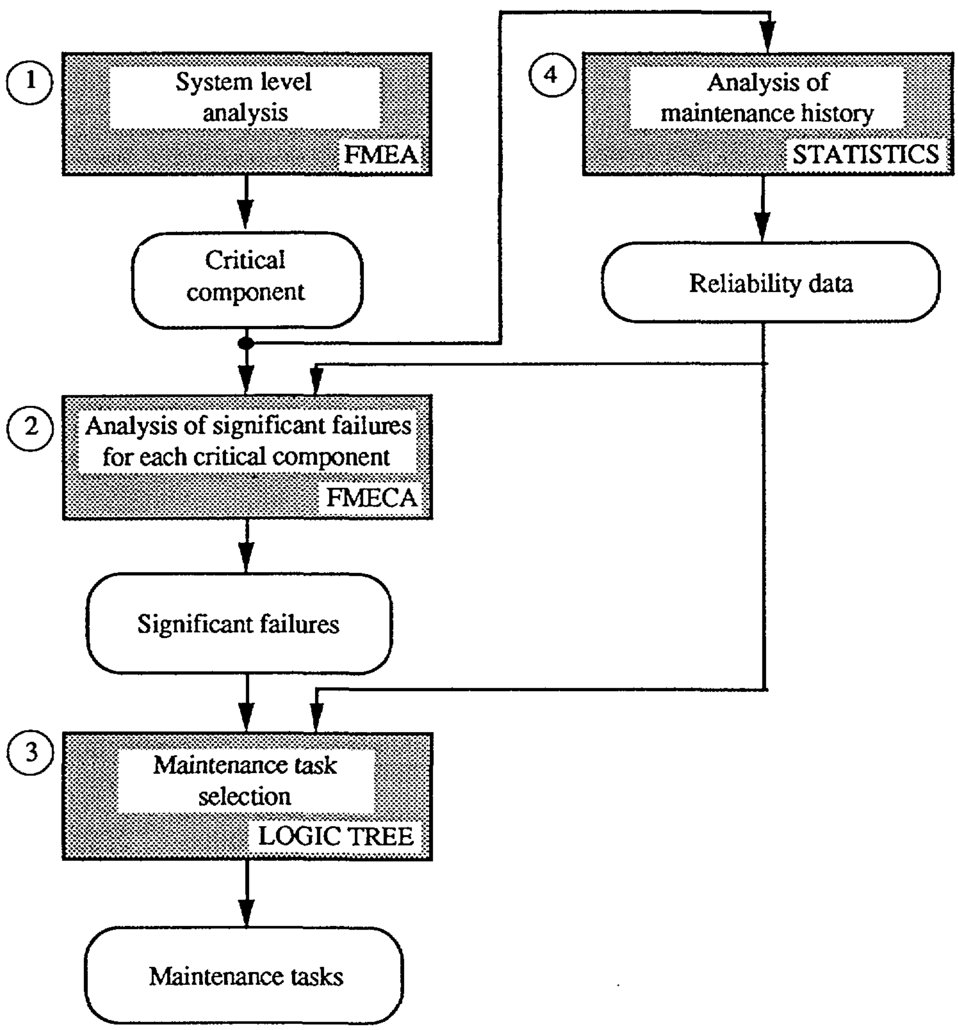


Figure 3 : RCM process

① Selection of critical components

The critical components (such as pumps, valves) are selected by an analysis of the functional consequences of each component failure mode.

Each failure mode can induce a consequence on :

- an essentiel safety function,

- the electricity generation as a result of plant shut down or load decreasing,

- the failure repairs costs.

Each failure mode is analyzed with an functional FMEA (Appendix A) giving its consequence on the system and on the plant. (Failure Mode and Effect Analysis).

After this first step, each component is classified as critical or none. Only critical equipments are considered for the next step. During the pilot application, nearly half of the components were detected as critical for safety, electricity generation or maintenance.

② Critical component failure analysis

In the previous step, each component (such as a pump, a valve, a motor...) was considered as an indivisible item. This second step consists of a more detailed failure study : the component is then divided into several **functional** items potentially at the origin of the failure (Figure 4).

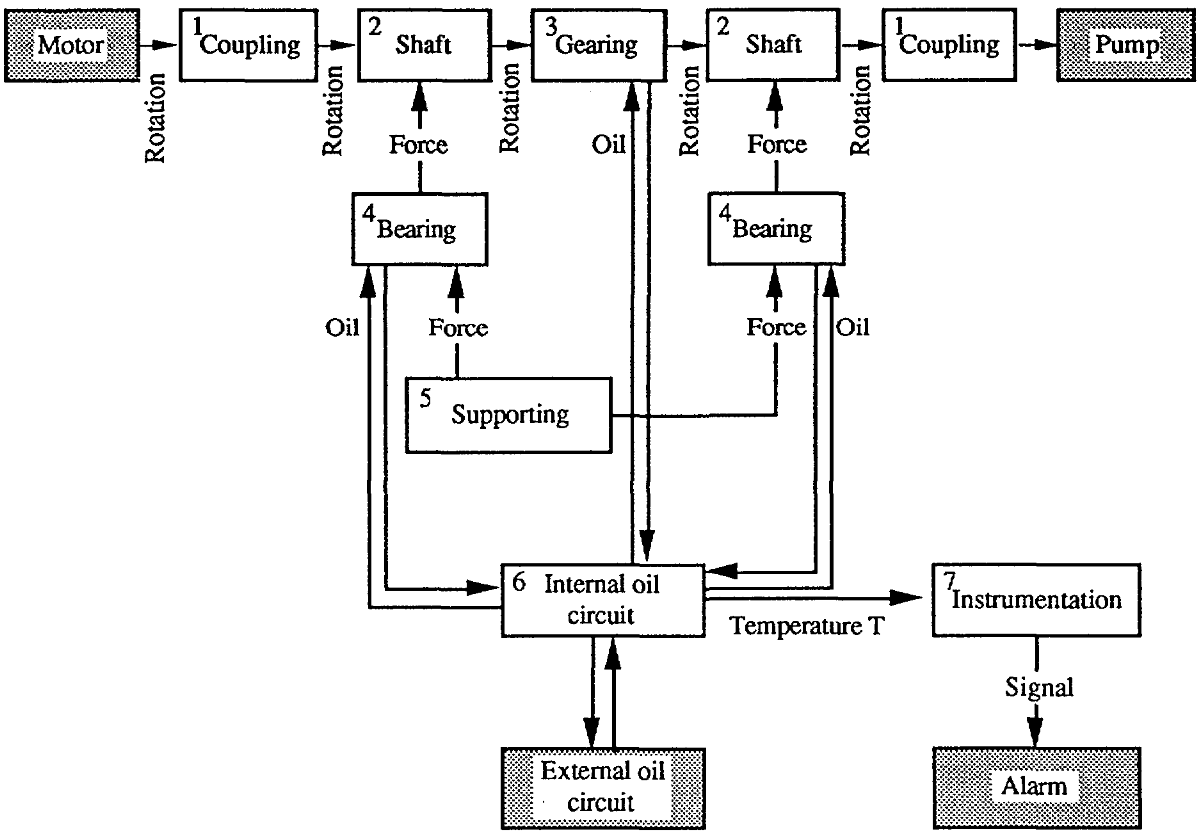


Figure 4 : Functional block diagram : gear reducer

This failure analysis is performed with a FMECA using all feedback information and available expert "know-how".

The FMECA obtained presents both failure causes and degradations (Appendix B).

The depth of this analysis is similar to that of a "classical" maintenance program. This means that if the classical maintenance program takes into account a shaft, a bearing, the RCM approach will do the same and garantee the best traceability for the analysis.

This second analysis gives, for each critical component, a list of significant failures classified according to its criticality level (negligible, acceptable, non acceptable).

③ Maintenance tasks selection to prevent significant failures

Preventive maintenance tasks are selected using a logic decision tree (figure 5) which is specific to a criticality level of failure.

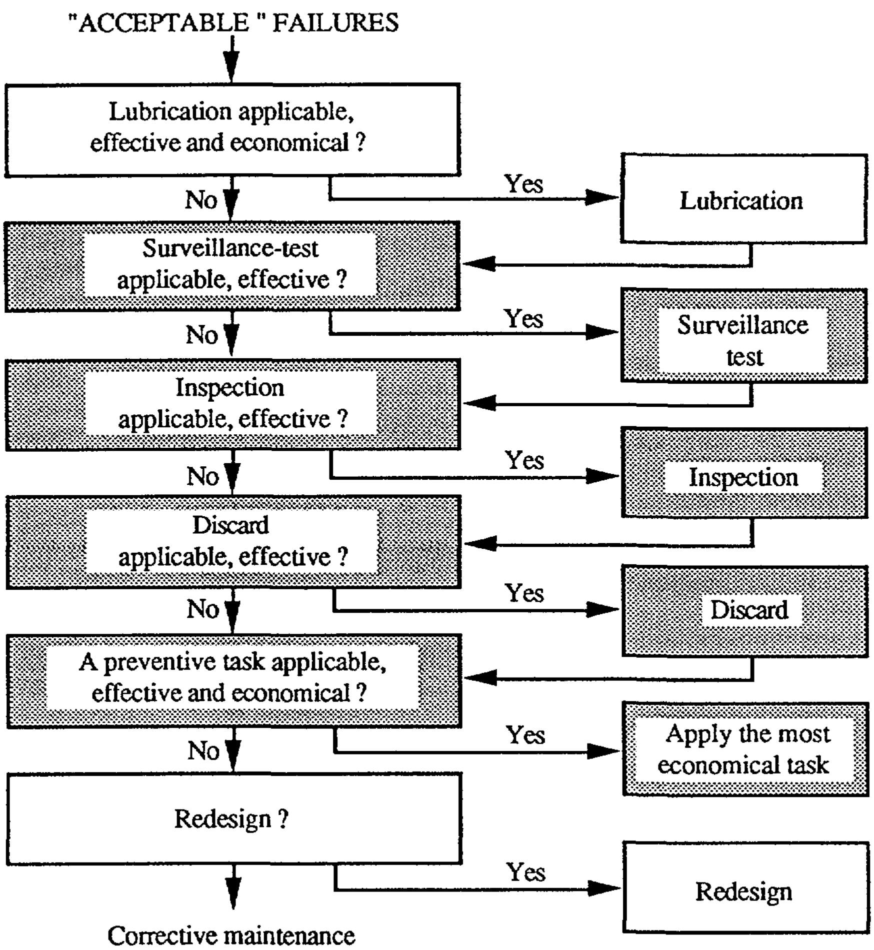


Figure 5 : The logic decision tree

The logic decision tree takes account of :

- the different maintenance task types (condition directed task, systematic maintenance...),

- applicability, efficiency and economical criteria where

a task is **applicable** if it is technically possible,

a task is **efficient** if it allows a failure rate reduction,

a task is **economical** if the maintenance task costs are less than the failure costs.

④ Feedback analysis

The significant failure analysis, the maintenance tasks selection requires a good knowledge of the failure and degradation mechanisms. The feedback information gives a substantial support to this analysis (figure 6).

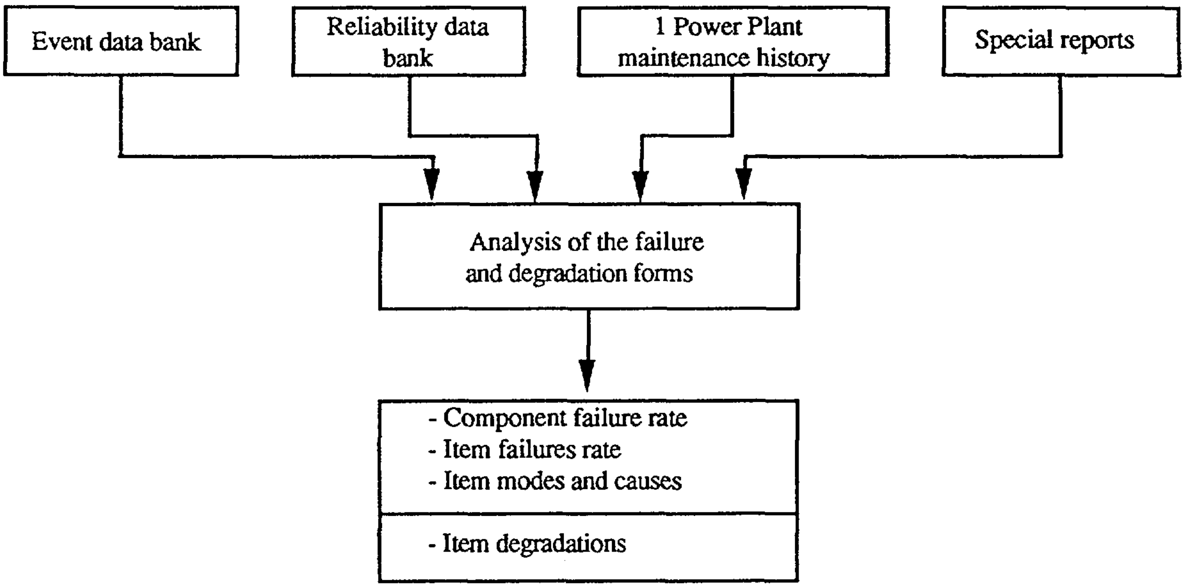


Figure 6 : Feedback analysis

The feedback information is obtained through a compilation of Maintenance Work Requests (MWR) and available on-site collected forms. It allows :

- the definition of observed failure causes,

- the estimation of the associated failure rate,

- if technically possible, an analysis of the failure rate versus the age.

During the pilot study, 1700 specific forms were collected from 28 identical 900 MW nuclear plants. Each form was associated to a degradation or a failure of a critical CVCS component.

4. RESULTS AND POTENTIAL IMPROVEMENTS

4.1. Comparison with the "classical maintenance program"

The CVCS component maintenance program has been prepared and applied (with a classical approach) for about 10 years. It is necessary to compare the RCM recommendations with the classical program.

Charging pumps :

RCM analysis recommends a modification in the maintenance program of several components (pump, reducer, ...) of the charging pumps subsystem :

- The daily surveillance tasks are reinforced (leak detection, temperature measurement, etc...)

- The time period between overhauls is significantly increased (these overhauls are the most expensive).

Valves :

The list of RCM critical valves is reduced by 30 % relative to a classical Preventive Maintenance (P.M.) program. For these critical valves, RCM recommends the addition of complementary functional tests to the classical program and new controls and inspections for the air Operated valves.The other tasks are not modified by RCM.

Sensors :

The list of RCM critical sensors is longer than that of the classical P.M. program. For these critical sensors, RCM recommends P.M. tasks depending on the "hidden/evident "failure" characteristic (surveillance or calibration).

Exchangers :

The RCM program recommends the addition of surveillance tasks and, for the lowest reliable exchanger, an eddy current inspection

In conclusion, the RCM analysis significantly modify the list of components concerned by a P.M. program. It recommends more surveillance tasks, new inspection tasks. On the other hand, it recommends to reduce the periodicity of overhauls (pumps).

4.2. Discussion about the advantages and disavantages of the EDF- RCM process

The EDF approach is different in three points from other RCM applications :

a) A two step FMEA analysis :

The FMEA analysis is divided in two analysis : the system analysis and the component analysis.

The pilot application clearly shows the advantages of this approach. The system engineer has only to consider "macro" components such as pumps, valves, etc... while the mechanical engineer is in charge of the precise analysis of these components.

This approach is especially profitable and interesting :

- for large components (such as pumps...) where good precision is necessary for the maintenance analysis.

- for "families" of identical or similar components : In such cases, the analyst has only to prepare one FMEA per family (generic analysis) which is finally applied to each specific case (within the exception of the severity and failure rate).

b) Depth of the analysis :

The component FMEA is prepared in order to give the same precision and quality as those of a classical program : The "causes" column of the FMEA describes all the information that the expert can identify including some description of the physical degradations. The advantage of the approach is clearly the traceability. On the other hand, the "risk" is to give too many details and thus, to increase the delay and the cost of the analysis.

After the pilot application, the conclusions concerning this question are :

- The cause column can be as exhaustive as possible, for a high traceability of the analysis, but the decomposition of each component in items has been stopped at the correct level : the "replaceable/maintainable" unit.

- This approach is especially feasable and interesting if the analysis is performed using the concept of a component "family" (generic analysis). In other words, it means that the FMEA is prepared for one generic component and reproduced for each specific case.

c) Systematic feedback analysis :

In aeronautics, the RCM analysis is prepared during the very preliminary steps of the plane design, and consequently, the feedback analysis is not possible for the initial maintenance program. In the nuclear industry, this analysis is sometimes systematic (ie : GINNA). The principle of a systematic feedback experience analysis was adopted for the pilot application because of the potentiality of 28 identical units. The cost of such an analysis is clearly high because of the number of specific forms requiring analysis. However, the advantage is clear : only the feedback analysis can give the necessary information to adapt and modify the initial RCM analysis during the living program phase.

4.3. Improvements in the methods

In parallel with the pilot application, different studies were started to improve the efficiency of the analysis. After the pilot application, and in conclusion of this R & D effort, the recommended improvements are :

a) Use of existing quantitative reliability models :

A large PSA project (EPS 900 - EPS 1300) has been carried out in EDF in 1990 to estimate the annual probability of core melt. The conclusions of the RCM complementary effort recommend the use of the models to identify the components which are critical for safety. The principle is to identify a component failure mode as critical if its contribution to the core melt probability is higher than a given level.

This approach has several advantages :

- It allows a ranking of the safety critical components

- It takes into account the redundancy of components which was impossible using the FMEA approach.

- It uses existing models and gives high coherence between safety and maintenance studies.

b) Give more quantitative criteria :

A quantitative approach can also give better criteria to identify and analyze components which are critical for electricity generation.

The basic principle is to estimate (if possible) the average loss of electricity per failure mode. This estimation can rank components which are identified as critical for generation. Combined with maintenance costs, it gives pertinent information for the selection of economical tasks.

c) Improve and formalize the analysis methods and selection criteria :

The RCM analysis is based on a functional description of systems and components. It uses criteria such as effectivness, and economy for the maintenance tasks selection.

The analysis would be more traceable, readjustable (living program) and in the future partly automatized if the methods could be clearly formalized and precisely defined (For instance : What is the best approach to identify all the functions of a subsystem or a component ? What parameters have to be examined to make sure that a maintenance task is effective ?, What costs have to be considered to decide if a maintenance task is economical ?). The objective is to give clear rules and indications to help the RCM analyst in his work.

5. CONCLUSION

After the first pilot application, the following benefits are clearly obtained from the Pilot RCM analysis :

- visibility
- traceability
- clear definition of the critical components list
- modification and readjustment of maintenance tasks and periodicity

For the next analysis, several improvements in the methods are recommended :

- Introduction of quantitative methods such as reliability models (fault trees, etc...) and the calculation of economical criteria,

- Optimization of the depth of component decomposition through the consideration of "replaceable/maintainable item" concept,

- Formalization of analysis methods and selection criteria,

The large amount of necessary data and documents managed in the RCM process, especially in the living program, clearly demonstrates the future need of computerized tools for the analyst.

REFERENCES

[1] C. EDGAR, W.D. MIDGETT, L.W. OWSENEK, J.F. WILSON. Demonstration of Reliability Centered Maintenance. Volume 3 : First Annual Progress Report From Ginna Nuclear Station - EPRI - NP - 6152 - September 1989.

[2] J.G. ANDERSON, M.J. FARRELL, A.J. HORN, E.A. HUGUES, R.E. LEVLINE, M.E. RODIN, L.C. SOUTH WORTH - Demonstration of Reliability Centered Maintenance - Volume 2 : First Annual Progress Report From San Onofre Nuclear Generating Station - EPRI - NP - 6152 - September 1989.

[3] J.P. JACQUOT, J. DEWAILLY, P. LEGAUD, L. PIEPSZOWNIK - Presentation of the development of the RCM methodology in nuclear plants - EUREDATA Meeting - Chamonix (France).October 1990.

APPENDIX A

System FMEA

System : CVCS			Sub system : 3 charging pumps subsystem			
Functional failure mode	**Component**	**Component failure mode**	**System effect**	**Plant effect**	**Severity**	**Evident/hidden failure**
Loss of flow to the charging line and seal injection subsystems	Pump RCV 01 PO	Fails to run	Temporary fail of charge and seal water injection	Shutdown due to technical specifications if repair duration > 14 days	S.P. if repair duration > 14 days	Evident
	Contactor 6,6 kV of RCV 01 PO	Fails to run	Temporary fail of charge and seal water injection	Shutdown due to technical specifications if repair duration > 14 days	S.P. if repair duration > 14 days	Evident

S.P.: Severe for Production

APPENDIX B

Component FMECA									
System : CVCS	Component : Gear reducer								
Item	Item functional failure	Component effect	Causes	Failure number	Deg. Number	Deg. Number/ overhauls	Severity	Criticality	Detection method
Bearing	Loss of guiding	Fails in run	* Failure of ball bearing	–	22	18	S.P. M >14 Days	Acceptable	Vibrations Overheating
			* Failure of journal bearing	–	6	6	S.P. if > 14 Days	Acceptable	Vibrations Overheating
			*						

S. P. : Severe for Production

THE RELIABILITY CENTERED MAINTENANCE (RCM) ANALYSIS APPLIED TO THE SAFETY RELATED COMPONENTS OF A NUCLEAR POWER PLANT

A. ERAMO, M. PASQUINI
Nuclear Safety Department,
ENEA,
Rome, Italy

Abstract

The present paper gives an outline of the activities that the nuclear Italian Inspectorate, in cooperation with the utility, has carried on to improve the nuclear power plant reliability and availability.

Some cases in which the "RCM" method has been applied for identification of applicable and efficient preventive maintenance (PM) programs are described (the maintenance also includes surveillance activities).

The analysis has been based on the operating experience, failure and maintenance data concerning an observation period of 8 ÷ 10 years.

Quantitative studies and statistical analyses on components as valves, D/Gs, instrumentations, snubbers have been made, but in this paper, a qualitative study with its conclusions is reported.

The components taken into consideration also for the significant results obtained, are:

- snubbers of the related safety systems of Caorso nuclear power plant;
- main isolation valves of Latina nuclear power plant;
- Diesel Generators of italian nuclear power plants;
- mechanical penetrations of the containment system of Caorso nuclear power plant.

The analysis performed in relation to the mentioned components have led to the following results:

- maintenance actions for a renewed PM-program;
- optimization of the surveillance test frequency;
- modification of the Technical Specifications.

All these measures taken have demonstrated a significant improvement of the components and systems performance. The operating experience data acquired successively have confirmed that benefits on the global plant safety have been carried out.

Tne "snubbers" operating experience from Caorso plant, being a significant sample, will be the basis for this study.

1. INTRODUCTION.

In this paper we illustrate an analysis of operating experience data with snubbers installated on the safety related systems of Caorso nuclear power plant.

This study has been initiated in 1980 taking the document "NUREG 0467 operating experience with snubbers", as reference.

Technical specifications and surveillance programs of these components were prescribed by the Authority Control basing upon a rather large amount of data that were available in the international biblography.

The analysis of snubbers was performed given that the reliability of these components was lower than that expected. Consequently surveillance requirements were imposed upon nuclear power plant licensees to assure operability of the all safety-related snubbers.

Increasing operational experience the most part of the problems were eliminated and recommendations for preventive maintenance tasks were implemented.

The reports deriving from Caorso plant failure reporting system have been analysed in detail. Anomalies and failure events in 426 snubbers have been re-analysed in according with the failure mode and effects analysis (FMEA) method.

2. OPERATIONAL CHARACTERISTICS AND FUNCTIONAL REQUIREMENTS OF SNUBBERS.

Hydraulic snubbers (fig. 1) are primarily utilized as seismic restraints for piping and equipment. They are designed to allow free

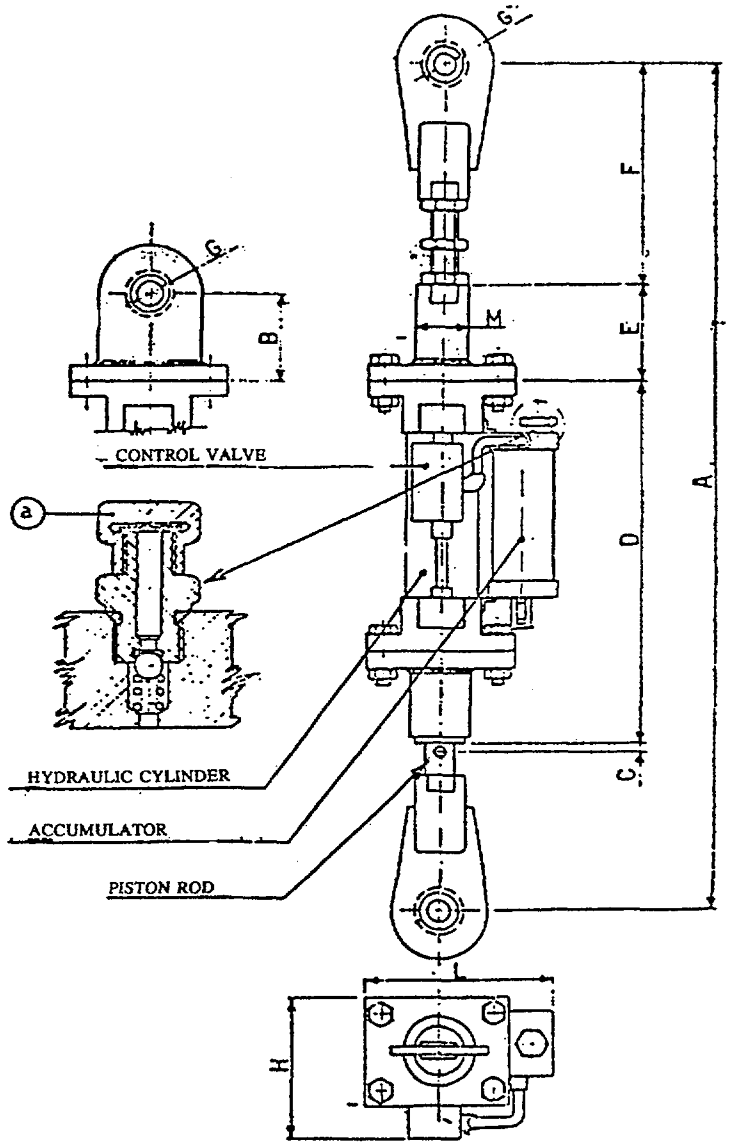


FIG. 1. Hydraulic snubber.

movements of piping systems or components when subjected to a nondynamic application of load such as that imposed by termal expansion during normal operations; when subjected to an impulsive dynamic load (seismic event) the snubber locks and controls motion of the system to which it is attached.

A schematic illustration of a snubber in operation is presented in fig. 2.

The mechanical operation mode of snubbers centers around the control valve that converts the component from a freely acting device to a strut with a given stiffness. If the snubber motion is exceeding

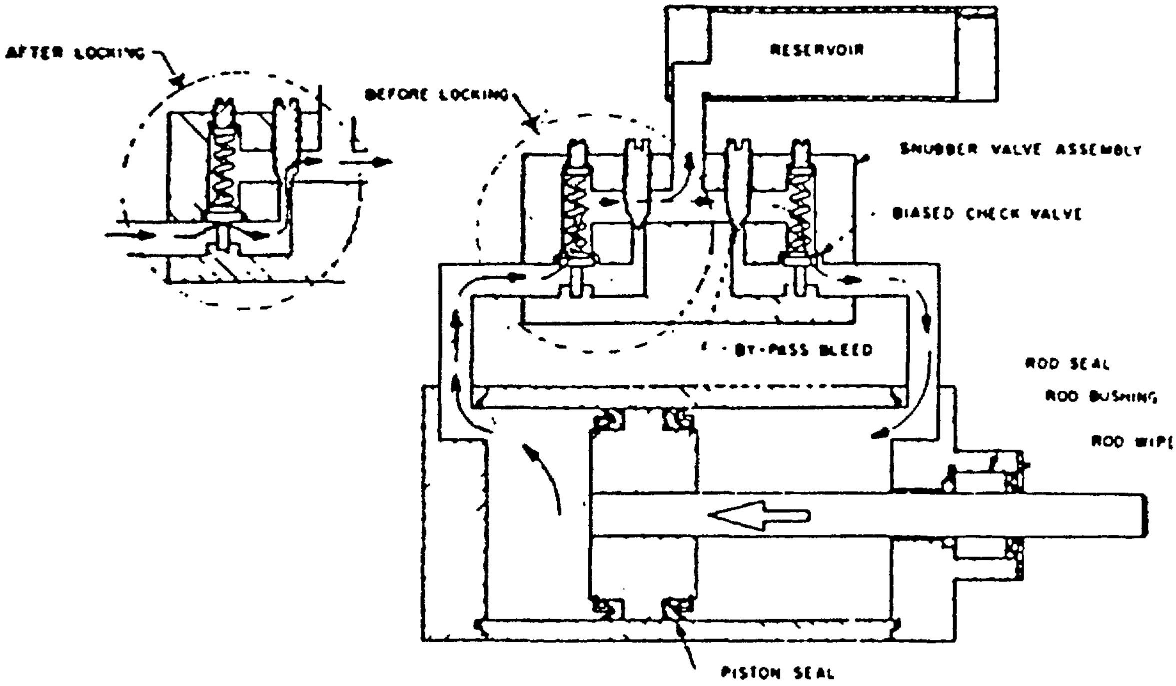
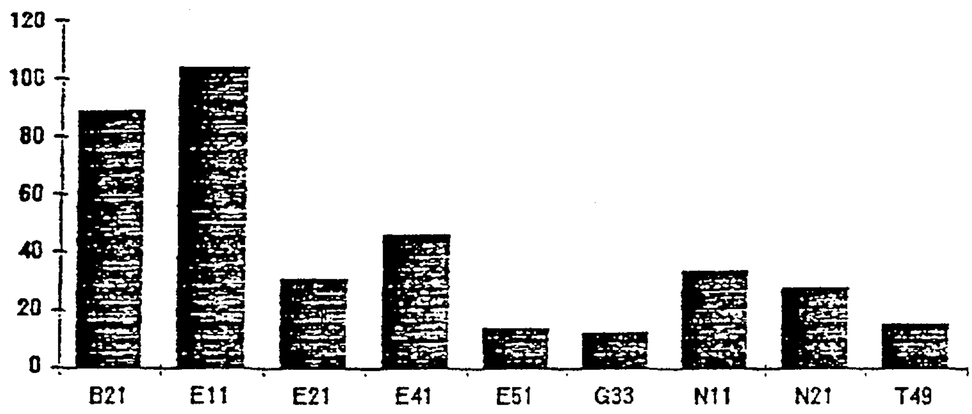


FIG. 2. Schematic illustration of a hydraulic shock arrestor in operation.

the lock up velocity (8 ÷ 20 inches/min), the poppet valve closes due to flow of hydraulic fluid (a pressure drop is created across the valve) and subsequent flow is directed to the smaller bleed orifice: the snubber is then able to carry a load because of the restricted flow. The snubber continues to translate at the bleed velocities (4 ÷ 6 inches/min) (proportional to the magnitude of the applied load) until the load is resisted.

The snubbers are located in the following safety systems (fig. 3):

- Nuclear Boiler System (B21),
- Recirculating System (B31),
- Main steam lines (N11)
- Main feedwater lines (N21),
- Residual Heath Removal (E11),
- Core Spray (E21),
- High Pressure Coolant Injection (E41),
- Reactor Water Clean up (G33),
- Reactor Core Isolation Coolant (E51),
- Post Accident Containment Atmosphere Mixing (T49).



	N. SNUBBERS		
Systems	Flexider	Grinnell	TOT
B21	89	19	108
B31		34	34
E11	104		104
E21	31		31
E41	46		46
E51	14		14
G33	12		12
N11	34		34
N21	28		28
T49	15		15
TOT	373	53	426

FIG. 3. Total snubbers installed on safety related systems.

The snubbers utilized at Caorso plant are divide in two significant groups: 53 Grinnell snubbers, all inaccessible and 373 Flexider snubbers of which 215 inaccessible and 158 accessible.

The sizes of Grinnell snubbers range from 2½" to 6" diameter bore while the Flexider snubbers from 10" to 40" diameter bore (Table 1). Being the operation mode enough similar the two snubber types have been considered as a single sample.

3. SNUBBER DATA AND ANALYSIS METHOD.

The data have been obtained from the plant failure reporting system of Caorso plant and include failure events reported in the period from 1.1.81 to 31.12.89.

The reporting system contains information on failure events in a coded form and time points related to the detection of failure and repair actions.

TABLE 1. TOTAL SNUBBERS SUBDIVIDED FOR SIZE AND ACCESSIBILITY

TYPE	FLEXIDER						GRINNELL			
SIZE	10"		20"		30"	40"	2"/3"	4"	5"	8"
SYSTEM	I	A	I	A	I	I	I	I	I	I
B21	86		3				15.	2	2	
B31							13	7	14	
E11	15	77	8	2		2				
E21	4	26		1						
E41	4	42								
E51	4	10								
G33	12									
N11			8		25	1				
N21	8		3			17				
T49	15									

I= INACCESSIBLE A= ACCESSIBLE

The failure reports have been studied mainly in order to identify the possible failure mechanism and their effects on the system.

A specific classification for failures was addressed in order to identify snubber parts failed, failure modes, causes, effects and ways of failure detection.

3.1. FAILURE MODES (see Table 2).

In the classification of failure modes only the most typical modes related to failed items are specified.

A "frozen" snubber represents the highest potential for system degradation. The frozen snubber is one which inhibits the normal

TABLE 2. PRINCIPAL FAILURE MODES AND CAUSES RELATED TO DIFFERENT FAILURE EFFECTS ON SNUBBER OPERABILITY

FALIURE MODE	FALIURE CAUSE	FAILURE EFFECT
Frozen snubber	Design or material deficiency wrong adjustment,vibration etc..	Not operable
Fluid leakage	Seal degradation,dirty,oxidation poor maintenance,wear	Operable,not operable
Functional requirements out of the allowble range	Characteristic of oil,dirty oxidation,wear	Not operable
Environmental condition	Characteristic of oil	Operable, Not Operable
Mechanical stress and localization	Vibration,design deficiency	Operable,not operable

free expansion of the system during thermal loading. It will frequently cause an overstressed condition, given that many times snubbers are specified in such a way the system cannot take the same stress associated with the use of a rigid restraint.

The second most serious operational problem for snubbers is fluid leakage that uncovers the hydraulic fluid reservoir in a hydraulic snubber. A snubber completely void of fluid will not satisfy the specified design requirements, although a partially voided snubber may provide some reaction during the dynamic event.

The third failure mode is that to identified during the surveillance test of the component when the lock up velocity and/or bleed rate are out of the allowable range.

Another important issue to be considered is the effect due to various environmental conditions during either normal operation or test of the snubber.

The last failure mode depends from the mechanical stress and localization of the component.

3.2. FAILURE CAUSES AND EFFECT ON SNUBBER OPERABILITY.

Often the failure modes concerning the snubber cannot be associated to a specific root cause, but more causes can lead to the same failure mode.

The snubber is divided into 8 components. These items are defined so that each reported failure may be assigned only to one hardware item.

The parts are following: cilinder, piston, piston seal, oil, poppet valve (compression and estension), pressure relief valve, accumulator, supporting structure.

The failure of a subcomponent not always affect the snubber operability; in many cases the failure of an item may have no immediate effect on the component operability but it is necessary to undertake repair actions in order to prevent the snubber inoperability.

The principal failure cause is classified in one of these defined groups:
wrong adjustment, seal degradation, poor maintenance, design or material deficiency, characteristics of oil, human factors, dirt and oxidation, vibration, etc.
A specific analysis to identify the root causes clearly is still in progress.

3.3. FAILURE DETECTION.

A failure can be only detected during either the visual inspections of all snubbers (every 18 months) or the functional testing (every 18 months).
Visual inspections shall verify that there are not visible indications of damage and that indicated service life will not be exceeded prior to the next scheduled review. The efficiency condition of the component depends on the zone reported in Fig. 4, with reference to the stem movement (T) and the accumulator pointer shifting (S) Zone B is optimal zone, C and D require some maintenance; if the component, performance is in zone A or E, it is declared inoperable and submitted to the functional testings. The number of snubbers, found inoperabale in this way, determines the time interval for the next required inspection (see Table 3).
Since outside of these controls it is not possible to know the snubber term, the Technical Specifications provide that, at least once per 18 months, a representative sample (10 Flexider Snubbers and 3 Grinnell snubbers) shall be functionally tested to verify that the lock-up velocity and bleed rate are inside the allowable limits.
For each snubber found inoperable an additional sample shall be functionally tested until no more failure is found.
A block diagram of the control operating procedure applied is reported in fig. 5.

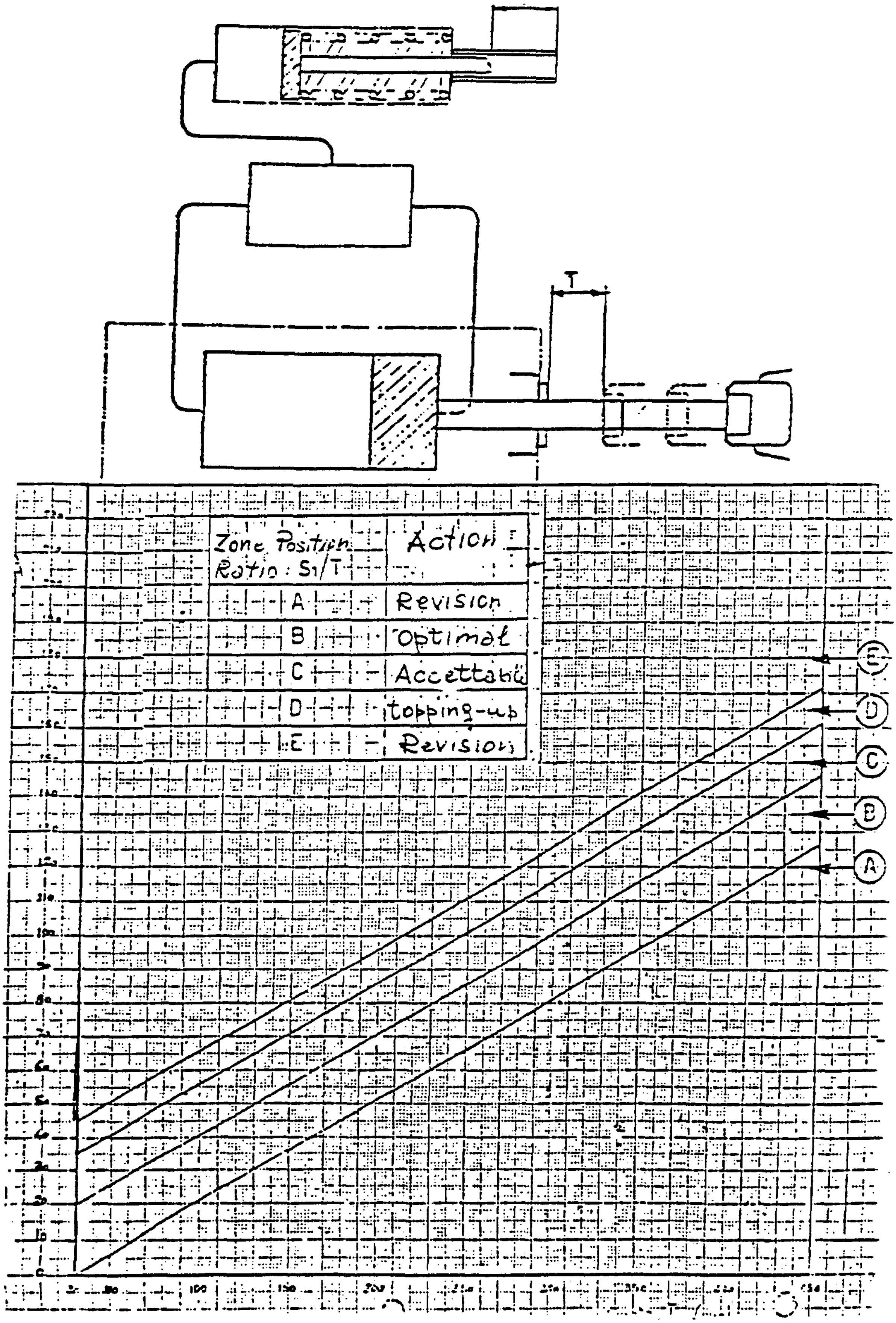


FIG. 4. Efficiency diagram of the snubber.

TABLE 3. INOPERABLE SNUBBERS AND TIME INTERVALS TO INSPECTION

Snubbers found inoperable	Next time interval of inspection
from 1 to 2	12 months
from 3 to 5	6 months
› 6	3 months

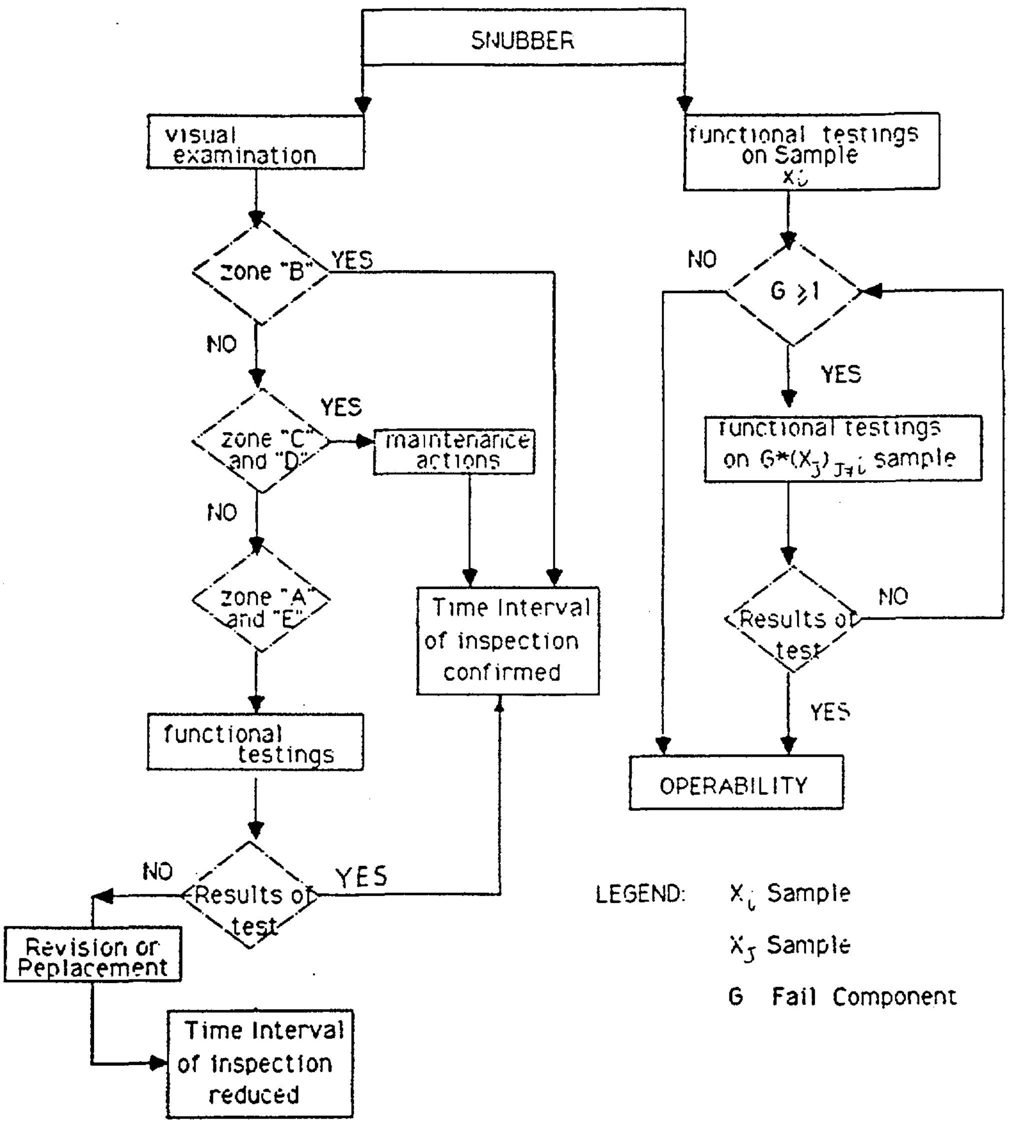


FIG. 5. Block diagram of control operating procedure.

4. RESULTS OF ANALYSIS.

Being the operational mode of the Grinnell and Flexider snubbers enough similar, a single sample in the analysis has been considered.

Originally there were non mandatory surveillance requirements and, therefore, there was no-systematic identification of snubber related problems.

In 1981, during the first inspection, many anomalies were uncovered and the utility decided to remove all the snubbers.

The most critical problem has been seal deterioration, successively replaced with the new seel materials (ethylene-propylene); the visual examination revealed large amounts of oxidations on the no-nickelage components; defects attributable to constructive deficiencies were also identified.

This wicked experience induced the Nuclear Safety Authority to insert in the Technical Specifications the operability verification by visual inspection and the functional testing in codified form.

The first true inspection conducted on the basis of inservice surveillance and testing programmes was conducted during the first refuelling of the plant in Genuary 1983. By the visual examination anomalies on the thirty-four percent of snubbers were found and among the snubbers placed in zone "A and E"; six snubbers were declared inoperable. Then as provided in the Technical Specifications (see table E), at the end of 1983 the plant was stopped to carry out an extraordinary inspection on these components.

By the visual examination a great amount of snubbers (57 on 356 of which 9 "accessible" and 48 "inaccessible") demonstrated abnormal occurrences: of these (57) the 81% failed the functional tests and at last 61% arised oil leakage; the 31% of snubbers presented evident marks caused from non correct movement.

Specific analysis pointed out that the snubbers inoperability was mainly due to the oil leakages attributable to field installation and manifacturing errors.

Since time on a correct application of snubbers control procedures produced a drastic cut in anomalies as table 4 and Fig. 6 show.
Table 5 and 6 represent rispectively the number of snubbers found in zone "A" and "E" and those declared inoperable to the functional tests carried on succesively as required by the control procedure (see Fig. 5).

The results obtained confirm the classic evolution of equipment failure rate according to the well known "Bath-tube curve".
The initial worries of the utility, caused by the considerable number of anomalies cecked that involved many man-ours for maintenance repairs and consequentily high doses absorbed by the workers, came less beginning from 1984.

The maintenance planning and the procedures applied correctly have showed all their efficacy, either in order to the component reliability or in order to the doses absorbed and maintenance costs.

TABLE 4. ANOMALIES FOUND ON SNUBBERS BY VISUAL EXAMINATION

YEAR	80/81	83	83	84	85	86	88	89
SYSTEM	%	1 Half	2 Half	%	%	%	%	%
B21		40	30	26	30	14	0	
B31		18	20	0	35	0	0	
E11		14	5	53	0	5	4	* 8
E21		8	3	22	13	13	0	* 0
E41		26	9	25	13	52	7	
E51		31	28	57	21	14	0	
G33		18	30	25	0	0	0	* 0
N11		38	0	66	11	32	15	
N21		36	8	50	7	14	4	
T49		21	36	0	13	0	20	
TOTAL%	100	34	28	35	15	15	5	5

* SYSTEMS REQUIRED OPERABLE IN SHUT-DOWN CONDITION

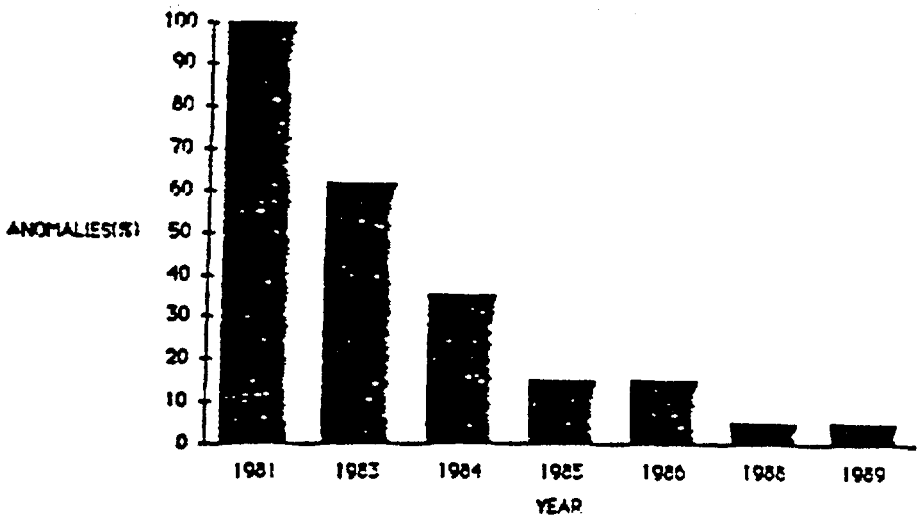


FIG. 6. Total anomaly trend of the snubbers.

TABLE 5. NUMBER OF SNUBBERS FOUND IN ZONES A AND E BY VISUAL EXAMINATION

YEAR	80/81	83	83	84	85	86	88	89
SYSTEM		1 Half	2 Half					
	N.A.	N.	N.	N.	N.	N.	N.	N.
B21			30		4	3		
B31					3			
E11		5	9		1		1	2
E21		2	2					
E41		13	4					
E51			1					
G33			4					
N11		13		1	1	3	1	
N21		10	1	2	2			
T49		1	6		1		1	
TOT		44	57	3	12	6	3	2

TABLE 6. SNUBBER INOPERABILITY DECLARED AFTER FUNCTIONAL TESTING

YEAR	80/81	83	83	84	85	86	88	89
NUMBER	N.A.	6	38	1	3	1	1	0

CONCLUSIONS

Analysis of the operating experience using FMECA method has been demonstrated.

The optimization of maintenance strategies of equipment has improved trend analisys of faults and at the same time has increased the component reliability.

The correct application of the procedures, the utilization of an articulated maintenance program based on revision, replacement, inspection and the application of Quality Assurance program has decreased the maintenance and outage costs moreover reducing the dose absorbed by the workers.

Unfortunately this considerable experience will not have any positive relapses on the Caorso plant, stopped definetively in 1990, but surely it will be utilized by the future generation of intrinsically safety reactors.

DEVELOPMENT OF THE TORNESS MAINTENANCE SCHEDULE

M.L. JENKINS
Scottish Nuclear Limited,
Glasgow, United Kingdom

Abstract

The paper describes the approach taken to establish the maintenance policy for safety-related systems to comply with pre-determined reliability criteria. The design safety guidelines for the AGRs require the system unreliability not to be higher than 10E-3 for credible initiating events. For the maintenance tasks, the procedures are developed within a "Maintenance Inspection and Test Schedule" document.

1. INTRODUCTION

1.1 Scottish Nuclear Limited was formed on 1st April 1990 as a private Company from the Nuclear Generation part of the South of Scotland Electricity Board. It is at present soley owned by the British Governement and our shareholder is the Secretary of State for Scotland. It operates under normal UK Company Law and it comprises two operating AGR Stations Hunterston B and Torness, and also a MAGNOX Station at Hunterston A which is currently being de-commissioned. The total capacity is 4 x 660 MW and the staff is approximately 2000 people. The HQ is located in Glasgow, Scotland.

1.2 Hunterston A is a 2 Reactor MAGNOX Station with 6 x 60 MW output generators. It is twenty-five years old and is currently being de-commissioned. It is located on the west coast of Scotland on the Clyde.

1.3 Hunterston B comprises 2 x 1500 MW AGR reactors and 2 x 660 MW generators, and has been running for 18 years. It is located with Hunterston A.

1.4 Torness comprises 2 x 1500 MV AGR reactors and 2 x 660 MW generators and has been generating for over three years and is presently working at full load. Load factor is at present limited by having to refuel off load. It is located on the East coast of Scotland near Dunbar about 60km from Edinburgh.

1.5 This paper gives the approach taken to establish the maintenance policy for safety related plant at Torness Power Station based on the requirement to establish pre-determined reliability criteria.

2. THE ADVANCED GAS COOLED REACTOR (AGR): DESIGN SAFETY GUIDELINES

2.1 The Health and Safety Department of the Central Electricity Generating Board (CEGB) set up "Design Safety Criteria for CEGB Nuclear Stations" in the late 1970's. From these criteria the CEGB Design and Construction Division prepared the Design Safety Guidelines to enable designers to achieve the required reliability for safe operation and maintenance of the AGR. These were adopted by the SSEB for the design of Torness Power Station.

2.2 In essence the Guidelines state that :
"Each reactor and Station shall be so designed and constructed that it may be readily maintained and operated economically without causing unacceptable risk to either the operators or members of the public".

2.3 In the case of In Service Inspection Testing and Monitoring, it stated that "all safety related plant should have the means of testing the operatility and functional performance of both systems and components to detect any deterioration. The frequency and method of examination and testing shall be determined by a proper consideration of the former rate of deterioration which can be foreseen and by any requirement to confirm claimed reliability".

2.4 These considerations may lead to continuous monitoring of the condition of certain components either because there performance is critical or because the nature and rate of deterioration cannot be accurately predicted.

2.5 External hazards such as earthquake, wind, flooding, aircraft crash, extreme temperature etc, were analysed and standards laid down against which the danger was measured. The criteria taken was that in the event of a specific hazard affecting the site, any activity releases from the plant will not result in a dose at the Station Boundary to rise beyond the E.R.L. (Emergency Reference Level).
Regarding reactor faults this condition will be assumed to have been met if it is shown that failure to shut down and failure to cool the reactor will each be no greater tham 10^{-6} per demand where failure is defined as the causation of doses in excess of one ERL.

2.6 The internal hazards such as fire, explosion, release of gases or liquids, disruptive failure of pressure points and rotating machines etc were analysed and standards laid down for each situation.

2.7 In the case of trip, shutdown and other essential systems, the basis of reliability targets and general reliability requirements are defined.
This can be expressed as :
Total probability of an uncontrolled release

$$<10^{-6} \text{ p.a.}$$

Following any initiating fault an unacceptable release can occur as a result of the trip, shutdown or cooling systems failing to work effectively, also for any initiating fault there can be many different fault sequences. These have been analysed and for this a criteria of performance of safety circuit set down as

$$ft \leq 10^{-7}$$

Where ft is the peak value of probability of failure of the safety system to initiate a shutdown on demand, excluding a maintenance factor.

Taking into account maintenance, the removal of equipment for test, the application of vetos and other factors which may cause temporarily reduced integrity, the instantaneous value of the fault shall at no time be increased by more than a factor of 10 and then for no more than 2% of the maintenance interval. The removal (from service) of such plant is controlled to achieve this aim.

2.10 From all the considerations the Reference Safety Statement (RSS) (or Safety case it is commonly referred to) is made for each plant item associated with reactor safety. On the basis of acceptance of these safety cases by the Nuclear Installations Inspectorate the Site Licence to operate is approved.

2.8 Whilst this is a target for design the overriding requirement which should be met is that following any single credible initiating fault, the system unreliability is not greater than 10^{-3}.

2.9 Fault Sequence Probability Analysis FSPA has been applied to all identified fault sequence and this influences the required performance, availability and reliability of plant and protection systems. It is further assumed that any maintenance of individual plant items as is either required periodically or inferred from the revealed condition of the plant is carried out as necessary. To maintain a satisfactory level of reactor availability it is necessary to ensure that both planned routine maintenance and any unplanned outage of certain plant items can be permitted while the reactor remains at power. This is made possible by the redundancy and diversity in design.

3. THE SITE LICENCE

This states that general conditions under which the Station may operate, and covers all aspects such as the marking of the boundary, incidents and emergency arrangements, operating rules, safe guards, quality assurance, construction, commissioning, de-commissioning, documentation, maintenance, etc.

In order to comply with these requirements a schedule has been compiled, called the Maintenance Inspection and Test Schedule (MITS).

To arrive at the activities necessary to assure the reliability of safety related plant the Reference Safety Statements were used. These give details of the probability of failure of certain plant items and what was required to be done and at what frequency in order to restore an anticipated deterioration of performance to a level which satisfied the Design Safety Guidelines.

4. REFERENCE SAFETY STATEMENT

These have a standard format: there is a description of the plant and how it functions; an analysis of the possible fault sequences and the protection provided; the equipment is specified and the probability of failure of each component analysed. From this an indication of the Critical Tests Inspections and Maintenance required is indicated.

5. MAINTENANCE INSPECTION AND TEST SCHEDULE

This is divided into an introduction and definitions of agreed time periods used in the schedule, followed by the detailed requirement of each plant item. The references are common to the RSS's.

In order to translate the simple statements into practical instructions, support documents have been prepared which define the plant, the tests and work to be done and references the Plant Item Operating Instruction or Plant Item Maintenance Instruction which is issued to the operator to carry out the work.

6. PRACTICAL APPLICATION

The planning of the MITS work has been computerised and the jobs are automatically issued for programming at the due time. Verified Certification is made for each task and this is kept in lifetime records.

Audit programmes are used to give an early indication of any MITS task approaching its due date and these are reviewed on a daily basis.

In 1990 the MITS tasks averaged approximately 1000 per month and all but 9 were completed on schedule. This is some 40% of the routine maintenance work carried out.

7. DOCUMENTATION

Procedures are in place which cover :-

7.1 How MITS items are developed from the RSS.

7.2 How MITS work is managed.

7.3 How modifications are controlled.

7.4 How Plant Item Operating and Maintenance Instructions are prepared, revised and validated.

7.5 How training is specified and carried out.

These have been audited by the Nuclear Installations Inspectorate but are under continuous review with changes caused by modifications and change to the RSS.

8. REVIEW

System Safety Reviews are incorporated in the MIT Schedule and these are used to measure the actual plant performance against that claimed in the RSS and Design Safety guidelines. The results hopefully will lead to a reduction in the maintenance work load whilst maintaining reliability.

REFERENCES

1. CEGB AGR Design Safety Guidelines DSG1
2. Nuclear Site Licence No. SC4B - Torness Nuclear Power Station
3. Fault Sequence Probability Analysis - Maintenance Study C34/SDD/108
4. Torness Maintenance Schedule Issue B2

INTERNATIONAL MAINTAINABILITY STANDARDS

J. KRASNODEBSKI, C.B. WAINWRIGHT, M.S. GROVER
Design and Construction Branch,
Ontario Hydro,
Toronto, Ontario,
Canada

Abstract

Electric power plant operators are paying increasing attention to maintenance because of the ever increasing maintenance work loads affecting plant availability, safety and costs. Techniques such as Predictive Maintenance, and Reliability Centred Maintenance (CRCM) are being utilized by plant operators to optimize maintenance programs and reduce plant life cycle costs. However, the ability to maintain equipment at a specified performance level, with expected staff and resources constraints, depends on plant maintainability. Maintainability is a parameter of design and is a result of decisions taken in the conceptual and detailed design stages of a plant in the areas of: Plant layout, System design, Equipment specification and selection. In addition to adequate maintainability, maintenance support in terms of spares, maintenance instructions, special equipment/tools, workshops and training of maintenance personnel must be provided for in the design stage.

In order to provide guidance in fields of maintainability, and maintenance planning and support, a set of international standards in this field has been prepared by the Technical Committee 56 - Reliability and Maintainability of the International Electrotechnical Commission (IEC). IEC is an international standard writing body in the electrotechnical fields and consists of a number of standard writing technical committees.

The standards on maintainability and maintenance planning and support are generic and can be applied to nuclear power station equipment, as well as, with some tailoring, to nuclear power station design. IEC Publication 706 - Guide on Maintainability of equipment consists of nine sections, six of which have been published, and others are expected to be published shortly. Contents of Section Five - Maintainability Studies During the Design Phase and Section Eight - Maintenance and Maintenance Support Planning will be described in more detail in this paper.

The salient aspects of a forthcoming draft standard on RCM which is an extension of Section 8, will also be described. This standard defines the application of RCM both to systems and structures.

The paper concludes that in order to achieve the required level of safety and availability economically in our nuclear generating stations, maintainability must be considered as one of the prime design parameters.

INTRODUCTION

Maintainability is defined as: "the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources". It is a design parameter and results from decisions taken in the conceptual and detailed design phases of a project in the areas of layout, system design, and equipment specification and selection. In order to ensure adequate maintainability, designers must plan and initiate development or acquisition of maintenance support logistics in terms of spares, maintenance instructions, special equipment and tools, workshops, training of maintenance personnel, etc, during design stage.

In the case of electric power utilities, maintainability is often not adequately considered in the early design cycle of a plant, or is forgotten or superseded by other considerations during the detailed execution of design. Planning of maintenance support is generally performed by operations personnel a few years before start-up but after a number of design decisions affecting it have already been made.

This is, to some extent, evident from the lower than expected capacity factors of nuclear plants worldwide as well as from the high maintenance costs and their rising trend. The 1990 and lifetime capacity factors (%) of various types of nuclear units of size larger than 500 MW (excluding those in USSR) are as follows:

Reactor Type	1990 (%)	Lifetime (%)
PWR	70.1	64.8
BWR	66.8	61.0
PHWR	67.1	75.1

Electricite de France reports (Ref. 1) that the annual maintenance costs of their PWR stations are showing a rising trend. In 1989 these costs were equal to 2% of construction cost of N4 type of plant (1400 MW size).

Considering the above, the electric power plant operators are paying increasing attention to maintenance aspects of the operating plant. Techniques such as Predictive Maintenance and Reliability Centred Maintenance (RCM) are being utilized by them to optimize maintenance programs in order to improve plant safety and availability, and to minimize life cycle costs. With this approach, however, electric power utilities are trying to influence only a small portion of plant life cycle costs. It is generally accepted that almost 80% of the project's life cycle costs are determined by the project design phase. It is, therefore, prudent to control costs associated with plant safety, availability and maintenance by addressing plant maintainability aspects during the design phase.

STANDARDIZATION

In order to incorporate maintainability considerations in the design of a new plant, or modifications/rehabilitation of an existing plant, a number of standards have been or are being developed. A standard can be defined as a document which provides optimized rules, goals and objectives established by consensus, based on the collective experience and learning of participants, and approved by a recognized body. Standards provide a means of retaining experience.

Standardization and standards exist at a number of levels. In ascending order of their applicability, the four most important levels are:

1. The company level - standards issued by an individual company or a group of companies, reflecting common agreement of constituent organizational units.

2. The industry level - standards developed by industries or a specific industry.

3. The national level - standards promulgated after obtaining a consensus of all interests in a country, through a national standards organization.

4. The international level - standards resulting from cooperation and agreement between a number of nations having common interests. Such standards are intended for worldwide use.

All these standards have similar but differently focused objectives. The main objectives of any standard are safety, quality and economy of a product or service. International standards have the additional objectives of eliminating trade barriers and of facilitating technical communication and technology transfer between nations. International standards also provide the basis for, and are frequently adopted as, national standards.

IEC MAINTAINABILITY STANDARDS

The following reviews international standards in areas of maintainability and maintenance support being developed by the International Electrotechnical Commission (IEC), Technical Committee 56 (IEC/TC56) - Dependability.

Founded in 1906, the objective of the IEC is to promote international cooperation on standardization and related matters in the fields of electrical and electronics engineering and thus to promote international understanding. In 1965, recognizing the importance of reliability to electronics, the IEC established a new Technical Committee, TC56 - "Reliability of Electronic Components and Equipment". In 1974, the IEC changed the name of TC56 to "Reliability and Maintainability" in recognition of the wide application of reliability to other disciplines in the electrotechnical field. In 1990, the TC56 name was changed again, this time, to "Dependability". Dependability is defined as: "The collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance". The mission of IEC/TC56 is: "To develop and maintain a coherent and complete set of generic international standards to assist the World Community on management and execution of specification, analysis improvement, evaluation and other activities related to dependability". IEC/TC56 activities were harmonized recently with those of ISO/TC 176 "Quality management and quality assurance" and ISO/TC69 "Statistics". As a result of this harmonization, the scope of TC56 was extended to cover all products well beyond the scope of IEC.

Working Group (WG6) of IEC/TC56, on Maintainability is responsible for the development of standards and guides in the field of Maintainability and Maintenance support. The document which is presently being developed by WG6 is a "Guide for Reliability Centered Maintenance". The methodology described in this guide is based largely on the document *Airline/Manufacturer Maintenance Program Development, MSG-3 Rev. 1,* prepared by the Maintenance Steering Group-3 Task Force of the Air Transport Association of America ATA. *MSG-3* is a descendent of *MSG-1,* the original document on RCM published in 1969. The IEC RCM Guide addresses the preparation of an initial preventive maintenance program for new systems or structures, but it can also be applied to existing ones. The Committee Draft of the IEC RCM Guide has been approved and the Draft of the International Standard is being prepared for final approval before publication. The Table of contents of this Guide is given in the Appendix 1.

The main document, which has been developed by the WG6 over a number of years, is the IEC 706 "Guide on Maintainability of Equipment" which is nearly complete. This guide contains nine sections which are grouped by common objectives.

IEC Publication 706-1, issued in 1982, contains the following sections:
Section One - Introduction to Maintainability
Section Two - Maintainability Requirements in Specifications and Contracts
Section Three - Maintainability Program

IEC Publication 706-3, issued in 1987, contains the following sections:

Section Six - Maintainability Verification
Section Seven - Collection, Analysis and Presentation of Data related to Maintainability.
IEC Publication 706-2 issued in 1990 contains the following section:

Section Five - Maintainability Studies during the Design Phase

The remaining sections of the guide are now complete and have been approved for publication. Their titles and expected publication dates are as follows:

Section Four - Diagnostic Testing (1992)
Section Eight - Maintenance and Maintenance Planning (1991)
Section Nine - Statistical Methods in Maintainability (1992)

The content of Section Five and Eight, which are considered to be of the greatest interest to this audience, are discussed in more detail in the following:

"Section Five - Maintainability Studies during the Design Phase" outlines maintainability studies to be performed during the preliminary and detailed design phase of systems and equipment. The objectives of these maintainability studies are to predict the quantitative maintainability characteristics of equipment, to identify requirements for certain features or changes to design to improve maintainability and to guide design decisions. It also provides guidance for design support activities, and maintainability checklists for design criteria and design reviews. The annexe provides an example of a maintainability target allocation.

"Section Eight - Maintenance and Maintenance Support planning" describes the tasks for planning of maintenance and maintenance support which should be performed during the design phase of systems and equipment in order that availability objectives in the operational phase can be met. The objectives of the above planning activities are to:

o Develop a maintenance concept, and make maintenance and maintenance logistic support requirements an integral part of systems requirements.

- o Determine the impact of required system maintenance activities on maintenance logistic support requirements and optimize the maintenance concept.

- o Define the maintenance logistic support requirements and the maintenance plan.

- o Specify the necessary maintenance logistic support resources.

Appendix A - "Maintenance Planning Analysis", of Section Eight, describes maintenance task identification and analysis and repair level analysis. The latter defines the appropriate line of maintenance (organizational, intermediate or depot) and level of equipment at which repair is to be made.

Appendix B - "Maintenance Support Resources Determination" of Section Eight, outlines the activities to define the following maintenance resources:

- o Personnel skills and training
- o Technical manuals and software
- o Test and Support Equipment
- o Spare parts provisioning
- o Maintenance Facilities

The Table of Contents of Section Eight is given in the Appendix 2.

The technical committee No. 56 also prepared a number of publications in the area of analysis techniques for system reliability, providing input and support to maintainability and maintenance support activities. The publication which was published is *Document 812 (1985) -Procedure for failure mode and effects analysis (FMEA).*

A number of other publications which were approved and are being edited before publication are as follows:

56(Central Office)121 - Procedure for Fault Tree Analysis (FTA)

56(Central Office)137 - Reliability Block Diagram method

56(Central Office)138 - General consideration of reliability/availability analysis methodology.

CONCLUSIONS

The IEC/ISO Standards described in this paper provide useful guidelines for essential maintainability-related design activities which have major impact on the life cycle of systems and equipment. These standards should be used during the design of new plant and/or of improvements to and rehabilitation of, existing facilities. This shall facilitate achievement of optimum levels of maintainability and maintenance logistic support and, consequently, higher availability and lower Life Cycle Costs than those currently realized at existing facilities.

REFERENCES

1. J.P. Mercier, 1990, ***Nuclear Power Plant Maintenance***, Editions Kirk, Collection Industries, Maison-Affort France

2. Air Transport Association of America, ***World Airline Suppliers Guide,*** Washington, D.C., USA

3. Air Transport Association of America, Airline/Manufacturer, ***Maintenance Program Development Document, MSG-3***, Rev. 1, Washington D.C., USA

APPENDIX 1

GUIDE FOR RELIABILITY CENTERED MAINTENANCE

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APPENDIX 2

GUIDE FOR MAINTAINABILITY OF EQUIPMENT

Section 8: Maintenance and Maintenance Support Planning

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IMPORTANT DECISIONS IN RELIABILITY CENTERED MAINTENANCE (RCM) PROGRAM PLANNING: INCEPTION TO IMPLEMENTATION

L.W. OWSENEK, W.D. MIDGETT
PRC Engineering Systems, Inc.,
Reston, Virginia,
United States of America

Abstract

Reliability Centered Maintenance (RCM) Programs in the US nuclear industry follow relatively standardized RCM analytical methodology. While much attention has been directed to subtle differences in technical approach, some of the more fundamental issues have not been as thoroughly debated and can have an even greater effect on the outcome of an RCM program.

Important and justifiable differences exist in RCM Programs based on differences in plant size, age, performing organization, character and adequacy of the existing PM program, goals and objectives set for the program, and a number of other factors based on the unique character of the plant and its engineering, operations and maintenance staff. This paper discusses a number of the more significant issues and decisions which must be made by utilities based on these differences, and how these decisions have a profound effect on the conduct of the RCM evaluations as well as the adequacy of the results.

INTRODUCTION

Large scale RCM demonstration projects at RG&E's Ginna Station and SCE's San Onofre nuclear generating station stimulated interest in RCM methodology across the USA and in the international community as a whole. Basic steps of the analytic method were defined and refined as each new utility started a pilot program or contemplated a similar large scale project. The focus on analysis methodology was intended to ensure that fundamental errors were not made in applying the new technology. As experience was gained, confidence and wider understanding of the analytical process resulted. With this maturation of the process, certain important issues surfaced which are fundamental to how the analysis is conducted. These issues are as important, if not more so, than the subtle differences which exist in the analytical methods used or the sequence of work.

The issues addressed in this paper were selected by the authors based on their involvement in various RCM programs at US nuclear utilities, related RCM objective is to raise awareness of a number of important issues for RCM Program planning purposes and to encourage debate and informed decision making before the RCM analysis is begun.

IMPORTANT DECISIONS IN RCM PROGRAM PLANNING: INCEPTION TO IMPLEMENTATION

Success in planning and implementing an RCM Program depends on a number of key decisions made by the RCM program planners. The decisions should be made by individuals thoroughly familiar with the RCM analysis process, and knowledgeable in both the analysis methodology and related issues. This paper identifies some of the more important issues which have emerged since the start of major RCM programs in the US in 1988. Not all of the issues are discussed in depth, nor are answers provided which are appropriate for all situations. Some of the issues involve decisions which affect conduct of the analysis, while others are more programmatic; both can have a significant effect on the ultimate success of the RCM program.

Justifying the Program - RCM Cost Effectiveness

The question of RCM cost effectiveness is almost always raised in the program planning and decision making process. Clearly identified cost savings are not easily identified from other utility RCM programs, nor are they necessarily representative of the savings which might be realized in the program being contemplated. Near term cost savings from PM task reductions are not fully realized unless accompanied by staff reductions, and long term cost savings from avoidance of potential equipment failure are probabilistic.

Is RCM cost effective? The answer to that question is a function of the applicability and cost effectiveness of the existing PM tasks, and the utilization of information created through the RCM process. The decision is an important one; whether or not to perform an RCM Program, and how much to invest in it.

In determining the potential value of an RCM program, the adequacy of the tasks in the existing PM program is probably the most significant factor. If the existing PM program contains excessive, inapplicable or ineffective tasks, the result is likely to be a reduction in PM tasks with an associated reduction in task performance labor. On the other hand, if the existing PM program does not contain all of the PM tasks that it should to prevent failure of critical components, an increase in the number of PM tasks will be the likely result. Here though, the increase in PM task performance labor will be offset by large cost savings resulting from failure avoidance in critical equipment.

The important point is, tangible cost savings from an RCM program are likely to be found in near term for plants with excessive or inapplicable PM tasks, and in the long term for plants with inadequate or weaker PM programs. Payback period estimates will vary considerably from plant to plant. Understanding this basic point, and knowing which situation applies, helps those planning the program to form appropriate expectations for its results. Plant to plant comparisons on the number of PM tasks provides some insight if the comparisons are on an equal basis. An evaluation of the cost of maintenance preventable equipment failures in the plant's recent past may also be a good indicator of potential savings.

Intangible benefits accrue as a result of nearly every RCM program. In certain cases, these may be even more significant than those associated with the PM tasks themselves. Assignment of appropriate value to these "by-products" of the RCM process will allow a more complete estimate to be made of the potential value of the RCM program. Depending on the situation, these may include;

- Accurate and consistent input for the plant's IPE Program
- A documented basis for the plant's PM Program
- Discovery of cost effective design improvement opportunities
- Discovery of failure trends by equipment type, age or failure mode
- Input for spare parts inventory upgrades
- Input for vendor manual upgrade programs
- Input for maintenance procedure improvements
- Input for root cause analysis programs
- Increased plant personnel equipment importance and function knowledge
- Increased system engineer system O&M knowledge
- Failure event data for the "Living RCM Program"
- Input to the work control process and maintenance management system

The value of each of these "by-products" of the RCM analysis process can be tangible and considerable, but full benefit is often limited by a lack of recognition or planning for their application.

Goals and Objectives

If a conscientious effort is made to explore all the potential benefits of an RCM program, the process of setting goals and objective will follow logically. The decisions which must be made in setting goals and objectives should be based on the character of the existing PM program, but even more importantly, should focus on planning for full utilization of the "by-product" benefits. Broad goals and objectives may also be necessary for policy reasons, but these have little real value in guiding performance of the work.

In setting project goals and objectives, consideration of the following is suggested;

- PM Task Reductions - Elimination of ineffective or inapplicable tasks is always an expected result of the RCM evaluation process. A specific objective here might be identification of tasks which reduce contracted labor or consume critical path time during outages, startup, shutdown or required inservice testing. The additional focus may yield greater real near term cost savings.

- PM Task Additions - Utilization of Existing Predictive Maintenance Capability - Substitution of predictive maintenance tasks for time directed tasks is a fundamental part of RCM methodology. In order to ensure that the predictive maintenance tasks proposed by the engineers can be implemented, specific objectives for utilization of existing or planned predictive maintenance technology are recommended. A sure path to difficulty in implementing RCM program results is the inability of the plant, either technically or organizationally, to perform the PM tasks recommended.

- Utilization of Information Derived through the RCM Process - The RCM process will generate information "by-products" which can be used to support other important plant activities or programs. While this is normally the case, unless specific objectives are established for information content, format and retrievability, important data will be lost or difficult to use efficiently. Specific objectives should be considered relative to spare parts data, suggested maintenance procedure demand history, etc. If a comprehensive review of equipment failure history is part of the RCM process, the review is also an excellent opportunity to identify and prioritize the non-maintenance related failure causes for separate action under a root cause analysis program.

RCM Program Scope and System Selection

Many utilities performing RCM programs have some difficulty deciding on the scope for the program. The technology is new and the benefits uncertain. But the decision can be more easily reached if system selection criteria is closely linked to program goals and objectives. For example, if an important goal is to reduce unplanned trips, those systems which have been major contributors should be candidates for inclusion in the program. If a reduction in safety system unavailability is an objective, an examination of the periodic test data will also indicate which systems are responsible.

The question of which systems should be included in the program based on their "importance" can lead to interminable debate because each individual involved in the selection process may have a different definition of the term "important". The fact that a system is "important" by itself is not necessarily relevant or a sufficient reason for its inclusion in the program. RCM will identify the most applicable and cost effective PM tasks or design change alternatives to optimize the reliability of critical equipment in a system. The "importance" of the system is a factor, but only when it has a direct relationship to program goals and objectives.

"Critical Component" Definitions

RCM methodology is a hierarchical evaluation process which leads to identification of cost effective PM or alternative design solutions. The purpose for identifying "critical components" is to focus analysis on those components whose failure has the most significant effect on safety, power production or the cost of corrective maintenance. In establishing this significance in the area of the cost of maintenance, assumptions must be made by the analyst on the cost of the failure, or repeated failures, over a certain period of time as well as the cost of the PM.

The result may be RCM evaluation of nearly all equipment for identification of cost effective PM, a costly process, or an inconsistent selection process which may overlook opportunities to cost effectively prevent equipment failure.

In defining the term "critical" for the purpose of selecting components for further analysis, consideration should be given to establishing uniform guidelines for calculating the cost of failure, including the accurate projection of repeat failures over a fixed payback period, and setting a threshold cost value for the failure(s). The decisions made in this area will effect the scope of the analysis, the cost of the RCM program, and the potential benefits to be derived.

Generic Component Types

In performing RCM evaluations on several systems at the same time, the analysts will be identifying possible failure modes, mechanisms, causes, and recommended PM tasks for similar design components. While the consequence of failure on the system will differ based on the function of the equipment and its operating environment, the number of possible failure modes and the underlying failure causes and mechanisms will generally be the same. Communication among members of the analysis team can produce consistency in the RCM evaluations and resulting PM recommendations, but there is generally nothing in the process that ensures it. This can result in inefficiency as well as inconsistency.

In developing the RCM program plan, consideration should be given to first assembling generic equipment data from the various industry sources and performing certain steps of the RCM analysis process for later use during system analysis. Motor operated valves, electrical sensors, small motors, swing check valves, etc., are just a few examples. Standardized equipment failure mode descriptions are also available in the literature as well as in the NPRDS database and may be useful in promoting consistency in failure mode descriptions.

Vendor Manual Recommendations

It is now widely recognized that the equipment vendor's recommendations do not necessarily optimize equipment reliability, provide for reliability at the lowest cost, consider the nuclear plant operating environment, or the precise function of the equipment in the system. Refinement of currently specified PM tasks based on equipment failure has tended to correct some of the inaccuracies, but others remain. For these, and a variety of other reasons, RCM is now being applied to develop new PM tasks for nuclear plant maintenance programs. Can equipment vendor recommendations be ignored in developing RCM tasks? The question has been answered very differently at utilities performing RCM evaluations and should be considered carefully when deciding on analysis elements.

A number of considerations are relevant to the decision, and the outcome may significantly affect cost and conduct of the RCM program .

- Is preventive maintenance according to vendor recommendations a specific technical specification or license requirement?

- For new equipment, will vendor warranties be affected if the vendor recommended maintenance is not performed?

- Are the necessary vendor manuals available and up to date?

- Are the currently specified PM tasks derived directly from the vendor manuals?

- How much experience does the RCM project staff have in identifying PM tasks for all of the equipment types involved?

The answers to these questions will determine whether or not vendor manual use is optional, mandatory, or selective. If selective, the criteria for required use might include failure mode criticality, equipment age or warranty position, effectiveness of the currently specified PM task in preventing failure or whether or not a PM task is currently specified and effective.

PM Task Cost Effectiveness

RCM Decision tree logic asks a simple question; is the proposed PM task cost effective? The answer, unfortunately, is often not that simple. For example, what is the cost of an additional periodic vibration monitoring task for a pump if the plant has a mature vibration monitoring program? Probably not that great. What if the plant has virtually no vibration monitoring capability? The cost may be very considerable when you include program development cost, staff, training, equipment and implementation. But what is the probability that the vibration monitoring task will detect the potential failure in sufficient time to derive full cost benefit from the advanced notice of potential failure? How does the cost compare to a periodic 5 year bearing replacement or overhaul?

How costly is a periodic teardown and inspection for a check valve in the safety injection system? What is the cost and reliability of non-intrusive acoustic monitoring? In many cases, these questions cannot be answered easily .

It is important that these questions be asked and answers developed with consistency. PM task recommendations are the end product of comprehensive and sometimes tedious evaluation process. If the goal of a truly optimized PM program is to be achieved, cost effectiveness determinations can not be treated lightly or trivially.

Once the basic decision is made that cost effectiveness determinations will be pursued with as much vigor as the basic analysis, the remaining decisions are technical. What is the cost of a labor hour, a new PM procedure, special tools or equipment, performance data analysis and trending, additional spare parts? How often will the equipment continue to fail if no PM is performed? Will the frequency change as the plant ages? All are questions that can be reduced to numbers for consistent and prudent task selection decision making.

Other Important Decisions

Successful RCM program planning requires a comprehensive knowledge of the process as well as the surrounding issues. Some additional questions that should be asked include,

- Is fault tree modeling really necessary?
- Should critical component failure modes and effects be determined by experience or postulated by analysis and validated by experience?
- What methods should be used to optimize the frequency of time directed PM tasks?
- How many years of plant experience are relevant or necessary to determine equipment failure frequency?
- How should task performance feedback be obtained for the RCM Living Program?
- Who should be in charge of the RCM program, Maintenance or Engineering?
- What industry data is available and useful; how should it be used?
- How should plant aging concerns be addressed?
- What procedures should be used for RCM effectiveness monitoring?
- What should be done during the course of the program to ensure implementation of results?
- How much documentation is necessary and sufficient?
- Where is automation most cost effectively applied?

An important part of the RCM planning and implementation process is knowing which questions to ask, and the effect the answers will have on the program. The knowledge base in the US nuclear utility is increasing and consensus on these and other important questions is developing. With continued communication through organized forums such an the IAEA Technical Committee Meeting and the EPRI RCM Users Group, greater understanding will be achieved and more successful RCM programs result.

DEGRADATION MODE ANALYSIS: AN APPROACH TO ESTABLISH EFFECTIVE PREDICTIVE MAINTENANCE TASKS

D.E. SONNETT, P.T. DOUGLASS, D.D. BARNARD
Life Cycle Engineering, Inc.,
Charleston, South Carolina,
United States of America

Abstract

A significant number of nuclear generating stations have been employing Reliability Centered Maintenance methodology to arrive at applicable and effective maintenance tasks for their plant equipment. The resultant endpoint of most programs has been an increased emphasis on predictive maintenance as the task of choice for monitoring and trending plant equipment condition to address failure mechanisms of the analyses. Many of these plants have spent several years conducting reliability centered analysis before they seriously begin implementing predictive program improvements. In this paper we present another methodology, entitled Degradation Mode Analysis, which provides a more direct method to quickly and economically achieve the major benefit of reliability centered analysis, namely predictive maintenance.

INTRODUCTION

Reliability Centered Maintenance (RCM) and Predictive Maintenance (PDM) have been strongly encouraged by proponents within the nuclear power industry to provide efficient, safe and cost effective maintenance on plant equipment. Published guidelines from EPRI, INPO and the NRC discuss RCM and PDM as recommended approaches to upgrade or enhance existing plant maintenance programs. This ensures that a formal review of system maintenance requirements has been accomplished using a thought logic-process to focus the analyst and generate documentation to justify the resultant maintenance activities. Proposed NUREGs discuss plant RCM and PDM programs as a method for each licensee to enhance their Plant License Renewal (PLR) submittals.

The proper application of PDM technology provides for machinery condition assessment, trending and forecasting capabilities and is a cornerstone in managing age related degradation. This is a major element of PLR guidelines as definitized in draft NUREGs currently in circulation.

It was recently estimated that over 60 percent of U.S. nuclear generating stations are upgrading their maintenance practices through RCM assessment processes patterned after EPRI sponsored pilot projects. The authors have participated in five of these upgrades, and in several RCM projects within other industries, and also maintain dialogue with engineers engaged in on-going RCM projects throughout the nuclear industry. One common result that is being universally realized from almost all of these projects is a strong move towards PDM. The non-intrusive aspects of PDM technologies are being proven as the most cost effective methods for addressing failure mechanisms identified through RCM analysis. PDM is also the most effective means of establishing just-in-time frequencies for preventive and corrective maintenance actions.

RCM is recognized as a viable approach to arrive at applicable and effective baseline maintenance tasks, but it is the PDM resulting from the RCM analysis which enables optimization of task selection and frequency of accomplishment, and provides machinery condition assessment capabilities to support PLR. It is not necessary to perform a comprehensive RCM analysis to arrive at applicable and effective PDM tasks which go beyond the generally accepted generic technologies of vibration, oil and infrared analysis. This paper introduces the Degradation Mode Analysis (DMA) process, through which a plant can identify the PDM maintenance activities they should be performing in one fourth the time and effort that a classical RCM process typically requires.

COMPARISON OF RCM TO DMA TECHNICAL APPROACH

Figure 1 depicts the basic steps used in a typical RCM process and compares them to the DMA process. RCM methodology and it's derivations have been the subject of many papers and publications and the authors assume the reader is familiar with the process.

The methodology for selecting and prioritizing systems, partitioning, reviewing maintenance history, implementation and operation/refinement of the living program are essentially the same for both RCM and DMA approaches.

In the system functional failure analysis used in the DMA approach, more emphasis is placed on identification of quantifiable system performance parameters, such as BTU/hr. heat rate, than in the functional failure analysis typically performed in the classical RCM approach. This difference focuses the analyst on identification of applicable PDM tasks that will facilitate assessment of component condition which is required to support the system performance criteria. Similarly, the component selection criteria used during the DMA is focused more directly on critical components that have historically proven to be cost effective to monitor. The DMA analyst should possess good working knowledge of PDM techniques and various applications during component selection, whereas the RCM analyst does not use this information until Logic Tree Analysis (LTA). The PM task selection process differs in that the DMA analyst is more focused to establish PDM tasks and frequencies which will collect sufficient data points to:

- assess and trend condition of a component to project useful life
- support outage planning to repair/replace degraded components

TYPICAL RCM APPROACH	DMA APPROACH
System Selection	Same
Partitioning	Same
Functional Failure Analysis	Similar
Component Selection	Similar
Failure Modes Causes & Effects	Degradation Mode Analysis
Logic Tree Analysis	Conditions to be Monitored
Maintenance History Review	Same
PM Task Selection	Similar
Implementation	Same
Living Program	Same

FIG. 1. Comparison of RCM to DMA — technical approach.

- support PLR submittals
- provide data and justification to optimize preventive and corrective tasks for just-in-time maintenance.

The DMA approach differs significantly from Failure Modes Causes and Effects Analysis (FMCEA) and LTA processes used in RCM, which comprise over 50 percent of the RCM effort. In lieu of FMCEA and LTA, an analysis of the degradation mechanisms of critical components is conducted to identify parameters that can be measured which relate to the components' condition. This process is called Degradation Mode Analysis.

DEGRADATION MODE ANALYSIS (DMA)

DMA for a component is conducted by completing a worksheet as shown in Figure 2 and explained below:

- Wear Part - List the first subcomponent that would normally be expected to wear or degrade and eventually limit the performance of the component. If the goal of the program is maintenance efficiency, then the concern is normal degradation, such as is experienced by a pump impeller gradually eroding. Examples include moving parts, such as impellers, wear rings, bearings, springs, pistons, and also non-moving parts, such as elastomers, winding insulation, seals, strainers. If the goal of the program is also Plant License Renewal, structural and pressure retaining subcomponents as identified in NUMARC Industry Reports and proposed draft NUREG Guide DG-1009 must be listed.

- Mode of Degradation - For the part that can degrade, list the mode or modes of degradation, such as erosion, corrosion, thermal breakdown, chemical breakdown, fouling, grinding, neutron embrittlement and thermal fatigue.

- Parameter Exhibiting Degradation - For each mode of degradation, list the parameter(s) that exhibit the degradation. There will often be more than one. For example, heat exchanger tube fouling is exhibited by decreased flow, decreased heat transfer, and visual inspection; impeller erosion is exhibited by decreased flow at the same head, increased power consumption for the same flow, and dimensional inspection; and gear wear can be exhibited by increased noise, detection of wear particles, and dimensional inspections.

- Technique to Monitor Parameter - For each parameter exhibiting degradation, list the technique(s) that can monitor or measure each parameter. For example, bearing wear can be monitored using oil analysis, vibration analysis, temperature monitoring and waveform analysis of current signature (if in an electric motor).

- Accuracy and Correlateability - In this column, exercise judgement and rate each monitoring technique. Consider, for the specific component being evaluated, how accurately the data from the technique correlates to the degraded condition you are trying to detect. Use excellent, good, fair and poor rating factors. For example, pump wear ring erosion detection by head/flow measurements is good, by power consumed is fair, and by dimensional inspection is excellent. You are evaluating the sensitivity of the technique to detect and measure the degradation.

- Difficulty/Problems/Expense - Again, exercise judgement and evaluate each technique. A head flow curve analysis may be more difficult than current consumption measurement, or can be a problem if there is no installed flow instrumentation, no throttling capabilities and the pump is inaccessible during normal operation. Indicate if the technique requires special instrumentation, special training, equipment modifications, requires abnormal lineups or if there would be significant radiation exposure. Without necessarily putting a dollar value on the technique, indicate if it requires expensive modifications versus simple gage changeouts, if it is time consuming, if it requires purchase of expensive instrumentation, etc. Where it is believed that extensive training or expensive instrumentation can be applied across numerous similar components, state so.

DEGRADATION MODE ANALYSIS WORKSHEET

System Circulating Water **Component Name** Circulating Water Pump

CIC CW-P-A, B, C, D **Manufacturer** Byron Jackson **Model** 102 PMR **Priority** C - Load Threatening - Spared

Wear Part	Mode of Degradation	Parameter Exhibiting Degradation	Techniques to Monitor Parameter	Accuracy and Correlateabilit y	Difficulties Problems	Expense	Viable CTBM Candidates/ Remarks
1. Impeller	Erosion	Flow	Head Flow Perf Test	Good	Ssytem does not have flow meter	Requires purchase of non intrusive flow meter ($2000), 4 mhrs to perform	Proceed if flowmeter required for other tests
		Power Consumption	Power Input vs Load Perf Test	Fair	Requires shutdown to install test equipment	Requires purchase of powerfactor meter ($1000), 8 mhrs to perform	Do not proceed
		Physical Condition	Physical Dimensions	Good	Disruptive, requires shutdown & power reduction	Requires 32 mhrs to perform	Accomplish at planned overhaul as validation
2. Ball Bearings	Fatigue	Noise	Vibration Analysius	Excellent	None	Eqpt. in house, requires 1 mhr to perform	Proceed
		Wear Particulates	Oil Analysis	Excellent	Non circulating oil reserviors require sampling from drain	Requires 1 mhr to perform, lab costs $200/sample	Proceed
		Temperature	Temperature Monitoring	Good	RTD's installed but readings not logged	None	Proceed
		Physical Condition	Physical Condition & Dimensions	Good	Disruptive, requires shutdown & power reduction	Requires 48 mhrs to perform	Accomplish at planned overhaul as validation

Prepared ______ **Date** ______ **Reviewed** ______ **Date** ______

Accepted ______ **Date** ______ **Approved** ______ **Date** ______

FIG. 2. Typical DMA worksheet.

- Viable Conditions to be Monitored (CTBM) Candidate/Remarks - considering the judgements of accuracy, correlateability, difficulty, problems, and expenses that have been rendered for each monitoring technique, determine whether this technique is worthy of further consideration in monitoring the degradation you expect to incur for the part in question. State "proceed", "do not proceed", or "further evaluation required". For the last category, state the evaluation that should be undertaken (e.g., evaluate cost of test fitting installation).

DMA provides a candidate list of CTBM, which is further validated and adjusted through a review of plant machinery history records and industry experience for that component.

REVIEW OF EQUIPMENT HISTORY (REH)

REH is a process which collects and reviews historical maintenance data from preventive and corrective maintenance tasks performed on a component and identifies previous/current system and equipment failure modes, frequencies and other problems. The actual failure modes identified during REH will complement the theoretical results of the DMA and provide the basis for finalizing the CTBM.

The REH process should be documented for each component that was selected as a PDM candidate. The documentation should identify plant specific and industry sources of information, record significant events, resulting actions or commitments, modifications and any effect the history may have on the candidate CTBMs arrived at through DMA. Effects can include:

- event supports CTBM
- event not supported by CTBM
- modify CTBM to include commitment
- delete CTBM, not required due to design or configuration change.

The REH validates and adjusts the CTBM, and the parameters and associated PDM techniques which best support the final CTBM are then selected for implementation and a frequency for monitoring is established.

PDM FREQUENCY DETERMINATION

Establishment of a frequency for each PDM task is not as difficult as establishing frequencies for preventive and corrective tasks. The initial frequency recommended for each PDM task should be based on expected life of the component, it's degradation rate, and the plant's operating schedule. The best source of information to establish PDM frequencies is usually the plant specific equipment data files. For example, if historical data of a plant operating on an 18 month refueling cycle indicates a pump normally required overhaul between 4 to 6 years, and a pump performance test is an excellent CTBM, then the frequency of performance should be established at 6 months. This will ensure 8 to 12 head/flow data sets over the expected life of the pump and provides 3 data sets for trend analysis between scheduled outages. This will allow for condition based adjustments to planned outage work. When in doubt, err on the side of monitoring more frequently than may be necessary, keeping in mind that in most cases the CTBM will be implemented somewhere after the beginning of life of the component, and that frequencies of monitoring can be extended later if data trending analysis supports this conclusion. Also, the easily accomplished monitoring activities, such as vibration analysis, gage reading/recording, etc. can be done more frequently with minimal investment.

REDUCING ANALYSIS TIME

There are several considerations that can be incorporated into the DMA process which will reduce analysis time and improve the efficiency and effectiveness of the process.

- PDM Techniques - provide the analyst with tables summarizing each technique to be considered, define the capabilities of the technique, limitations, what parameters it can be successfully applied to, how it compares to other techniques, special requirements to conduct the technique, and reference materials for more detailed information, if required.

- Generic PDM - there are generic techniques that have obvious application to a large population of components; have demonstrated effectiveness, acceptance and widespread use at nuclear generating stations; and are of a complex nature requiring focused expertise. These include such technologies as vibration analysis, oil analysis, infrared thermography, MOVATS monitoring, and insulation testing. Generic techniques can be implemented programmatically, and the component specific DMA assessment reduced to ensuring subcomponents are considered for inclusion into the generic programs.

- Generic Components - components can be grouped into generic types, such as centrifugal pumps, AC motors, molded case circuit breakers, heat exchangers, etc. DMA can be accomplished on each generic group, reducing the specific component assessment to a comparison with the generic model, addressing only the differences.

- Computerization - the DMA process can be programmed to lead the analyst through the methodology, providing standard choices for decision making at each step, incorporating templates of generic component assessment for comparison, HELP screens enhancing decision making process and training, control of the approval and modification of the analysis. The authors have automated the RCM process in a similar manner. In their experience using it, they have realized a reduction in analysis time of approximately one-third of that normally required. Consistency between analysts has also been significantly improved.

CONCLUSIONS AND RECOMMENDATIONS

The DMA approach to establish PDM tasks has been tried with success in non-utility industries, and is currently being implemented at Cooper Nuclear Station in Brownsville, Nebraska. It does provide a more direct path to arrive at applicable and effective predictive tasks using a structured methodology.

However, the DMA approach does not accomplish a complete assessment of preventive and corrective maintenance, nor does it focus on identification of unnecessary maintenance tasks. The RCM approach, when accomplished properly by qualified analysts, will do all of these things. The authors are strong advocates of RCM, but suggest the DMA approach should be considered by generating stations under the following scenarios:

- The baseline preventive and corrective maintenance actions are believed to be generally correct such that RCM analysis is not warranted, but there is room for improvement in the application of PDM.
- Resources for pursuing the RCM process are limited
- RCM was accomplished but did not result in much PDM (this may be the result of analysts not being familiar with PDM technologies or the station did not possess the equipment or necessary staffing to consider PDM at the time).
- Incremental funding considerations dictate that RCM analysis will require several years to accomplish.

It should be noted that the DMA process accomplishes many elements of the RCM process, such that if RCM is undertaken after DMA none of the effort is wasted. Assessment of PDM data could reduce the number of systems/components selected to undergo RCM analysis through improved focus on problems identified during machinery condition assessment.

RISK ANALYSIS ENHANCEMENT VIA COMPUTER APPLICATIONS

D.D. BARNARD, D.E. SONNETT
Life Cycle Engineering, Inc.,
Charleston, South Carolina,
United States of America

Abstract

Since the development of Reliability Centered Maintenance (RCM) by the airline industry, there has been various alternative approaches to applying this methodology to the nuclear power industry. Some of the alternatives were developed in order to shift the focus of analyses on plant specific concerns but the greatest majority of alternatives were developed in attempt to reduce the effort required to conduct a RCM analysis on as large of scale as a nuclear power station. Computer applications have not only reduced the amount of analysis time but have also produced more consistent results, provided an effective working RCM Analysis tool and made it possible to automate a Living Program.

During the development of a RCM Program at South Carolina Electric and Gas' V. C. Summer Nuclear Station (VCSNS), computer applications were developed to:

- Standardize the approach and thought process of conducting RCM analyses between various analysts
- Implement integrity checks to prevent breakdowns in data analysis results throughout the process
- Maximize the use of importing and exporting data so that data can be downloaded directly from a mainframe or other computer data bases in order to minimize data entry efforts and errors
- Relate the various RCM phases such that complete traceability of decisions and various analysis results can be reviewed from anywhere in the process
- Include data coding schemes that will be used to automate a "Living Program" process
- Permit transportation of all analysis results to a mainframe and therefore allow easy access of the RCM analysis results to other related efforts such as spare parts programs, design and modifications, PRA, etc.

Current efforts include developing the "Living Program" which will be driven by the automated maintenance work request system that will include failure data codes established during initial efforts. These codes will be used to automatically calculate mean time between failure (MTBF) rates, compare MTBF rates with expected values and flag system analysts when less than or greater than expected values are obtained."RCM Analysis Enhancements Via Computer Applications" not only addresses the details of the existing applications and how each of the elements are structured, but also discusses the benefits of having additional capabilities such as integrated condition monitoring and reliability trending modules.

BACKGROUND

The RCM approach that is being used to optimize the VCSNS PM Program typifies the approach that was established by the airline industry, the Department of Defense, and demonstrated by several EPRI projects. The major differences are that systems aren't broken down into functional subsystem and components within a system boundary are grouped according to their functionality of supporting the system. In brief, the methodology that was computerized follows:

- System Prioritization
- Functional Failure Analysis (FFA)
- Critical Component Analysis (CCS)
- Failure Modes Causes and Effects Analysis (FMCEA)
- Preventive Maintenance Evaluation Analysis (PMEA)
- Preventive Maintenance Comparison Analysis (PMCA).

VCSNS uses the CHAMPS management and information system to generate work orders, assist in maintaining configuration, schedule maintenance, tasks, etc. The station has been using CHAMPS since power production began in 1984. CHAMPS is the primary data collection resource.

The primary objective of the RCM Program was to optimize the existing maintenance program. There was a high level of confidence that existing programs (preventive and predictive maintenance, check valve testing, Surveillance Testing, etc.) achieved a high level of reliability and safety but that these programs were not effectively optimized. Therefore, the following approach was followed for achieving goals and objectives of the RCM Program:

- Keep the analysis practical- Some previous RCM efforts expended considerable resources attempting to use reliability models, failure data for the purpose of establishing failure mode dominance, unit unavailability caused by equipment failures, etc. Although those elements are important indicators of effectiveness, they are not critical to the RCM process nor to establishing applicable and effective maintenance tasks.

- Computerize the RCM analysis process- The RCM analysis software was to use coding techniques as much as possible to standardize results and recommendations, be compatible with the Living Program, NPRDS, and other station data and to produce reports that would simplify implementation efforts. The software was to also be user friendly, mirror the analytical process as defined in station procedures, and to utilize pull down menus as much as possible.

- Develop a highly automated Living Program- The results of the RCM Analyses will establish a sound PM baseline consisting of predictive, preventive, and planned corrective maintenance tasks. It will be the Living Program that will continually evaluate the effectiveness of the RCM Program and flag system engineers if target reliability values are not being met, unaddressed failure modes are being experienced, or any other effectiveness measurement is not satisfactory. Therefore, during the development of the RCM Analysis, Living Program specifications were considered so that the results of RCM analyses would be compatible with the Living Program. It is intended that the Living Program will be entirely automated so that maintenance efforts of the Program will be minimized.

TECHNICAL APPROACH AND RCM MODULAR STRUCTURED SOFTWARE

The computer programming that was developed for this RCM project is structured in modules that support each major element of the RCM process. Each of these modules are discussed below.

System Prioritization

All plant systems were evaluated to determine each system's significance to safety and plant reliability, manpower usage for performing corrective and preventive maintenance, and the amount of manpower required to support Surveillance Tests. This process was accomplished by downloading plant specific data and then computing a rating factor that weighted various elements and normalized each rating factor to allow for differences in the system sizes (number of equipment) of each system. The entire process was done electronically and consisted of the following data:

- Number of equipments in each system
- Total number of all equipments
- Number of equipments in each safety rating classification (1A & 2A, 1B & 2B)
- Number of equipments in each system rated IE, EQ and QR, SR
- Number of manhours committed to each system performing Surveillance Tests over two cycles
- Number of manhours committed to each system for performing Preventive Maintenance over two cycles
- Number of manhours used to perform Corrective Maintenance for each system over the last two cycles.

The data was weighted such that a greater emphasis was placed on maintenance related data (corrective, preventive, and surveillance tests). Figure 1 is a partial listing of the resulting system ranking and associated numbers.

SYSTEM PRIORITIZATION ANALYSIS

TOTAL NO. OF COMPONENTS RATED: 56,675

RANK	SYSTEM NAME	NUMBER OF COMPONENTS	SYS CODE	NOTES	SEISMIC	QRSR	1A & 2A 1B & 2B	1E,EQ	PM	ST	MWR	RATING
1	REACTOR COOLANT	2390	RC		1822	741	678	790	1407	3856	23555	14836
2	CIRCULATING WATER	893	CW	NOTE 1	14	14	0	1	372	0	13660	11822
3	FEEDWATER	2327	FW		750	197	237	347	1290	359	17896	11400
4	DIESEL GENERATOR SERVICES	869	DG		596	32	473	122	956	3072	10925	10416
5	MAIN STEAM	2103	MS		1223	153	601	524	1110	1216	13466	9377
6	SERVICE WATER SYSTEM	1038	SW		676	100	392	227	576	323	8936	7895
7	CHEMICAL AND VOLUME CONTROL	1701	CS		1298	377	790	277	898	689	9655	7596
8	ELECTRICAL SYSTEM	2646	ES		943	89	0	869	5134	1680	7434	6864
9	FIRE SERVICE	2321	FS	NOTE 2	59	1603	7	1	498	1719	10069	6368
10	CONDENSATE	1036	CO		146	144	1	123	726	0	5977	5498
11	RADIATION MONITORING	385	RM		66	90	7	8	369	640	4911	4990
12	HEATER DRAINS	792	HD		0	4	0	0	645	0	5031	4883
13	SAFETY INJECTION	1011	SI		743	186	512	126	724	757	4735	4659
14	AIR HANDLING (HVAC)	4100	AH		958	502	537	352	1873	711	13920	4436
15	RESIDUAL HEAT REMOVAL	406	RH		339	25	299	34	384	652	3538	3763
16	COMPONENT COOLING	1585	CC		1196	112	969	129	758	330	3676	3380
17	RADWASTE LIQUID HANDLING	1065	WL		172	191	13	13	267	123	3850	3373
18	PLANT SURVEILLANCE	343	PS		2	4	0	0	0	310	3330	3158
19	DEMINERALIZED WATER	784	DW		0	1	0	0	88	5	3495	3088
20	RADWASTE GAS HANDLING	948	WG		378	379	6	1	112	75	3386	2959
21	CHILLED WATER	1010	VU		754	50	596	119	329	26	3121	2954
22	EXTRACTION STEAM	622	EX		1	1	0	0	64	0	3159	2869
23	GENERATOR AND MAIN TRANSFORMER	266	EG		0	0	0	0	253	0	2716	2830
24	CONDENSER CLEANING	200	AT		0	0	0	0	120	0	2678	2699
25	MAIN CONTROL BOARD	87	MC		85	36	0	48	14	10	2450	2439
26	STEAM GENERATOR BLOWDOWN	458	BD		87	7	54	12	151	59	2425	2387
27	EMERGENCY FEEDWATER	663	EF		554	88	314	153	880	394	1660	2363
28	MISC A.C. DISTRIBUTION	1364	EN		195	28	0	195	0	82	3022	2324
29	NON-NUCLEAR PLANT DRAINS	269	ND		0	0	0	0	104	0	2273	2264
30	REACTOR BUILDING SPRAY	379	SP		301	41	229	58	270	248	2055	2246
31	COMMUNICATIONS SYSTEM	26	EE		0	0	0	0	144	0	2091	2225
32	CONDENSER AIR REMOVAL	360	AR		0	0	0	0	219	0	2109	2180

FIGURE 1. SYSTEM PRIORITIZATION ANALYSIS EXAMPLE

Functional Failure Analysis (FFA)

The only FFA data that is handled electronically is the recording of system functions, functional failures, system inputs/outputs, and references in the RCM database. Each system function is sequentially numbered by a two digit number and subsequently each functional failures are sequentially numbered by a four digit number in which the first two digits correspond to the associated system function. From this step on, all other analysis results are tied to system functions and functional failures.

There is no attempt to further subdivide a system into functional partitions. Further division of system functions greatly increases the level of effort for the remaining analyses without any affect on the final PM tasks that are selected to preserve a system's functions.

Critical Component Selection (CCS)

Critical Component Selection (CCS) is the process of selecting equipments that are critical to preserving system functions as identified in the FFA. This part of the RCM analysis is very significant in that it establishes the population of equipments that will be analyzed using RCM techniques.

Minor modifications to the criteria that establishes the criticality of equipment, can drastically increase or decrease the analysis effort. This phase of the analysis slightly deviates from approaches taken in other classical efforts. During CCS, the following RCM elements are established:

- Each piece of equipment is given a ranking of one to four. The ranking corresponds to an equipment's criticality to safety, power production, economics, or not critical. Non-critical equipment (rating of four) are not evaluated using RCM but are assessed to determine if there could be secondary benefits of maintaining these non-critical equipments in the same manner as similar equipment is being maintained via RCM Analysis results.

- Each piece of equipment is assigned an exclusion/function code. This code:

  - Establishes equipment that is excluded as a candidate for RCM Analysis. Usually equipment is excluded because it is maintained by another program or it does not satisfy minimal acceptance criteria (small manual valves, temporary test connections, installed spares, blank flanges, piping, etc.).

  - Identifies equipment that directly preserves a system function or as a secondary piece of equipment that supports the functionality of a primary piece of equipment. This step greatly reduces the level of effort since failure modes and effects are only determined for primary equipment while failure causes are determined for primary and secondary equipment. All primary equipment that are identical in design and functionality and their supporting pieces of secondary equipment are grouped and analyzed together for the remaining RCM analyses.

  - Is used to identify those pieces of equipment that establish system boundaries and are not included in the subject system analysis.

- Program effectiveness indicators such as MANREM exposure received while performing maintenance, number of corrective maintenance manhours, and cause of unit unavailability are recorded for each piece of equipment to establish a baseline and to assist in determining an equipment's criticality.

Approximately 75% of all the data in the CCS data base is obtained by importing data directly from the CHAMPS maintenance information system. Figure 2 illustrates example of CCS results.

Failure Modes, Causes and Effects Analysis (FMCEA)

The computer module for FMCEA guides the analyst through the entire process and utilizes pull down menus and data that was previously entered during the FFA and CCS. The FMCEA module consists of two screens. The first screen gives identification information such as: a list of all primary and secondary equipment that will be assessed at the same time; manufacture code; technical manual number; and safety classification. The second screen is used for analysis and for entering failure modes causes and effects information. The FMCEA is enhanced with use of the following attributes:

- The module automatically assesses the component code of the primary component(s) and posts the corresponding failure modes that are possible for that type of equipment. For example, if there are four primary equipments that exist in that group and each piece of equipment has

SYSTEM: (CS)

COMPONENT ID NUMBER	COMPONENT NOMENCLATURE	RCMA #	EXCL	CRITICAL COMPONENT ANALYSIS: SAFETY FUNCTION					PRODUCTION FUNCTION		MAINT. BURDEN		GROUP	REMARKS
				SC	ISI	LCO	ST	PRA	FF	RED. AVAIL.	CM	MANREM		
XPP0043A	CHARGING/SI PUMP A	019	CC	2A	Y	Y	Y		Y		23		1	
XPP0043A-FL1	CHARGING/SI PUMP A LUBE OIL FILTER	019	EP	2B	Y	-	-		Y		15		2	
XPP0043A-FL2	CHG/SI PUMP A GB OIL PUMP SUCT FILTER	019	EP	2B	Y	-	-		Y				2	
XPP0043A-GB	CHARGING/SI PUMP A GEARBOX	019	EP	2A	Y	Y	Y		Y				2	
XPP0043A-HE1	CHARGING/SI PUMP A LUBE OIL COOLER	019	EP	2B	Y	Y	Y		Y				2	
XPP0043A-HE2	CHARGING/SI PUMP A GEARBOX LUBE OIL CLR	019	EP	2B	Y	Y	Y		Y				2	
XPP0043A-M	CHARGING/SI PUMP A MOTOR	019	EP	1E	Y	-	-		Y		6		2	
XPP0043A-DR1	CHARGING/SI PUMP A LUBE OIL RESERVOIR	019	EP	2B	Y	-	-		Y				2	
XPP0043A-PP1	CHARGING/SI PUMP A AUXILIARY OIL PUMP	019	EP	SR	Y	Y	Y		Y		19		2	
XPP0043A-PP1-M	CHARGING/SI PUMP A AUX OIL PUMP MOTOR	019	EP	SR	Y	-	-		Y				2	
XPP0043A-PP2	CHARGING/SI PUMP A GEARBOX LUBE OIL PP	019	EP	2B	Y	Y	Y		Y				2	
XPP0043A-PP3	CHG/SI PUMP A ATTACHED LUBE OIL PUMP	019	EP	2B	Y	Y	Y		Y				2	
XVC18111A-CS	CHG/SI PUMP A GB L.O. PUMP SUCT HDR CHK	019	EP	SR	-	-	-		Y				2	
XVC18113A-CS	CHG/SI PUMP A AUX OIL PP DISCH CHK VLV	019	EP	SR	-	-	-		Y				2	
XVC18122A-CS	CHG/SI PUMP A ATT OIL PP DISCH HDR CHK	019	EP	SR	-	-	-		Y				2	
XVR18112A-CS	CHG/SI PUMP A OIL SYS BYPASS RELIEF VLV	019	EP	SR	-	-	-		Y				2	
XPP0043B	CHARGING/SI PUMP B	019	CC	2A	Y	Y	Y		Y		222		1	
XPP0043B-FL1	CHARGING/SI PUMP B LUBE OIL FILTER	019	EP	2B	Y	-	-		Y		16		2	
XPP0043B-FL2	CHG/SI PUMP B GB OIL PUMP SUCT FILTER	019	EP	2B	Y	-	-		Y				2	
XPP0043B-GB	CHARGING/SI PUMP B GEARBOX	019	EP	2A	Y	Y	Y		Y				2	
XPP0043B-HE1	CHARGING/SI PUMP B LUBE OIL COOLER	019	EP	2B	Y	Y	Y		Y				2	
XPP0043B-HE2	CHARGING/SI PUMP B GEARBOX LUBE OIL CLR	019	EP	2B	Y	Y	Y		Y				2	
XPP0043B-M	CHARGING/SI PUMP B MOTOR	019	EP	1E	Y	-	-		Y		227		2	
XPP0043B-DR1	CHARGING/SI PUMP B LUBE OIL RESERVOIR	019	EP	2B	Y	-	-		Y				2	
XPP0043B-PP1	CHARGING/SI PUMP B AUXILIARY OIL PUMP	019	EP	SR	Y	Y	Y		Y				2	
XPP0043B-PP1-M	CHARGING/SI PUMP B AUX OIL PUMP MOTOR	019	EP	SR	Y	-	-		Y				2	
XPP0043B-PP2	CHARGING/SI PUMP B GEARBOX LUBE OIL PP	019	EP	2B	Y	Y	Y		Y				2	
XPP0043B-PP3	CHG/SI PUMP B ATTACHED LUBE OIL PUMP	019	EP	2B	Y	Y	Y		Y				2	
XVC18111B-CS	CHG/SI PUMP B-GB L.O. PUMP SUCT HDR CHK	019	EP	SR	-	-	-		Y				2	
XVC18113B-CS	CHG/SI PUMP B AUX OIL PP DISCH CHK VLV	019	EP	SR	-	-	-		Y				2	

FIGURE 2. CRITICAL COMPONENT *SELECTION* REPORT EXAMPLE

four possible failure modes, then 16 failure modes will be posted and require assessment to determine if they are significant failure modes. A copy function makes it possible to assess only one set of failure modes and then copy the results to the remaining sets.

- A pull down menu of all functional failures that were established during FFA is used to identify those functional failures that would occur if a subject failure mode should occur. If no functional failure can be correlated to a failure mode, that failure mode is not addressed any further.

- A pull down menu is available to select local, system, and plant failure mode effects. At this time the analyst also enters the number of failures that the subject equipment has experienced and records whether the failure mode is significant. Various codes are used to identify failure mode significance (safety, production, economic, or not significant). If there are no significant effects, that failure mode is not addressed any further.

- Once the failure mode significance is established, failure causes down to the subcomponent level can be established. If the failure mode was determined to be insignificant, the software will not permit any further analysis of that mode. Failure causes are standard NPRDS causes that can be selected for the major subcomponents of the primary equipment and its associated secondary equipments. The software automatically assesses the type of equipment being assessed and has a pull down menu available to select applicable subcomponents. After a subcomponent is selected, a pull down menu is used to select the probable failure causes of that subcomponent.

Figure 3 illustrates a typical report of the FMCEA results. The results are concise and consistent in context.

FAILURE MODES, CAUSES AND EFFECTS

Page: 1

FAILURE MODES AND ASSOCIATED FUNCTIONAL FAILURES

RCM ANALYSIS NO.: CS019 TITLE: Pacific Multistage Centrifugal Pumps and Motors
FAILURE MODE DESCRIPTION: Fails to start
FAILURE MODE SIGNIFICANCE: Hidden mode that can effect production
ASSOCIATED FUNCTIONAL FAILURE:
01.02 INSUFFICIENT SEAL WATER TO RECTOR COOLING PUMPS.
02.02 IMPROPER MAKEUP/WATER LEVEL TO RCS.
04.01 LOSS OF HIGH PRESSURE PUMPING TO RCS.
04.02 IMPROPER FLOW/PRESSURE FROM CVCS TO RCS.
05.02 IMPROPER FLOW/PRESSURE FROM CVCS TO ECCS.

FAILURE MODE EFFECTS

LOCAL EFFECT: Physical Fault
SYSTEM EFFECT: Loss of Train/Channel
PLANT EFFECT: Indicates LCO Condition

FAILURE MODE CAUSES

COMPONENT ID	COMPONENT DESCRIPTIONS	SUBCOMPONENT DESCRIPTIONS	FAILURE MODE CAUSES
XPP0043A	CHARGING/SI PUMP A	BEARING, RADIAL BEARING, RADIAL BEARING, RADIAL	LUBRICATION PROBLEM, QUALITY LUBRICATION PROBLEM, QUANTITY NORMAL/ABNORMAL WEAR
XPP0043B	CHARGING/SI PUMP B	BEARING, RADIAL BEARING, RADIAL BEARING, RADIAL	LUBRICATION PROBLEM, QUALITY LUBRICATION PROBLEM, QUANTITY NORMAL/ABNORMAL WEAR
XPP0043C	CHARGING/SI PUMP C	BEARING, RADIAL BEARING, RADIAL BEARING, RADIAL	LUBRICATION PROBLEM, QUALITY LUBRICATION PROBLEM, QUANTITY NORMAL/ABNORMAL WEAR
XPP0043A-FL1	CHARGING/SI PUMP A L.O. FILTER	N/A	NONE
XPP0043B-FL1	CHARGING/SI PUMP B L.O. FILTER	N/A	NONE
XPP0043C-FL1	CHARGING/SI PUMP C L.O. FILTER	N/A	NONE
XPP0043A-FL2	CHARGING/SI PUMP A GB OIL PUMP SUCTION FILTER	N/A	NONE
XPP0043B-FL2	CHARGING/SI PUMP B GB OIL PUMP SUCTION FILTER	N/A	NONE
XPP0043C-FL2	CHARGING/SI PUMP C GB OIL PUMP SUCTION FILTER	N/A	NONE

FIGURE 3. FMCEA RESULTS EXAMPLE

Preventive Maintenance Evaluation

Essentially the Preventive Maintenance Evaluation module leads the analyst through a decision logic tree to determine the type of actions (preventive maintenance, predictive maintenance, a combination of preventive and predictive maintenance, run to fail, or time directed tasks) that are most applicable for either predicting or minimizing the occurrence of each failure cause identified during the FMCEA. After an end point of the LTA is achieved, the software provides a pull down menu of only those tasks that are applicable to the subject end point and the type of equipment. For example, if a pump is being analyzed and the LTA path ended at a time directed task, then the pull down menu would only allow selection of time directed tasks for pumps.

This module greatly enhances the analysis in that the programming ensures that the analyst can not assign a PM task that conflicts with the LTA path. It often prompts the analysts to reevaluate the LTA path when other than expected PM tasks are available for selection. Once again, the relational structure of the data bases forces the analyst to address all failure causes that were identified in the FMCEA. The menu of available PMs greatly assists the analyst in understanding what types of PM tasks are available and quickly educates lesser experienced analysts.

Figure 4 illustrates a typical report of the PM evaluation.

PREVENTIVE MAINTENANCE EVALUATION Page: 1

RCM ANALYSIS NO.: CS019 TITLE: Pacific Multistage Centrifugal Pumps and Motors

FAILURE MODE DESCRIPTION: Fails to start

COMPONENT ID	COMPONENT DESCRIPTIONS	SUBCOMPONENT DESCRIPTIONS	FAILURE MODE CAUSES	LTA END POINT	PM TASK DESCRIPTIONS
XPP0043A	CHARGING/SI PUMP A	BEARING, RADIAL	LUBRICATION PROBLEM, QUALITY	PERFORM CONDITION MONITORING WITH TIME DIRECTED TASK	OIL ANALYSIS CHANGE OIL
		BEARING, RADIAL	LUBRICATION PROBLEM, QUANTITY	PERFORM TIME DIRECTED TASK	CHECK OIL LEVEL
		BEARING, RADIAL	NORMAL/ABNORMAL WEAR	PERFORM CONDITION DIRECTED TASK	VIBRATION ANALYSIS
XPP0043B	CHARGING/SI PUMP B	BEARING, RADIAL	LUBRICATION PROBLEM, QUALITY	PERFORM CONDITION MONITORING WITH TIME DIRECTED TASK	OIL ANALYSIS CHANGE OIL
		BEARING, RADIAL	LUBRICATION PROBLEM, QUANTITY	PERFORM TIME DIRECTED TASK	CHECK OIL LEVEL
		BEARING, RADIAL	NORMAL/ABNORMAL WEAR	PERFORM CONDITION DIRECTED TASK	VIBRATION ANALYSIS
XPP0043C	CHARGING/SI PUMP C	BEARING, RADIAL	LUBRICATION PROBLEM, QUALITY	PERFORM CONDITION MONITORING WITH TIME DIRECTED TASK	OIL ANALYSIS CHANGE OIL
		BEARING, RADIAL	LUBRICATION PROBLEM, QUANTITY	PERFORM TIME DIRECTED TASK	CHECK OIL LEVEL
		BEARING, RADIAL	NORMAL/ABNORMAL WEAR	PERFORM CONDITION DIRECTED TASK	VIBRATION ANALYSIS

FIGURE 4. PREVENTIVE MAINTENANCE EVALUATION REPORT EXAMPLE

Preventive Maintenance Task Comparison

This element of the analysis compares existing maintenance related tasks to vender recommendations and to PM tasks that were selected during PM Evaluation. Existing maintenance related tasks include all scheduled PMs tasks, Surveillance Testing, and ISIs. Existing PM, ST and ISI data are down loaded and requires no data entry. Duplication between RCM tasks and existing tasks is easily recognized. Until this phase of analysis, no recommendations have been made. Only after the analyst can review the type of maintenance profile an equipment has and what PM tasks are supported by the RCM analysis, can recommendations be made. Recommendations are then directed at only updating the existing PM Program. Taking this approach ensures that as few program changes as possible are required and therefore reduces the implementation effort. Typical recommendations are:

- Modify the frequency of an existing task
- Delete an existing task
- Add a new task
- Continue performing an existing task with no changes.

For each recommendation, justification is provided. Justification supports why the task was recommended, addresses whether a vendor's recommendation is being deviated from, and references any other information that may be helpful in supporting the recommendation or that could be useful during implementation. An additional field that is used for addressing supporting requirements is available for the analyst to pass on information that will be useful during implementation. For example, a time directed task may be recommended for deletion. If the deletion of that task was due to a condition directed task being added, it would be very important that the implementing group be advised that the task deletion could not be carried out until predictive task was in place.

Figure 5 provides an example of PM Comparison results.

PM Recommendations

Page: 1

RCM Analysis No. : CS019 ORIGINATOR :
RCM Analysis Title : CHARGING AND SAFETY INJECTION PUMP & MOTOR COMB.
COMPONENT ID NUMBER: XPP0043A DESCRIPTION: CHARGING/SI PUMP A APPROVED BY:

Current PM/ST and Commitments				TRP & Vendor Recommendations		RCM PM Task Results			
Procedure	Description	Freq	EST MH	Description	Freq	Code	Technique	Freq	No.
EMP0295.005	VIBRATION ANALYSIS	1M2	1.0	NONE	NA	C076	Vibrations Monitoring and Analysis	1M2	
LUBE MANUAL	INSPECT COUPLING MOTOR & GEARBOX	3A2	0.0	NONE	NA	C030	Visual Inspection	120	:
STP0105.001	CHARGING/SI PUMP C TEST	CD1	4.0	NONE	NA	C027	Pump Performance Test	1S1	:
STP0105.013	ECCS FLOW BALANCE -- POST MOD.	120	0.0	NONE	NA				,

RCM Conclusions

No.	Recommendations	RCM Code	Freq	EST MH	Justification	Supporting Requirements
1	CONTINUE PERFORMING VIBRATION ANALYSIS	C076C	1M2	1.0	THE RCM ANALYSIS INDICATES THAT VIBRATION ANALYSIS ADEQUATELY MONITORS BEARING DEGRADATION. COMMON INDUSTRY PRACTICES INCLUDING THE VIBRATION MONITORING EQUIPMENT'S VENDOR CONCUR WITH A MONTHLY FREQUENCY.	NO SUPPORTING REQUIREMENTS
2	CHANGE FREQUENCY OF INSPECTION TO AS REQ	C030F	120	0.0	COUPLING WEAR, LOOSENESS, OR MISALIGNMENT FOR THE MOTOR/PUMP WILL BE DETECTED BY VIBRATION ANALYSIS AND OIL ANALYSIS. INTERNAL INSPECTIONS SHOULD ONLY BE CONDUCTED IF DICTATED BY THE VIB/OIL ANALYSIS RESULTS.	NONE
3	CHANGE FREQUENCY OF STP0105.001	C027F	1S1	0.0	A SEMI-ANNUAL FREQUENCY FOR A PUMP PERFORMANCE TEST IS FREQUENT ENOUGH TO DETECT INTERNAL DEGRADATION AND TO PROVIDE ADEQUATE TRENDING DATA.	
4	CONTINUE TO PERFORM STP0105.013	X000C	120	0.0	STP01015.013 IS A SYSTEM LEVEL REQUIREMENT THAT IS IN THE PM PROGRAM FOR SCHEDULING PURPOSES.	NONE

FIGURE 5. PREVENTIVE MAINTENANCE COMPARISON REPORT EXAMPLE

LIVING PROGRAM

Living Program specifications are currently being developed at VCSNS. This program will be highly automated and reside in the station's mainframe computer. It will primarily be driven by corrective maintenance work orders and will:

- Contain the RCM data base that contains failure modes, failure causes, failure mode effects and associated PM tasks

- Calculate mean time between failures and meat time to repairs

- Flag system engineers if:

  - Target reliability values of critical components are exceeded

- RCM equipment experiences failure causes or modes that were not addressed during the RCM analysis

- Non-RCM equipment experiences failures that cause significant system or plant effects.

- Calculate reliability values of critical components

- Monitor RCM effectiveness by calculating or tracking indicators such as:

  - PM/CM ratio

  - Number of corrective work orders

  - Plant unavailability due to equipment failures

  - LCOs, LERs, reduced power events resulting from equipment failures

  - Number or equipment failure modes, causes, and effects being experienced that were not addressed in the RCM analysis

Figure 6 illustrates the basic functional diagram of the Living Program.

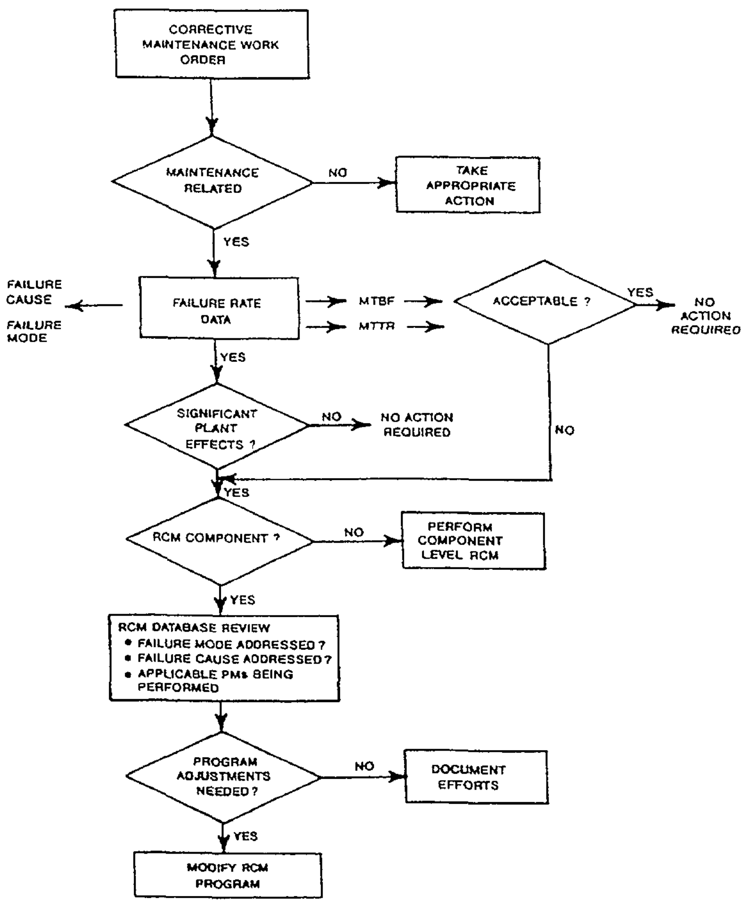

FIGURE 6. BASIC FUNCTIONAL DIAGRAM OF THE LIVING PROGRAM

SUMMARY

The RCM process has been greatly enhanced by computer applications. The enhancements include: reductions in analysis time; improved analysis accuracy; simplified data retrieval; reduction in implementation efforts and the capability to develop an automated Living Program.

The table below identifies some of the enhancements from conducting RCM analysis on computers.

TABLE 1.

ENHANCEMENTS	RELATED COMPUTER FUNCTIONS
Reduced Analysis Time	• Downloading of plant specific data • Copy functions for templating analysis results of identical components • Data sorting for simplifying data interpretation • Relational structure eliminates need for duplication of data entry efforts • Report generator automatically produces reports.
Improved Accuracy	• Pull down menus ensure consistency and prevents oversight • Built-in integrity checks eliminate conflicting results between various RCM elements • Data screening eliminates use of unrecognized entries • NPRDS coding allows use of industry data
Simplified Data Retrieval	• Numerous copies of analyses results are not needed • Universal dBase structure allows import/export of results • Automatic report generator
Implementation Efforts Reduced	• Existing procedures listed • Technical specifications listed • Amplifying instructions with recommendations are provided
Living Program Automation	• Coding for failure causes and effects allows automation of data analysis • Main frame application permits data to be used by design, spare parts, maintenance and engineering • Coded PM tasks automate the process of determining analysis benefits by calculating how many and what kind of PM tasks have been added, deleted or modified

DECISION SUPPORT SYSTEM FOR EFFECTIVE PLANT MAINTENANCE

S. SHIMIZU, S. SAKURAI, T. MORI
Toshiba Corporation,
Kawasaki, Kanagawa

I. TAKEKURO
Tokyo Electric Power Company, Inc.,
Tokyo

Japan

Abstract

A Systematic Reliability Improvement (SRI) program and its supporting computerized tool for nuclear power plants have been developed to enhance plant reliability based on improving information-handling methods in the Reliability Centered Maintenance (RCM) methodology.

In developing the program, the information-handling methods in the Failure Mode Effects and Criticality Analysis (FME/CA) and the Logic Tree Analysis (LTA) were modified to more accurately determine the reliability improvements. The developed SRI program has been validated through its application to a primary loop recirculation (PLR) system in boiling water reactor (BWR) plants.

The decision support system has been developed with the following functions:

1) The FME/CA information management function can manage 13 types of criteria for each failure mode by using assessment rankings.

2) The interactive LTA support function can support decision making in determining improvement priorities. In this function, the improvement priorities are retrieved from the FME/CA assessment rankings by using an interactive logic tree, which can easily be constructed by the user through on-screen interaction.

In this paper, the authors discuss the outlines of SRI program and its support computerized tool as well as their effectiveness.

1. INTRODUCTION

Maintenance planning in nuclear power plants has recently become more important than ever, due to both the increasing number of power stations in operation and their longer period of operation.

Plant maintenance must include measures against component degradations while maintaining maximum component reliability and plant availability with minimum maintenance cost. Therefore, maintenance planning must revaluate current maintenance tasks and apply more effective/appropriate maintenance plans based on systematic reliability evaluation. However, this is a very complex task for plant personnel and system designers, since it requires making decisions based on a significant amount of filed maintenance information and a broad knowledge of component design, failure mode characteristics, maintenance conditions, etc.

To deal with this complex situation, the authors have conducted research to develop a SRI program for plant maintenance based on improving the RCM methodology. Because this RCM methodology, which was developed and successfully applied in the aircraft industry, is a systematic approach to support decision making for optimal maintenance planning, the authors conducted research to improve current information-handling methods in the RCM methodology for nuclear power plants in Japan. The RCM method is now being studied and used in a number of nuclear power plants in the USA (1-3).

First, the authors conducted a feasibility study to develop SRI program. The purpose of this program is to more accurately discriminate the priority of reliability improvements, which include improving not only maintenance tasks but also design, quality, and operation procedures.

In this study, the authors examined the information-handling methods of FME/CA and LTA. As a result, the proposed improved program now enables us to recommend reliability improvements and their action priorities. The effectiveness of this program has been validated through a study on its application to the PLR system in BWR plants. A total of 70 improvements were recommended in this case study.

It was found through this feasibility study that the proposed SRI program, based on an improved RCM method, is an effective approach to enhancing plant reliability. On the other hand, since this proposed SRI program was used to manage FME/CA results and to make complex decisions that would determine reliability improvements on LTA, it was necessary to develop a decision support system that would enhance the proposed SRI program's capabilities.

Second, the authors developed a decision support system, which can support decision making in this SRI program, on an engineering work station (EWS;TOSHIBA AS-3000 series). This system has two main functions:

1) An FME/CA information management function: manages 13 types of criteria for evaluating failure mode characteristics, e.g., failure detection abilities, failure effects, and maintenance conditions; each with its own assessment rankings. These rankings interact with LTA and support decisions made by LTA.

2) An interactive LTA support function: supports decision making by determining the action priority of reliability improvements. In this function, a logic tree (LT) is constructed through on-screen interaction. Decision making is carried out by retrieving information from the FME/CA database using the constructed LT.

2. Systematic Reliability Improvement Program

2.1 SRI Program Outline

The SRI program was developed with the following two objectives:

1) to more accurately discriminate the failure mode characteristics and their environments;

2) to clearly evaluate and make more accurate decisions regarding reliability improvements.

Figure 1 shows a flow diagram of the SRI program, which consists of two steps, after determining the subsystems and their functions.

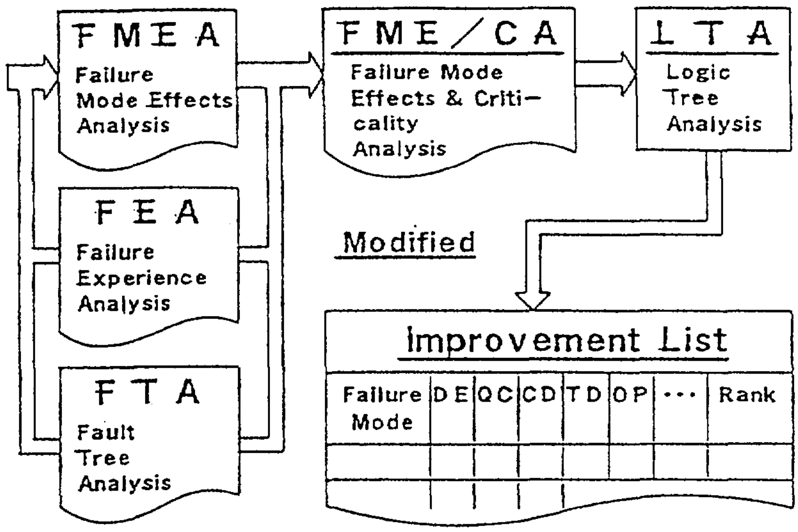

Figure 1 Flow diagram of Systematic Reliability Improvement Program

The first step is to conduct the Failure Mode Effects Analysis (FMEA), Failure Experience Analysis (FEA), and the Fault Tree Analysis (FTA). In FMEA, two levels of analyses are conducted, one is system level analysis and the other is component level analysis. Almost all failure modes are discriminated through these analyses by technical experts based on their knowledge. In FEA, failure information is analyzed by using the authors' previously developed failure information management systems to discriminate any overlooked failure modes in the above FMEA (4). In FTA, hierarchical relationships between a subsystem's functional failures and component parts failure modes are constructed. The FTA enable us to analyze various failure probabilities. These three results are reviewed at meetings of various technical experts and analysts.

In the second step, all these results are integrated by using a modified FME/CA. Finally, improvement lists are made by using a modified LTA.

Figure 2 shows a sample of the modified FME/CA. Traditional FME/CA has concentrated on the importance of evaluating failure effects and the criticality of each failure mode. However, in the authors' new modified FME/CA method, failure mode characteristics and their environments can be evaluated by using 13 types of specialized

ID.NO. 1-1-1	Component Name	PLR-Pump(A)	Component Type	XXX-YYYY		
Functional Failure	Failure Mechanism		Failure Detection	Failure Effects	Failure Frequency	Maintenance Conditions
	Mode	Cause				
Recirculate	Hydraulic vibration	Cavitation	Sound monitor C	Transient B	None C	1 month A

Figure 2 Sample of modified FME/CA

criteria, such as failure detection abilities, effects, maintenance conditions, and so on. In addition, these criteria are discriminated by both text information and criteria assessment rankings, which are indicated by using "A", "B", or "C". These modifications of FME/CA enable us to more clearly discriminate the failure mode characteristics and their environments.

Table 1 shows some examples of assessment rankings for each criterion. These rankings are determined based on the collective decision making of technical experts. For example, the failure detection rank "A" indicates "no detection method", rank "B" indicates that the failure mode is detectable during a scheduled outage, and rank "C" indicates that a failure mode is detectable during plant operation.

Table 1 Some examples of assessment rankings

Criteria \ Rankings	A	B	C
1 Effects	Unscheduled shutdown	Transient	No effect
2 Detection	No detection	Scheduled outage	Plant operation
3 Frequency	Over two times	Only one time	No experience
4 Repair action	During plant outage		During plant operation

Figure 3 shows an example of a modified LTA diagram. This modified LTA has three feature points. First, in the traditional LTA method, each question in the logic tree is answered with a "yes" or "no", but in some cases, it is difficult to answer with a simple "yes" or "no". In this method, each question can be answered by using modified FME/CA assessment rankings, namely, "A", "B", or "C". Second, in the traditional LTA method, the recommended improvements are not prioritized. In this method, a combination judgment method, shown in Fig.3, is used to evaluate the priority of improvements and to assign one of four classification levels, i.e., "high", "medium", "low", or "no improvement", because determining a priority among the recommended improvement is important for planning. The methods for improvement, such as the development of a new technique, improved maintenance, design, quality, and operation, are also classified by using a logic tree. Third, the recommended improvements are categorized into a matrix, consisting of the priority rankings and the methods of improvement. These three modifications enable us to more accurately make plans for reliability improvements.

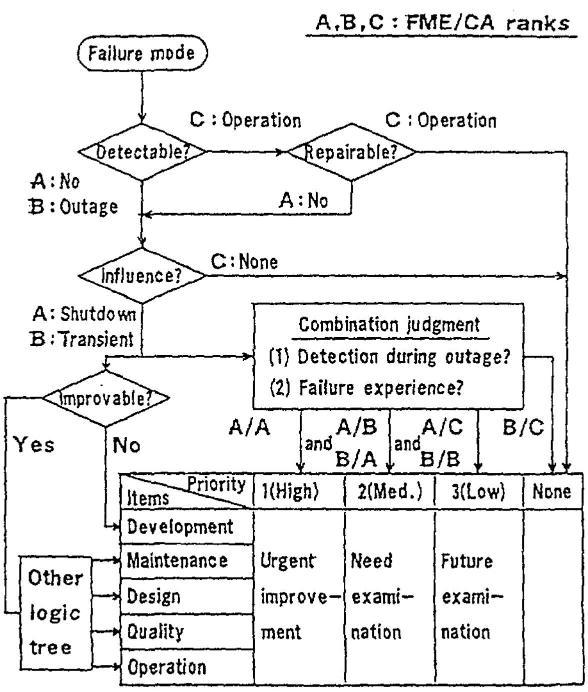

Figure 3 Example of modified LTA diagram

2.2 SRI Program Application to a PLR System

A study of a PLR system was conducted by applying a series of information-handling methods to the developed SRI program.

Figure 4 shows an outline of the PLR system, which is one of the critical systems used to control reactor power by changing the recirculation pump flow. This system is suitable for use in examining the usefulness of the developed SRI program because it includes several types of components.

Figure 5 shows the PLR system reliability improvement areas. 17 types of components and about 4 to 500 individual components were evaluated in this study.

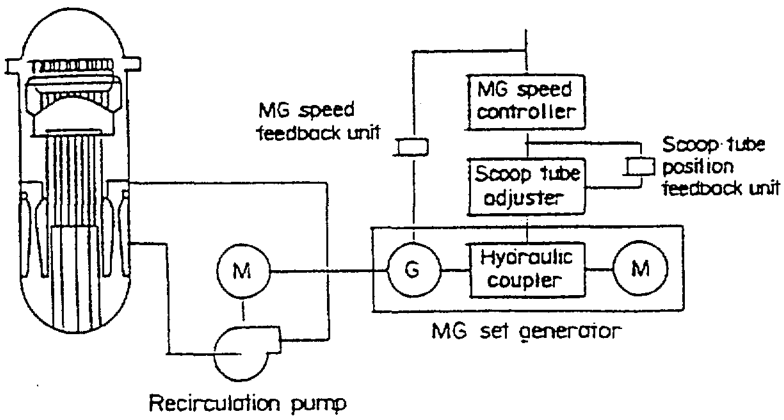

Figure 4 Outline of primary loop recirculation system

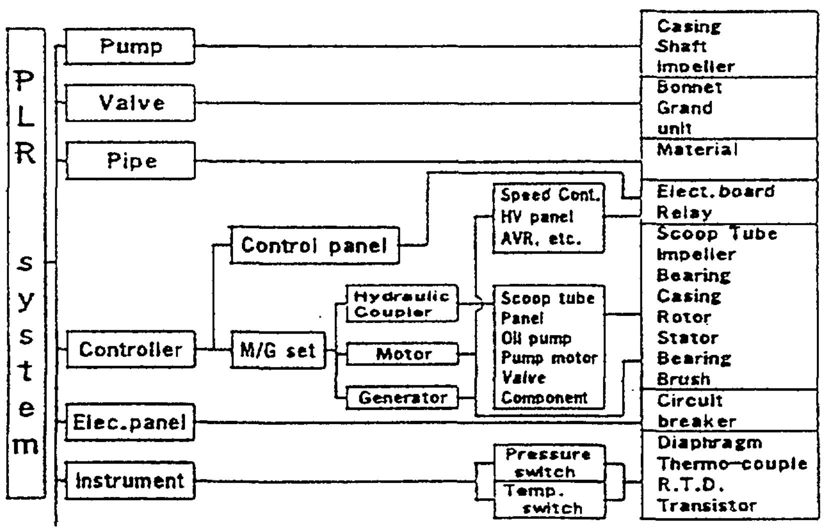

Figure 5 PLR system reliability improvement areas

Table 2 shows the results of the SRI program conducted on the PLR system. Each figure in this matrix indicates the number of recommended reliability improvements, and each improvement is listed according to its action priority and improvement classification. A total of 70 improvements are discriminated for both "high" and "medium" priorities. These improvement, are now being examined to determine whether it is practical to carry them out in the plant system or not. The developed SRI program can be validated through these application studies to be effective and efficient in systematically evaluating items for reliability improvement.

Table 2 Results of SRI program conducted on PLR system

Priority	Mainten.	Design	Quality	Operate	Develop	TOTAL
1 (High)	3	7	–	–	5	15
2 (Medium)	33	13	2	–	7	55
SUB TOTAL	36	20	2	–	12	70
3 (Low)	(85)	(16)	(8)	(4)	(2)	(115)

3. Decision Support System

The study on the PLR system was examined to develop a computerized tool to supporting decision making for the developed SRI program with the following three objectives:

1) to effectively manage the modified FME/CA information;

2) to interactively make decisions on the modified LTA;

3) to extensively apply the FME/CA information to other types of decision making, such as trouble shooting, design review, alarm handling, and so on.

Figure 6 shows an outline of the decision support system consisting of two main functions; 1) the FME/CA information management function, and 2) the interactive LTA support function. This system was developed on the Toshiba AS-3000 series engineering work station.

Users can easily input the FME/CA information using the man-machine interface function. The main feature of this system is the reliability improvement lists derived by using decision logic rules through on-screen interaction. Namely, the users' decision making process can be displayed and interacted with on the screen in the form of a logic tree.

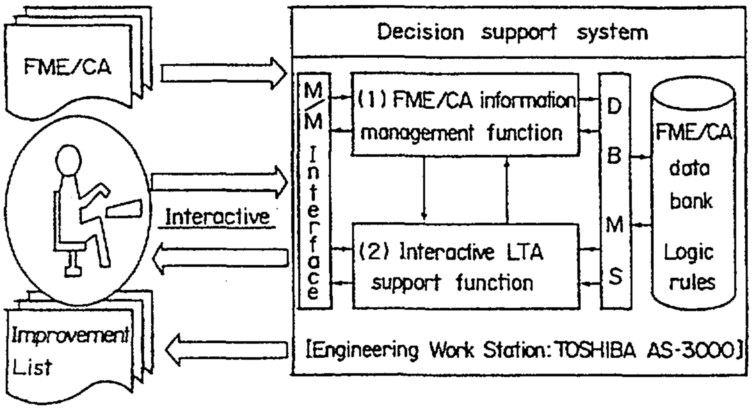

Figure 6 Outline of decision support system

Figure 7 illustrates a screen image of the modified FME/CA information management function. Users can speedily retrieve and update FME/CA information with its man-machine interface function. Almost all keywords and rankings are easily input by pointing to the sub-windows with a mouse icon. It has been confirmed by users that this function is very effective in managing FME/CA information for making various decisions.

Figure 8 illustrates a screen image of the interactive LTA support function. With this function, users can express their decision making process by constructing and modifying the logic tree. A logic tree is constructed by combining decision rules, which consists of a criterion and its assessment rankings. Decision making is carried out by using this constructed logic tree to retrieve information about each failure mode from the FME/CA database. For example, in the case where a failure mode detection criterion is ranked "C", and the repair criterion is also ranked "C", the failure mode falls into the "no improvement" category. It has been confirmed by users that this function is very effective in determining reliability improvements.

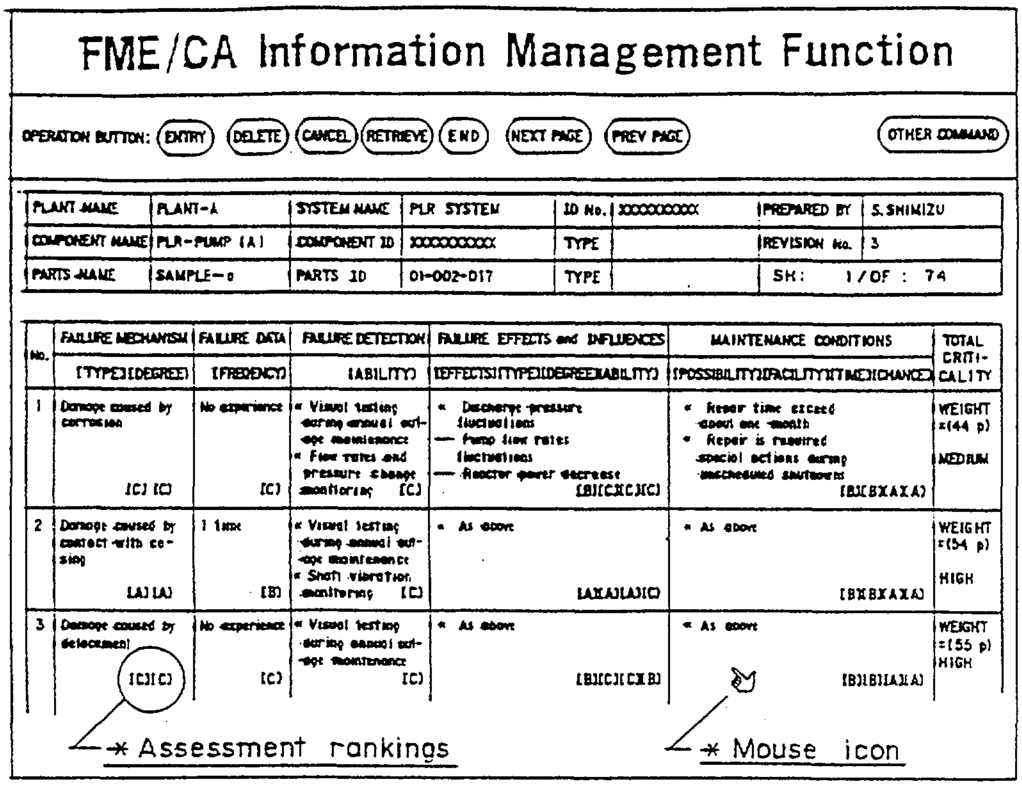

Figure 7 Screen image of modified FME/CA function

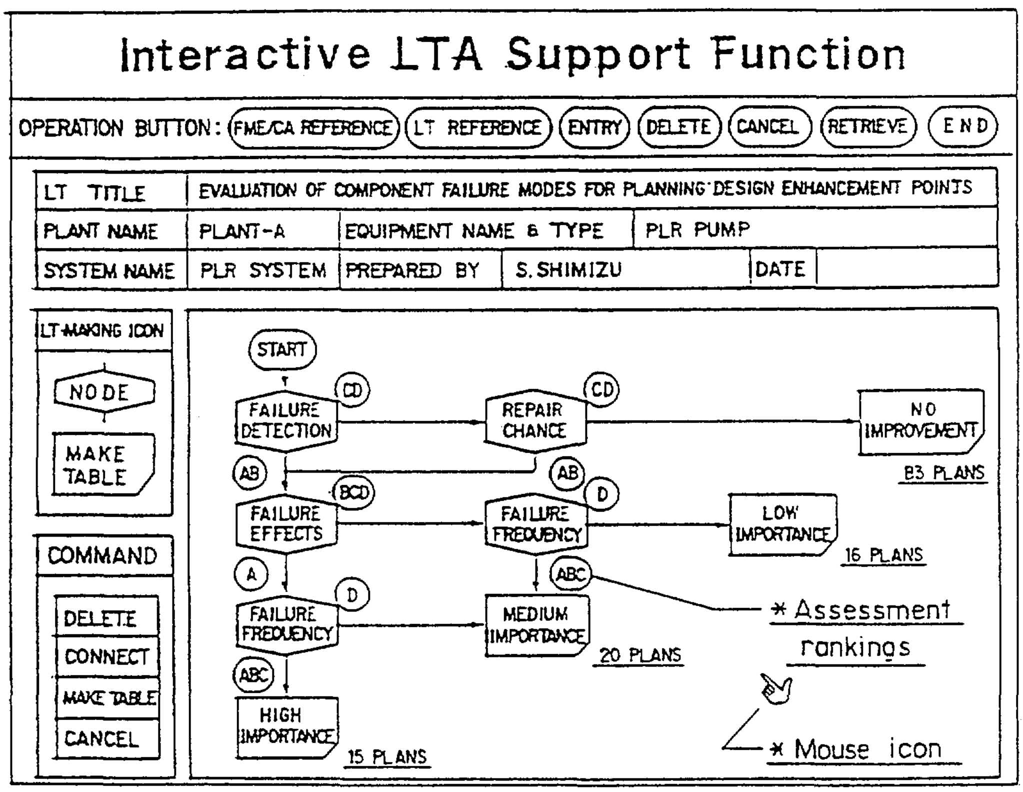

Figure 8 Screen image of Interactive LTA Support function

4. CONCLUSION

It was learned through these studies that the developed SRI program and the decision support system have great potential in improving nuclear power plant reliability and providing more effective plant maintenance.

Extensive study has led the authors to conclude that:

1) in the SRI program investigations, the authors have developed modified FME/CA and LTA methods, These methods enable us: a) to more accurately evaluate the failure mode characteristics and environments, and b) to more clearly determine the action priority for improvement plans. A study on a PLR system validated the effectiveness of SRI program. In this study, 70 reliability improvement and their action priority were determined.

2) Regarding computerized tool development, the authors have developed a decision support system, which includes the development of a modified FME/CA database and an interactive LTA Support method, which can support complex reliability improvement planning. These functions are effective and are indispensable in optimal decision making for effective plant maintenance.

Further more, the authors hope the decision support system will lead to a more informed decision making for plant reliability enhancement and plant maintenance capabilities in nuclear power plants.

REFERENCES

(1) Nowlan F.S.,et al.:AD-A066-579,1978

(2) EPRI NP-6152,Vol.1-3,1989

(3) Taylor G.M.:Nuclear News,Nov.1989,49-56,1989

(4) Shimizu S.,et al.:J.N.S.T.,(in japanese),Vol.31,1144-57,1989

A PROCESS FOR RISK FOCUSED MAINTENANCE

E.V. LOFGREN, S.E. COOPER,
R.E. KURTH
Science Applications International Corporation,
McLean, Virginia,
United States of America

Abstract

This paper describes work performed for the U.S. Nuclear Regulatory Commission (NRC) as technical support for a proposed Maintenance Rule. A risk-centered approach for identifying equipment to be included within the purview of such a rule (critical equipment) was developed, along with a stylized Reliability-Centered Maintenance (RCM) approach that would be specified for such equipment. Maintenance of equipment not classified as critical would be left to the discretion of the plant. The characteristics of the approach include:

- A top logic that consists of two parts: (1) a method for identifying critical equipment and (2) minimum considerations for performing RCM on critical equipment

- Identification of critical equipment consists of two parts: (1) a method using the results of a Probabilistic Risk Analysis (PRA), and (2) a method when a PRA is not available

- The steps to consider in performing RCM on the critical equipment include three parts: (1) review of preventive maintenances currently specified for the equipment, (2) review of repair and maintenance histories for the equipment, and (3) when appropriate, qualitative assessments such as fault tree and reliability block diagram analysis to identify potential failure vulnerabilities.

The processes defined were demonstrated through a series of trial applications with cooperating Utilities. The five trial applications were: (1) identifying critical equipment using a PRA (2) identifying critical equipment when a PRA is not available (3) RCM on standby equipment using the prescribed steps (4) RCM on normally operating equipment using the prescribed steps, and (5) RCM on passive equipment using the prescribed steps. The conclusion was that a risk-focused maintenance approach could be specified that was useable, presented only a small additional burden to the plant, and was regulatable.

A Process for Risk-Focused Maintenance

1.0 Introduction

The objective of the risk-focused maintenance process described in this paper is to focus maintenance resources on components that enable nuclear plant systems to fulfill their essential safety functions and on components whose failure may initiate challenges to safety systems, so as to have the greatest beneficial impact in decreasing risk. This paper is abstracted from the analysis described in Reference 1.

The risk-focused maintenance concept should be applied to all categories of equipment that control off-site radioactive doses or that could adversely impact the ability of the plant to prevent or mitigate accidents or transient. This includes any components whose failure could result in initiating an accident or transient or could prevent or mitigate an accident after its occurrence. Both passive and active components are included.

One major purpose of the risk-focused process is to provide a systematic set of criteria, based on risk, for deciding which of the components considered in the process are to be defined as critical to risk ("risk-critical components") and which are not. Only risk-critical components are included within the scope of the risk-focused maintenance process.

The risk-focused maintenance process addresses only a portion of the total plant maintenance program. Plant equipment receives and should continue to receive maintenance for reasons other than the rick-focused process described herein. Use of the risk-focused maintenance process should not preclude other maintenance activities the utility considers necessary for proper maintenance of its equipment.

The second major purpose of the risk-focused maintenance process is to provide criteria and guidance for establishing a reliability-focused maintenance program for the risk-critical components that accounts for the unique reliability characteristics of each component.

The risk-focused maintenance process, therefore, consists of two major steps, paralleling the two purposes described above: (1) identifying risk-critical components and (2) determining what maintenance activities are required to ensure reliable operation of the risk-critical components identified. Note that the overall process and the first step are "risk-focused"; the program for individual components is "reliability-focused."

Figure 1-1 illustrates the top-level process for implementing a risk-focused maintenance program for a nuclear power plant. The first major step is to determine if the component is risk-critical. If a component is not risk-critical, it is not included within the purview of the overall risk-focused maintenance process. If the component is determined to be critical to risk, then it is incorporated into a reliability-focused maintenance program. Any systematic, self-consistent approach for implementing the process illustrated in Figure 1-1 is appropriate, as long as it is focused by risk and reliability considerations.

This paper addresses two approaches to the first step in the risk-focused maintenance process. Both approaches begin with consideration of functions that must be performed for safe operation of the nuclear power plant. They then identify major systems that provide essential safety functions, including mitigation of accidents, and the components that enable each such system to perform its safety functions. They then identify systems that provide support to the systems providing the essential safety functions and components that enable these support systems to provide their support functions. In parallel, both approaches identify normally operating systems and components whose failures could initiate an accident or transient which challenges safety systems.

The two approaches differ in their methods of identifying risk-critical components. One approach uses the results of a Probabilistic Risk Assessment (PRA). The other approach is appropriate for plants that do not have or do not wish to use their PRA to identify risk-critical components. This approach is based on a methodology which, although it does not use results of a PRA study, has a basis in PRA. Thus, the first step will be performed by, or with the assistance of, personnel familiar with PRA techniques and concepts. The two approaches to identifying risk-critical components are discussed further in Sections 2 and 3.

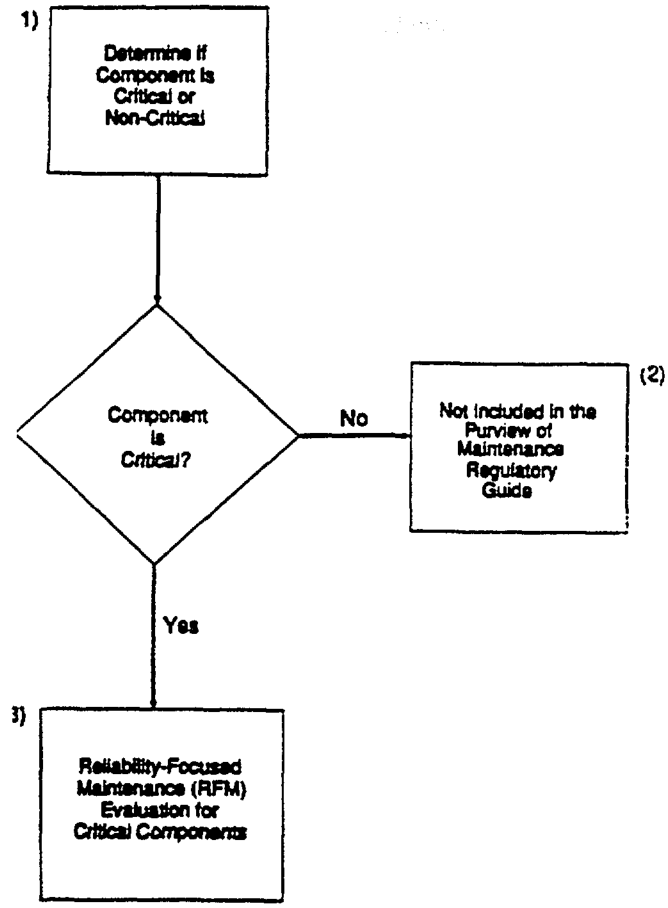

FIGURE 1-1 TOP-LEVEL RISK-FOCUSED MAINTENANCE PROGRAM APPROACH

After the risk-critical components have been identified by one of the two approaches mentioned above, the risk-focused maintenance process uses a single methodology for the second step: determining what maintenance activities are required to ensure reliable operations of the risk-critical components identified. The methodology evaluates failure modes of the risk-critical components identified in the first step and identifies maintenance activities required to defend against those failures and thus to be incorporated into a reliability-focused maintenance program. Figure 1-2 illustrates this part of the overall process. Section 5, "Reliability-Focused Maintenance," provides a more detailed discussion of the methodology.

2.0 Identifying Risk-Critical Components When PRA Is Not Used

This approach is appropriate for those plants that do not have a PRA or do not wish to use their PRA to identify risk-critical components.

The approach begins with consideration of functions that must be performed for safe operation of the nuclear plant and identification of systems performing those functions, as illustrated by examples given in Figure 2-1. The first step in the approach identifies (1) structures, systems and components (SSCs) that are relied upon to prevent or mitigate accidents, and (2) components whose failure would cause a transient or accident requiring plant shutdown. These would include all front-line safety systems. These comprise the initial set of equipment that should be under review to determine which components are risk-critical.

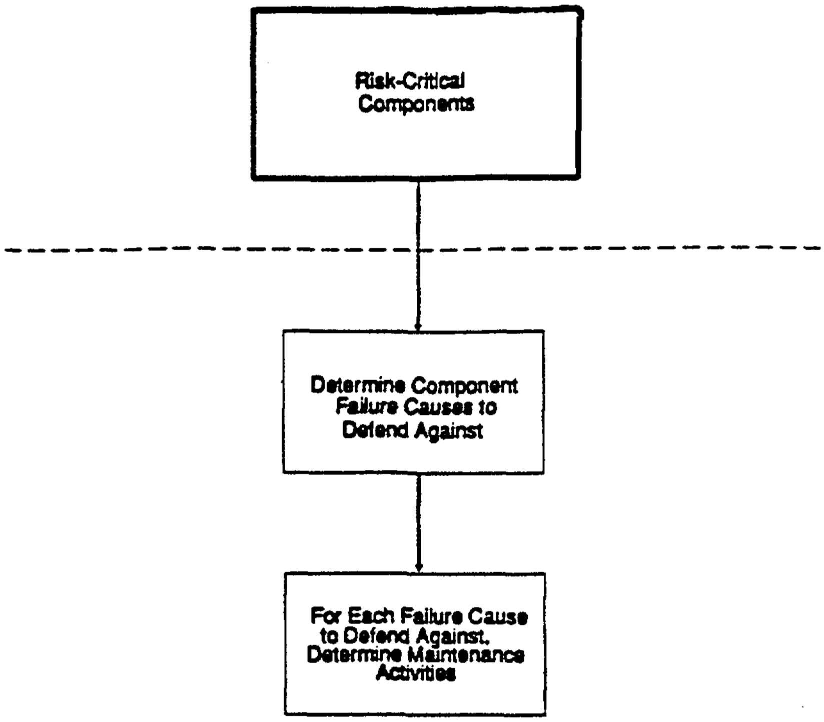

FIGURE 1-2 MAINTENANCE EVALUATION PROCESS FOR RISK-CRITICAL COMPONENTS

The next step in the approach is to identify which of those pieces of equipment are most directly involved with the safe operation of the plant. The evaluation follows the logic shown on Figure 2-2. Components that have any of the characteristics shown on Figure 2-2 are designated as risk-critical components.

The next step in the approach is to add to the components identified above any components that are needed to support any component surviving the screen represented by the logic shown in Figure 2-2. This step is summarized in Figure 2-3.

Balance of plant equipment whose failure would result in an accident or transient should be considered risk-critical. However, only the most likely BOP component failures and the ones whose failure would have the largest consequences need be designated as risk-critical components. Similarly, components in systems that support risk-critical components should be considered as risk-critical. As with BOP components, only those support system components that fail most often and those whose failure is most consequential need be designated as risk-critical.

Finally, passive equipment whose failure would violate Final Safety Analysis Report (FSAR) success criteria or could result in offsite doses comparable to 10CFR100, "Reactor Site Criteria," would also be designated as risk-critical. The determination of risk-critical passive components should center on the identification of failure modes than can, or will, impact safety. If failure of a component could initiate an accident or if the component is required to mitigate consequences of any accident, given that it has occurred, it should be considered a risk-critical component.

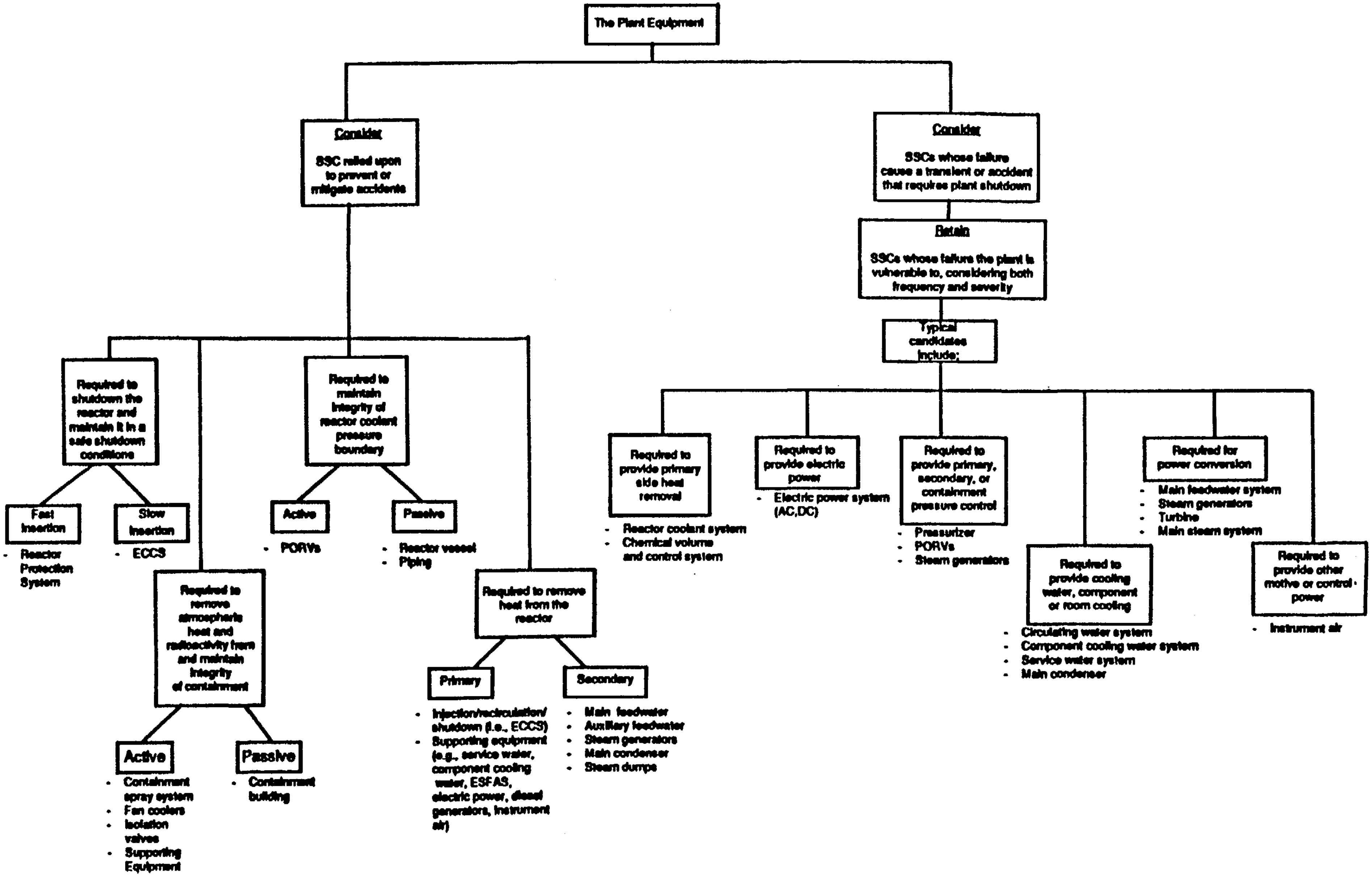

FIGURE 2-1 NON-PRA PROCESS: DEFINING THE BROADEST SET OF COMPONENTS

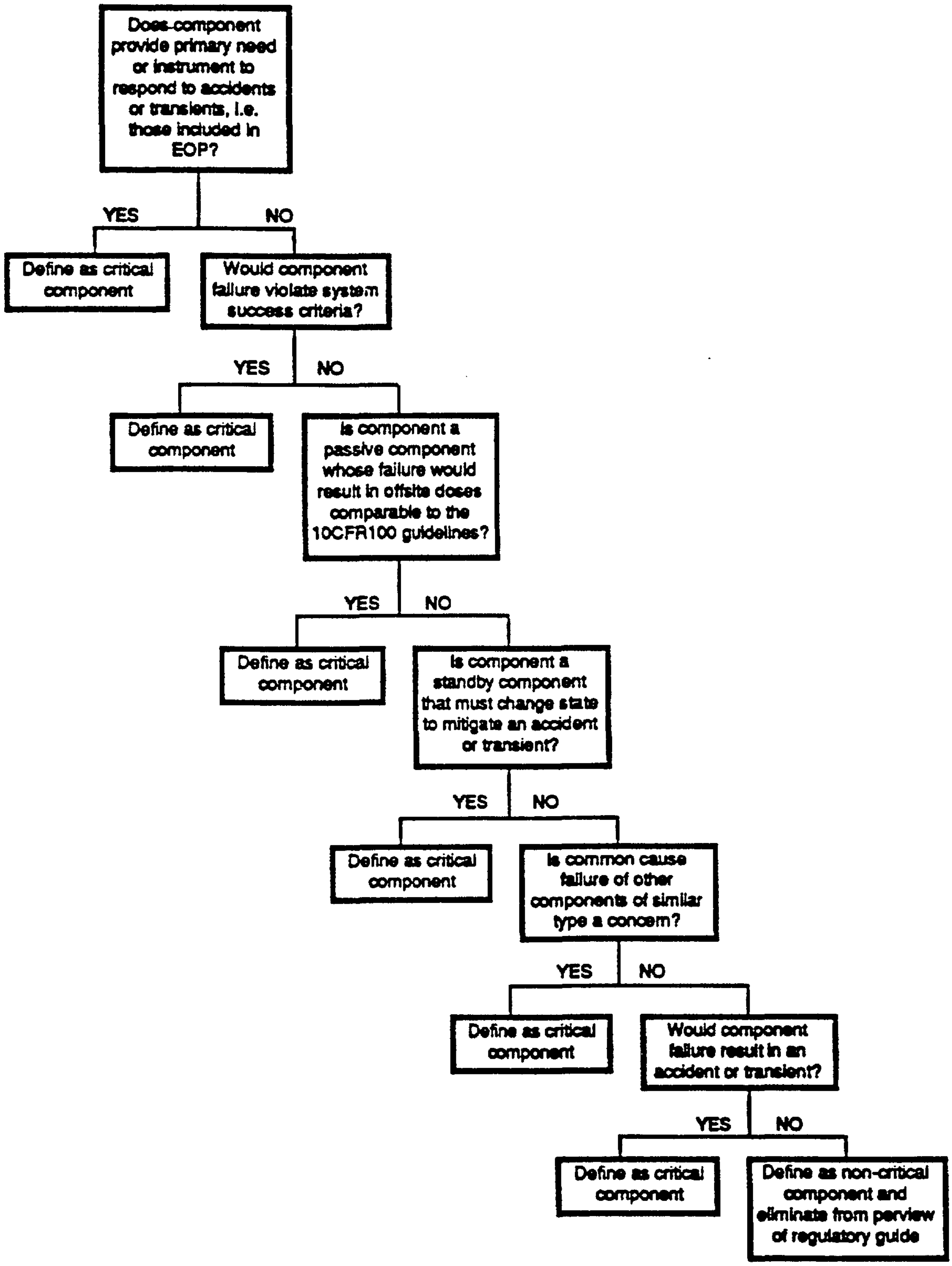

FIGURE 2-2 SECOND-TIER EQUIPMENT EVALUATION PROCESS: NON-PRA EVALUATION OF RISK-CRITICAL EQUIPMENT

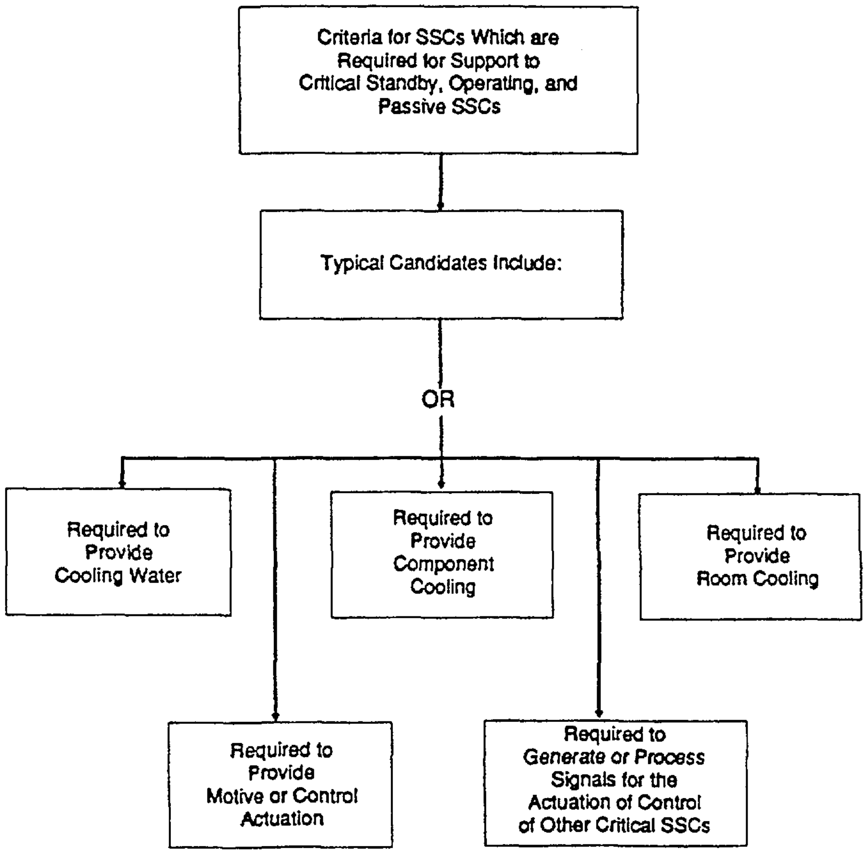

FIGURE 2-3. EVALUATION OF SUPPORT EQUIPMENT FOR CRITICAL STANDBY, OPERATING AND PASSIVE SSCs (NON-PRA BASED EVALUATION)

Figure 2-4 summarizes the types of equipment that would be included as risk-critical components, using the non-PRA approach described above. Major front-line safety system active components that must change state to respond to an accident or transient would be included, as well as equipment that has single failure modes that would fail a safety function. Front-line safety system active components for which there could be common cause concerns (e.g., containment isolation valves) would also be included.

The methodology developed for determining risk-critical components without using PRA was applied to a PWR. This demonstration included:

1) the determination of components which are critical to the prevention or mitigation of an accident,

2) The identification of potentially dominant initiators of accidents specific to the cooperating PWR plant, and

3) the determination of candidate risk-critical passive components.

The process for determining risk-critical components for initiators was illustrated in the PRA approach demonstration and was not repeated for the demonstration involving the PWR plant.

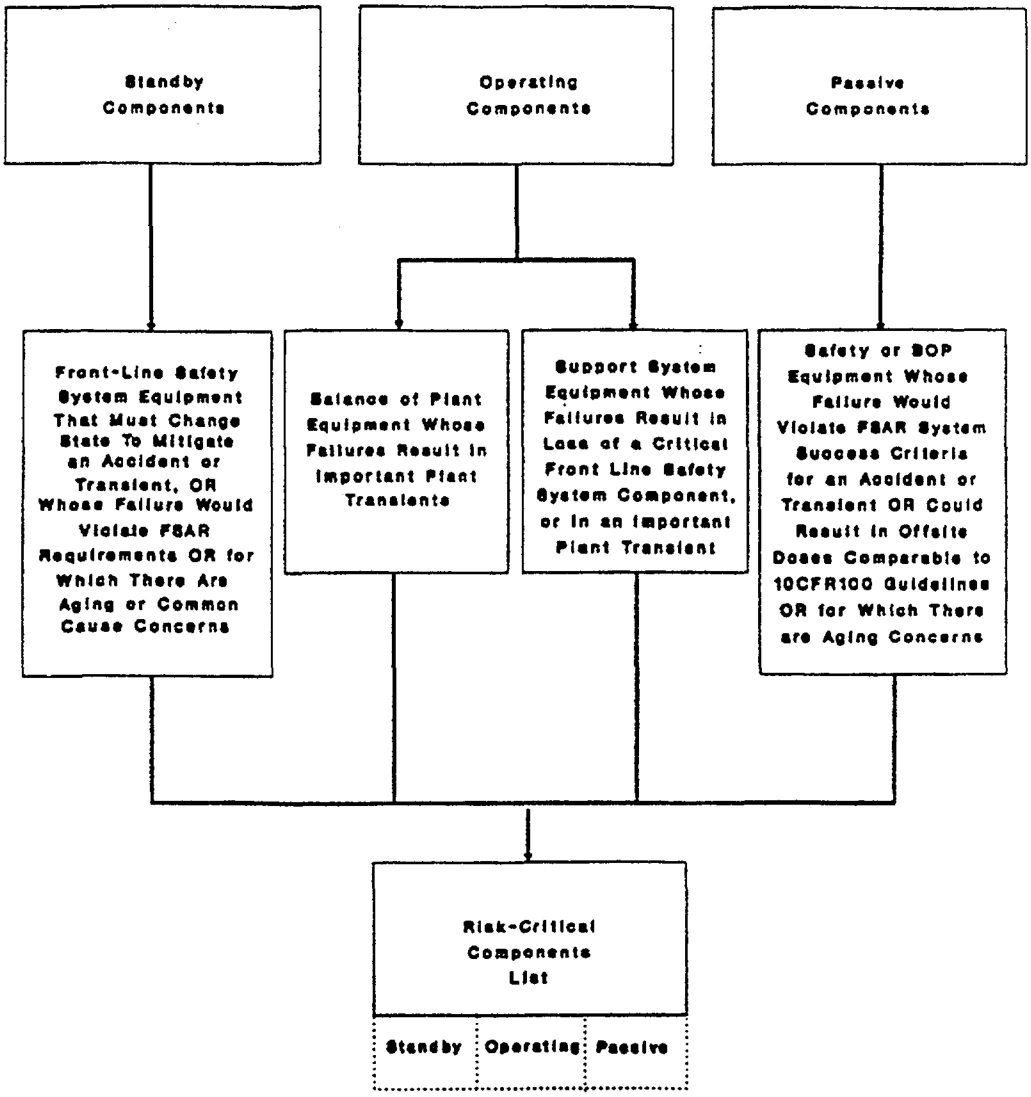

FIGURE 2-4. SUMMARY OF COMPONENTS IN RISK-CRITICAL COMPONENTS LIST

Application for the developed criteria was generally straightforward for the determination of active components (i.e., non-passive, normally operating, or standby components). First, front-line systems were reviewed one at a time, using the following steps:

1) The function of the system was verified as being important to the prevention or mitigation of an accident or to the support of important systems or components,

2) the criteria developed for the non-PRA approach were applied in the review of the system description and drawings, and

3) support systems for components identified as critical were identified, when possible and appropriate, from the description and drawings.

Some assumptions of functional importance were made, not unlike those in PRA system modeling. For instance, some miniflow lines were judged to be important for pump operational protection.

For support systems such as cooling water systems, the developed criteria were also straightforward to apply. For the electric power system, however, the only applicable criterion was determined to be the requirement of support for other critical equipment. The FSAR load list and drawings proved to be the most useful in applying this criterion. The results obtained for this demonstration and that described above are shown in Tables 2-1, 2-2, 2-3, and 2-4.

As was expected, the demonstration of the non-PRA approach was more time-intensive than was the demonstration of the PRA approach (Section 3.0) However, the results obtained are expected to be representative of what a utility should obtain as a result of following the steps in this section.

TABLE 2-1

TRANSIENTS IDENTIFIED IN EPRI NP-2230

1	Loss of RCS Flow (1 Loop)
2	Uncontrolled Rod Withdrawal
3	CRDM Problems and/or Rod Drop
4	Leakage from Control Rods
5	Leakage in Primary System
6	Low Pressurizer Pressure
7	Pressurizer Leakage
8	High Pressurizer Pressure
9	Inadvertent Safety Injection Signal
10	Containment Pressure Problems
11	CVCS Malfunction-Boron Dilution
12	Pressure/Temperature/Power Imbalance - Rod Position Error
13	Startup of Inactive Coolant Pump
14	Total Loss of RCS Flow
15	Loss or Reduction in Feedwater Flow (1 Loop)
16	Total Loss of Feedwater Flow (All Loops)
17	Full or Partial Closure of MSIV (1 Loop)
18	Closure of All MSIV
19	Increase in Feedwater Flow (1 Loop)
20	Increase in Feedwater Flow (All Loops)
21	Feedwater Flow Instability - Operator Error
22	Feedwater Flow Instability - Misc. Mechanical Causes
23	Loss of Condensate Pump (1 Loop)
24	Loss of Condensate Pumps (All Loops)
25	Loss of Condenser Vacuum
26	Steam Generator Leakage
27	Condenser Leakage
28	Misc. Leakage in Secondary System
29	Sudden Opening of Steam Relief Valves
30	Loss of Circulating Water
31	Loss of Component Cooling
32	Loss of Service Water Systems
33	Turbine Trip, Throttle Valve Closure, EHC Problems
34	Generator Trip or Generator Caused Faults
35	Total Loss of Offsite Power
36	Pressurizer Spray Failure
37	Loss of Power to Necessary Plant Systems
38	Spurious Trips - Cause Unknown
39	Auto Trip - No Transient Condition
40	Manual Trip - No Transient Condition
41	Fire Within Plant

TABLE 2-2

RISK-CRITICAL COMPONENTS IDENTIFIED BY NON-PRA APPROACH

HARDWARE BY COMPONENT TYPE AND SYSTEM/FUNCTION

COMPONENT TYPE	SYSTEM/FUNCTION	No.
Pumps (All Types) (20)	Auxiliary Feedwater	4
	Feedwater/Condensate	4
	Low Pressure Injection/Shutdown Cooling	2
	High Pressure Injection	2
	Containment Spray	2
	Component Cooling Water	2
	Chilled Water	2
	Service Water	2
Motor-operated Valves (47)	Auxiliary Feedwater	9
	Feedwater/Condensate	2
	Low Pressure Injection/Shutdown Cooling	10
	High Pressure Injection	12
	Containment Spray	8
	Safety Injection (General)	4
	Component Cooling Water	2
Solenoid Valves (21)	Safety Injection	10
	Reactor Coolant (Venting)	7
	Main Steam	4
Relief Valves	Main Steam	27
Main Steam Isolation Valves(MSIV)	Main Steam	4
Atmospheric Dump Valves (ADV)	Main Steam	4
Primary Safety Valves	Reactor Coolant	4
Check Valves (All Types) (51)	Auxiliary Feedwater	9
	Feedwater/Condensate	2
	Low Pressure Injection/Shutdown Cooling	4
	High Pressure Injection	8
	Containment Spray	4
	Safety Injection	16
	Service Water	2
	Main Steam	6
Chiller Units	Chilled Water	2
Air Cooling Units	HVAC	10
Strainers	Feedwater/Condensate	2
Pressure Transmitters (All Types) (40)	Emergency Safeguards Features Actuation System	4
	Emergency Safeguards Features Actuation System/Reactor Protection System	8
	Reactor Protection System	28
Level Transmitters (12)	Emergency Safeguards Features Actuation System	4
	Emergency Safeguards Features Actuation System/Reactor Protection System	8
Temperature Elements	Reactor Protection System	12
Neutron Flux	Reactor Protection System	4
Control Element Assembly Position	Reactor Protection System	89
CEA Calculators	Reactor Protection System	89

(continued on next page)

(Table 2-2., continued)		
Bistables (157)	Emergency Safeguards Features Actuation System	24
	Reactor Protection System	133
Initiation Logic (12)	Emergency Safeguards Features Actuation System	6
	Reactor Protection System	6
Initiation Circuits	Reactor Protection System	4
Actuation Logic (14)	Emergency Safeguards Features Actuation System	12
	Reactor Protection System	2
Trip Breakers	Reactor Protection System	4
	Total:	629

TABLE 2-3

CANDIDATE RISK-CRITICAL PASSIVE COMPONENTS IDENTIFIED BY NON-PRA APPROACH

HARDWARE BY COMPONENT TYPE AND SYSTEM/FUNCTION

COMPONENT TYPE	*SYSTEM/FUNCTION*	No.
Heat Exchangers (4)	Low Pressure Injection/Shutdown Cooling	2
	Component Cooling Water	2
Steam Generators	Main Steam	2
Reactor Vessel	Reactor Coolant	1
Accumulators	Main Steam	4
Tanks	Chemical Volume Control (RWST)	1
	Total:	12

TABLE 2-4

RISK-CRITICAL ELECTRICAL COMPONENTS IDENTIFIED BY NON-PRA APPROACH

COMPONENT AND NUMBER OF COMPONENTS	
Main Switchyard	1
Transformers (12):	
Main	3
Auxiliary	1
Emergency Safeguards Features	2
Load Center	6
Buses (20):	
Intermediate	2
High Voltage Emergency Safeguards Features	2
4.16 KV	2
480 V	6
Motor Control Center	8
Circuit Breakers (40):	
Emergency Safeguards Features Bus	2
High Voltage	2
Emergency Safeguards Features Main	2
4.16 KV Supply	6
480 V Main Feeder	6
Motor Control Center Feeder	8
Battery	4
Battery Charger	4
DC Panel Feeder	4
Diesel Generator	2
Diesel Generators	2
Batteries	4
Battery Chargers	4
DC Control Center	4
DC Distribution Panel	4
Total:	91

3.0 Identifying Risk-Critical Components When a PRA is Used

This approach is appropriate for those plants that have a PRA or wish to perform a PRA as a basis for identifying risk-critical components.

An approach for identifying risk-critical components that is based on using a Level I PRA is illustrated in Figure 3-1. Note that the PRA takes a function into account inherently -- it is a logical process for identifying components whose failure to function would contribute to core melt.

In order to identify risk-critical components from a PRA's accident sequences, the first step is in this approach is to choose a fraction of the core melt frequency that represents the most likely accident scenarios (e.g., choose the top ninety percent as far as likelihood of occurrence is concerned). This selection can be based upon the fraction of core melt frequency results reported in existing PRAs or the fraction recommended for the Individual Plant Examination (IPE) submittal. Another possible consideration may be related to natural breaks in the ranking of cutsets. The next step in this approach is to identify the components whose failure modes are represented in this set of accident scenarios. These components are considered to be risk-critical

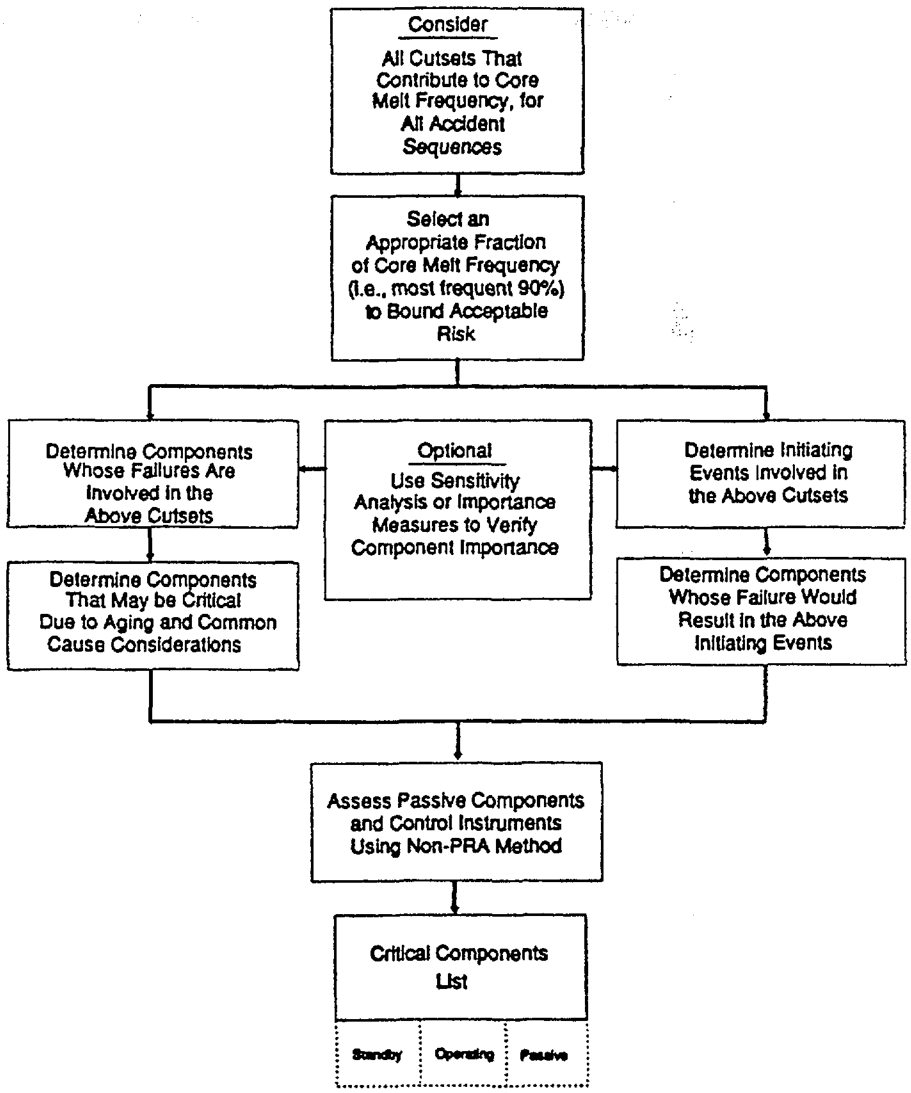

FIGURE 3-1. PRA PROCESS FOR CRITICAL COMPONENT DETERMINATION

components. Passive components which satisfy the criteria described previously for passive components in the non-PRA approach (Section 3) should also be identified. In addition, any standby components for which aging or common cause failure is a concern, either from plant-specific or industry experience, should be added to the list of risk-critical components.

In order to identify risk-critical components from accident sequences, only the most likely accident sequences are considered. The initiating events associated with those sequences are then identified. Finally, all BOP or other equipment having failure modes that could result in these transients or accidents are identified. The components experiencing the most frequent failures for each of the "dominant" initiating events are kept as risk-critical components.

This completes the criteria and considerations for a PRA-based identification of risk-critical components. Variations to this approach are acceptable. For instance, instead of choosing the initiating events and components whose failure modes appear in a top percentage of the cutsets, an acceptable approach would be to use importance measures or sensitivity analysis to accomplish this.

The methodology developed for determining risk-critical components from a PRA was straightforwardly applied to the PRA results which the cooperating utility provided to SAIC.

The results of this process are shown in Tables 3-1, "Risk-Critical Active Components Identified by PRA Accident Sequences;" 3-2, "Risk-Critical Components Identified by PRA, by Component Type;" and 3-3, "Risk-Critical Components Identified by PRA, by System." One complication in the process of identifying risk-critical electrical components from this particular PRA was the inability to match up some components (e.g., relays, contact pairs, fuses, etc.) with specific risk-critical equipment (e.g., pumps, MOVs, etc.) due to the lack of notation in the master data file.

This problem could be solved by consultation with the PRA staff at the cooperating utility. However, SAIC recommends that the criticality of these components be verified in the risk-focused maintenance process.

Overall, the performance of this demonstration went as planned. In reviewing the contributors to the accident sequences for this PRA, it was evident that the majority of the modules and their associated component failure modes could have been captured by using only 75% of the PRA results. However, SAIC elected to report all the results available to us. SAIC anticipates that application of this approach to other PRAs will involve similar efforts and results.

TABLE 3-1

RISK-CRITICAL ACTIVE COMPONENTS IDENTIFIED BY PRA ACCIDENT SEQUENCES

COMPONENT TYPE	SYSTEM/FUNCTION	No.
Pumps (All Types) (33)	Core Spray	2
	Feedwater/Condensate	10
	Low Pressure Injection	4
	Main Steam	1
	Standby Liquid Poison	2
	Service Water	4
	Other Cooling Water System	8
	Firewater	2
Motor-operated Valves (17)	Feedwater/Condensate	1
	Isolation Condenser	2
	Low Pressure Injection	6
	Main Steam	2
	Service Water	1
	Other Cooling Water Systems	3
	Reactor Water Cleanup	2
Air-Operated Valves	Reactor Water Cleanup	1
Check Valves (All Types) (38)	Core Spray	4
	Feedwater/Condensate	10
	Isolation Condenser	2
	Low Pressure Injection	8
	Standby Liquid Poison	6
	Service Water	4

(Continued on next page)

(Table 3-1, Continued)		
(Check Valves, Cont.)	Other Cooling Water Systems	4
Relief Valves (7)	Automatic Depressurization	6
	Reactor Water Cleanup	1
Safety Relief Valves		30
Manual Valves (9)	Core Spray	2
	Service Water	5
	Other Cooling Water Systems	2
Strainers	Other Cooling Water Systems	2
Vent Header	Reactor Coolant (Venting)	1
Vent Line	Reactor Coolant (Venting)	1
Downcomer Pipe	Reactor Coolant (Venting)	1
Vacuum Breaker	Reactor Coolant (Venting)	1
High Drywell Pressure Sensor	Emergency Safeguards Feature Actuation System/Low Pressure Injection and Core Spray	4
Low-Low Reactor Level Sensor	Emergency Safeguards Feature Actuation System/Low Pressure Injection and Core Spray	4
Switches, Pressure (15)	Feedwater/Condensate	14
	Reactor Water Cleanup	1
Switches, Level (3)	Feedwater/Condensate	2
	Isolate Condenser	1
Switches, Manual	Other Cooling Water Systems	1
Switches, Common Start	Standby Liquid Poison	1
	Total:	169

TABLE 3-2
RISK-CRITICAL ELECTRICAL COMPONENTS IDENTIFIED BY PRA BY COMPONENT TYPE

COMPONENT TYPE AND NUMBER OF COMPONENTS	
Main Switchyard	1
Emergency Gas/Turbine Generator	1
Emergency Diesel Generator	1
Diesel Generators	2
Motor Generator Set	1
Buses (11):	
High Voltage - AC	7
Medium Voltage - AC	2
Low Voltage - AC	1
Vital AC	1
DC Batteries	2
Transformers	4
Motor Control Centers (5):	
400 V	4
DC	1
DC Switchboards	4
DC Panels	5
Automatic Bus Transfer	2
Circuit Breakers (All Types)	91
Coils (All Types)	69
Contact Pairs	230
Auxiliary Breaker Contacts	2
Relays (All Types)	30
Fuses	·15
Control Switches	3
Total:	479

TABLE 3-3
RISK-CRITICAL COMPONENTS IDENTIFIED BY PRA BY SYSTEM

SYSTEM AND NUMBER OF COMPONENTS	
Core Spray	8
Feedwater/Condensate	37
Isolation Condenser	5
Low Pressure Injection	18
Main Steam	3
Standby Liquid Poison	9
Service Water	14
Other Cooling Water Systems	20
Fire Water	2
Emergency Safeguards Feature Actuation System	8
Relief Valves	36
Reactor Coolant	4
Electric Power *	39
Reactor Water Cleanup	5
SubTotal:	208
Electric Power **	91
SubTotal:	299
Electric Power ***	349
Total:	648

* Includes major equipment such as the switchyard, diesel generators, buses, MCCs, batteries, transformers, switchboards, panels, etc.

** Breakers only.

*** Includes coils, contact pairs, relays, fuses, breaker contacts, and control switches.

4.0 Reliability-Focused Maintenance

This section describes the methodology for developing a reliability-focused maintenance program for risk-critical components. This methodology is appropriate for establishing a reliability-focused maintenance program for risk-critical components identified by either PRA or non-PRA approaches described in the preceding sections.

Establishing a reliability-focused maintenance program for a risk-critical component involves determining the preventive or predictive maintenance actions (e.g., surveillance, condition monitoring, overhaul) or other maintenance-related activities such as redesign or reconfiguration, which are responsive to the reliability needs of that component (i.e., a reliability-focused maintenance program akin to Reliability-Centered Maintenance (RCM)). Information on RCM techniques may be found in References 3, 4, and 5 respectively.

Figure 4-1 indicates the two steps that should be addressed by a reliability-focused program for a risk-critical component. The first step is to determine the dominant component failure modes that should be defended against. The second step is to determine maintenance activities that will defend against those dominant failure modes. Methodologies for completing each step are discussed below. Other methodologies would be appropriate, as long as they account for the reliability characteristics of a component and develop a maintenance program to defend against the most important failure modes of the component.

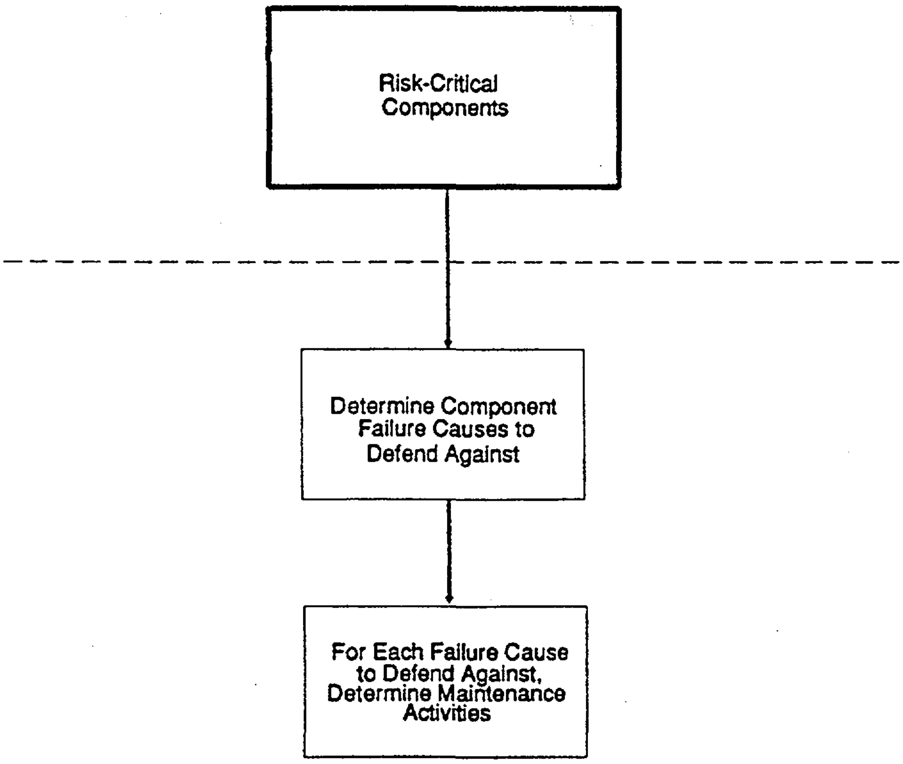

FIGURE 4-1. MAINTENANCE EVALUATION PROCESS FOR RISK-CRITICAL COMPONENTS

Figure 4-2 shows an expanded version of a reliability-focused process for identifying the most important component failure modes. Three assessment paths are shown in that figure: "Identifying Risk-Critical Pieceparts Using Qualitative, Analytical Methods;" "Identify Risk-Critical Pieceparts from Failure History;" and "Identify Existing Maintenance-Related Activities and Requirements." These three assessment paths are denoted Assessment Path A, Assessment Path B, and Assessment Path C, respectively.

Assessment Paths A and B are options for identifying the dominant failure modes.

- Assessment Path A would be used for complex equipment such as diesel generator systems or feedwater systems or where failure history data is not available.

- Assessment Path B would be used for less complex equipment when failure history data is available.

Both of the above paths should be used to provide substantiating evaluations of failure modes to defend against when this is appropriate. Identifying the dominant failure modes is assumed to be synonymous with identifying the risk-critical pieceparts.

Assessment Path C should be done for each risk-critical component (after or in parallel with Assessment Path A or B) and is not to be considered optional.

The activities using qualitative, analytical methods to identify dominant failure modes of the risk-critical components are characterized by the left-most column of Figure 4-2. In this option, a qualitative analytical reliability tool such as fault tree, Failure Modes and Effects Analysis (FMEA), or reliability block diagram is used to identify pieceparts of risk-critical components whose failures are of the types:

- Single piecepart failures that fail the component's function and that are likely to occur
- Latent piecepart failures that are not detectable through ordinary component demand testing
- Piecepart failures that, though internally redundant, have common cause potential

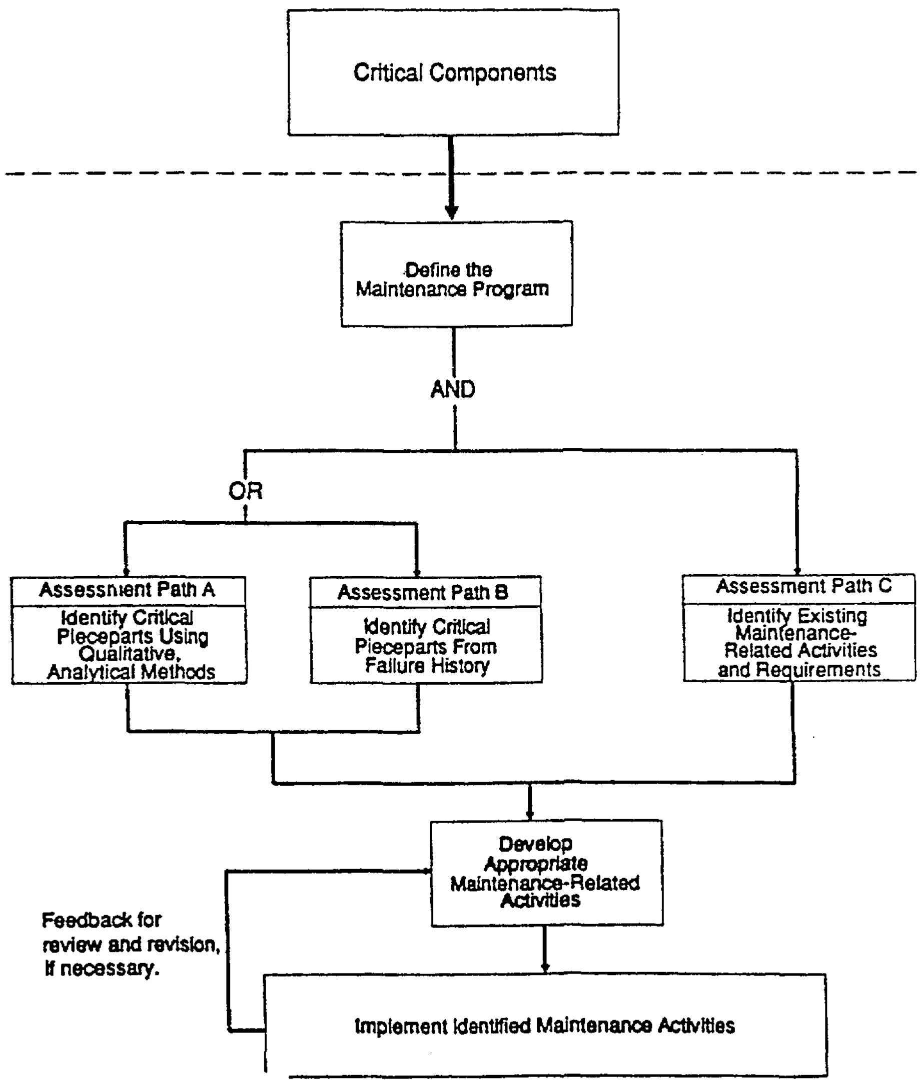

FIGURE 4-2 EVALUATION PROCESS FOR OPERATING AND STANDBY EQUIPMENT

- Piecepart failures that have large consequences in terms of repair resources required, or that could cascade to more serious failures. The piecepart failures that will be defended against by preventative/predictive maintenance or by other means should be chosen from this set.

A failure history assessment option for determining dominant failure modes of the risk-critical components is characterized by the box representing Assessment Path B of Figure 4-2. Since a reasonably long failure history is necessary for most components to determine the dominant failure modes from failure and repair data, it may be useful to combine components into categories that would allow pooling or mixing of the failure histories from several components. One appropriate option would be to combine the failure histories of components of the same type in the same environment, such as large MOVs that see borated water environments. Thus, the first step in this option is to develop the analysis boundary in terms of categories of equipment whose repair and failure data would be pooled.

The next step in this option is to construct a list of failure modes found in the particular data. This should be accomplished in terms of piecepart failures using, if available, piecepart failure cause data. If piecepart failure cause data is not available, the list should be constructed by major piecepart failure (e.g., "valve driver," valve gate binding," etc.).

The occurrence frequency of each category is then computed and the categories ranked by occurrence frequency, with the most frequently occurring piecepart failures indicated as the prime candidates for inclusion as the dominant failure modes.

The steps to assess existing maintenance requirements and recommendations for each risk-critical component are characterized by the box representing Assessment Path C in Figure 4-2. This assessment is to be conducted after, or in parallel with, the assessment in Path A or B; it is not considered an option.

In overview, the suggested assessment process is to collect and review all maintenance requirements and recommendations for the component from all relevant sources, and then partition these into maintenance actions that are part of the existing maintenance plan for the component and those that are not being performed.

Rationales are developed for both sets of maintenance actions. That is, a rationale is developed for each maintenance act that is currently being performed, and a rationale is developed to explain why each recommended performance is in the "not performed" category. This explicit set of steps could serve as a starting point for the assessment of maintenance needs for the component.

The dominant failure modes which should be defended against and for which maintenance strategies should be devised will be those identified in Assessment Path C, plus those identified using a reliability assessment similar to Assessment Paths A and/or B.

The process of determining effective maintenance to defend against the dominant failure modes of a component is largely one of engineering judgment. However, there are bookkeeping tools that can aid systematic completion of this task. Table 4-1 represents one configuration that could assist the process of determining effective maintenance. All dominant failure modes for a single risk-critical component are listed in the left-most column of the matrix, usually as individual piecepart failures. Succeeding columns, from left to right, list:

- Consequences of these piecepart failures in terms of resources for repair, impacts on risk, impacts on technical specifications (if any), potential for cascading or common cause failure, etc.

TABLE 4-1 CRITICAL FAILURE MODE DETECTION MATRIX
(RCM Matrix)

Critical Failure Mode	Failure Mode Impacts			Occurrence Frequency	Instrumentation	Latent or Announced	Potential Detection or Defenses	Critical Failure Mode?
	Repair Outage Time	Impact on Risk	Impact on LCO's					
fM1								Yes
fM2								Yes
.								.
.								.
.								.
fMn								No

- The estimated occurrence frequency for each piecepart failure, estimated either from historical failure data, or as a category such as high, medium, or low.
- Instrumentation, if any, that would provide an indication that the piecepart has failed or is likely to fail.
- Whether the piecepart failure is latent or announced.
- Potential maintenance defenses such as preventive or predictive maintenance, surveillance, etc. that could be used to detect the piecepart failure or a precursor to piecepart failure or prevent failure.

The last column represents a final assessment as to whether or not the failure mode will be defended against.

Reference 1 describes three applications of the reliability-focused maintenance process described in this section. However, since this process is essentially the same as RCM processes currently in common usage (References 3, 4, and 5), these applications are not repeated here.

References

1. "A Process for Risk-Focused Maintenance," by E. V. Lofgren, S. E. Cooper, R. E. Kurth, and L. B. Phillips, NUREG/CR-5695, March 1991, prepared for Division of Regulatory Applications of the U. S. NRC, prepared by Science Applications International Corporation.

2. Stetson, et al., "Analysis of Reactor Trips Originating in Balance of Plant Systems," prepared for U. S. NRC, SAIC-89/1140, September 1989.

3. F. S. Nowlan, et al., "Reliability-Centered Maintenance," prepared by United Airlines, Report No. A066-579, December 1978.

4. T. G. Hook, et al., "Application of RCM to San Onofre Units 2 and 3 Auxiliary Feedwater System," EPRI Report NP-5430, September 1987.

5. "Demonstration of Reliability-Centered Maintenance, Vol. 1: Project Description," (EPRI-6152), Interim Report, January 1989.

USE OF RELIABILITY DATA FOR MAINTENANCE OF A FAST REACTOR SYSTEM

R. NAKAI, Y. KANI
Power Reactor and Nuclear
Fuel Development Corporation,
Oari, Ibaraki,
Japan

Abstract

In Japan the experimental fast reactor Joyo has been operating for more than 10 years and construction of the prototype fast breeder reactor Monju has been just completed. In the course of fast reactor development the liquid metal component reliability database CREDO (Centralized Reliability Data Organization) has been developed for experimental fast reactors and sodium test facilities in Japan and US. This paper describes the method of evaluating maintenance effects quantitatively through the failure data analysis for liquid metal specific components such as a sodium valve using the CREDO database. The time trend of failure rate is calculated and the component aging failure rate is estimated based on linear aging model. It is observed that the aging failure rate is decreasing with time, whereas the failure rate is increasing with time. This reduction in aging failure rate is considered to be due to maintenance effects. Then the maintenance effectiveness is quantitatively calculated in the form of equivalent age reduction factor. The quantitative index for maintenance effects can be utilized for evaluation of maintenance method such as maintenance type and maintenance interval.

Introduction

The experimental fast reactor Joyo has been operating for more than 10 years and construction of the prototype fast breeder reactor Monju has been just completed at Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan. In order to upgrade the operational plant availability, much efforts are focused on the prevention of event occurrence rather than the mitigation. The improvement and planning of preventive maintenance in fast reactor systems are required to be achieved rationally in view of safety and availability.

Since the operating experiences of fast reactors are limited, the effective use of those operating data is important. Since 1985, the Centralized Reliability Data Organization (CREDO)[1] has been developed and is now operated as a cooperative project between PNC and US Department of Energy. CREDO is the liquid metal cooled fast breeder reactor (LMFBR) component reliability database, which involves about 23,000 components and 2,100 events. The accumulated operating experiences are approximately 2.7×10^9 component-hours.

The role of inspection, maintenance and monitoring is minimizing the component degradation effect. The key issue of improvement in maintenance work is to evaluate the current maintenance effectiveness, especially on the basis of quantitative indicator. This study examines the operating experiences in fast reactor system using CREDO to identify and characterize component aging trends and to quantify maintenance effectiveness.

Approach

Component failures are categorized into two groups: aging related failure and non-aging related failure. The aging related events occur time-dependently. The linear aging model[2] defines that the failure rate is increasing linearly with time. The increase in failure rate due to aging of the component is called as aging failure rate of which unit is /hr-yr. The stress on a component is accumulated as a hazard. The probability of failure is proportional to the hazard at that time. On the other hand it is known that there exists an initial failure for very early life of the component. It is assumed that component failure rate would increase linearly after some time threshold without maintenance as shown in Fig. 1. The maintenance works such as clean-up, overhaul and parts renewal are considered to reduce the hazard to some level. Therefore it can be expressed that maintenance effects contribute to the reduction of equivalent component age, which means the decrease of aging related failure probability. If the perfect maintenance is realized, the component is considered as good as new, while such maintenance could be achieved only by replacement of the component itself. The actual maintenance will contribute to eliminate some parts of aging related failure.

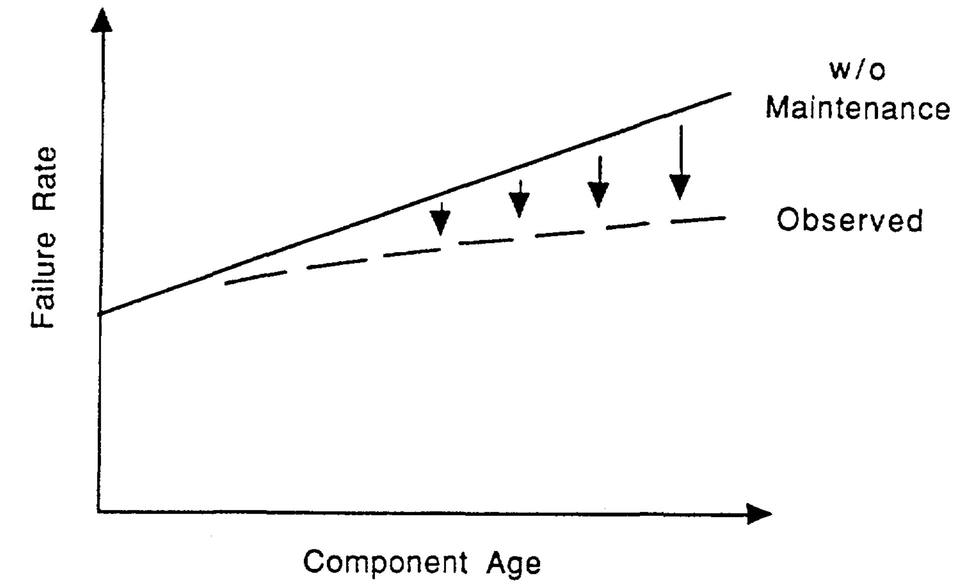

Fig. 1 Time trend of failure rate

The CREDO database provides useful information about the failed component, which includes the component installation date, the event date, the time since last maintenance and the contents of last maintenance. The modeling of component age reduction due to maintenance is shown in Fig. 2.

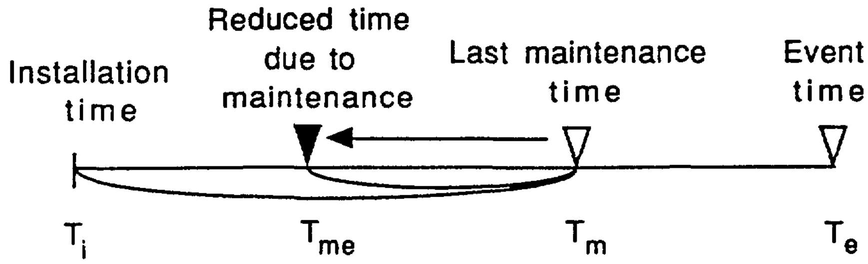

Fig. 2 Illustration of age reduction due to maintenance effect

$$T_{age} = T_e - T_i \qquad (1)$$

$$\begin{aligned} T_{age\text{-}eq} &= (T_{me} - T_i) + (T_e - T_m) \\ &= (1-\alpha) * (T_m - T_i) + (T_e - T_m) \\ &= T_{age} - (T_m - T_{me}) \\ &= T_{age} - \alpha * (T_m - T_i) \qquad (2) \end{aligned}$$

T_{age}	Calendar age
$T_{age\text{-}eq}$	Reduced age due to maintenance
T_i	Installation time
T_e	Event time
T_m	Last mantenance time
α	Equivalent Age reduction factor (maintenance effectiveness)

The component age, T_{age}, is calculated as the time difference between the event time and installation time. When the maintenance is performed, the component age is assumed to be reduced by a factor of α. Then the equivalent component age after the maintenance is defined as $T_{age\text{-}eq}$ in eq. (2). $(T_e\text{-}T_m)$ is obtained from the time since last maintenance. If α is one, the component is equivalent to be renewed. If α is zero, the maintenance is perfectly ineffective. For simplicity it is assumed that α is constant for the whole period.

Then the equivalent age is calculated with a parameter of α value. Based on the equivalent age, failure plot curves are produced. The resultant failure plot curve is approaching the parabolic shape. The least square method is applied to fit the parabolic curve. The coefficient of failure rate, aging failure rate, is obtained from the approximation equation. The aging failure rate is compared to the value directly obtained from the failure rate increase in the initial phase when the effect of maintenance does not appear. The estimated initial failure rate is also utilized to support the degree of agreement on the fitting curve. The best fitted value of α represents the effectiveness of current maintenance.

Result

Since more than 90 percent of CREDO components have not been experienced failure, statistically sufficient failure data are not available at this moment. Data combining from different plant was not conducted because maintenance activities vary plant to plant. Although a little failure data is available, the LMFBR-specific component, sodium valve, is chosen for an application of this proposed approach. There are 18 failure data out of a population of 95 sodium valves for a plant.

The role of maintenance is minimizing the effects of aging. At first the current failure data in CREDO database are reviewed and categorized into aging related event and non-aging related event. The aging related events are identified based on the event causes, which have a characteristics of aging effect. Wear, corrosion, fatigue, and erosion are judged as an aging category. In addition, event narratives in the database are used to support to examine whether it is aging related or not. In spite of the detailed examination of event narratives, the category for three of 18 failure data is still undetermined due to ambiguous real root cause. These data are treated as an uncertainty range. The fraction of aging failures is estimated as 40%. The upper value is 50%, while the lower value is 33%.

The time trend of failure rates is calculated for two-year time interval as shown in Fig. 3. The upper bound and lower bound are also displayed. Since the failure data during pre-operation test were not originally included in the database, the failure rate increases with time. It is observed that degree of increase tends to decrease with time, while failure rate is increasing with time. Based on the linear aging model, the aging failure rate is obtained as 3.1×10^{-7}/hr-yr for the early component life. This value is equivalent to about three-year doubling time. Averaging over the whole component life, the aging failure rate is obtained as 7.3×10^{-8}/hr-yr. This change indicates that maintenance reduces the effects of aging degradation by a factor of three or four.

Of 18 failures, the components associated with four events have not been experienced any maintenance or inspection before the

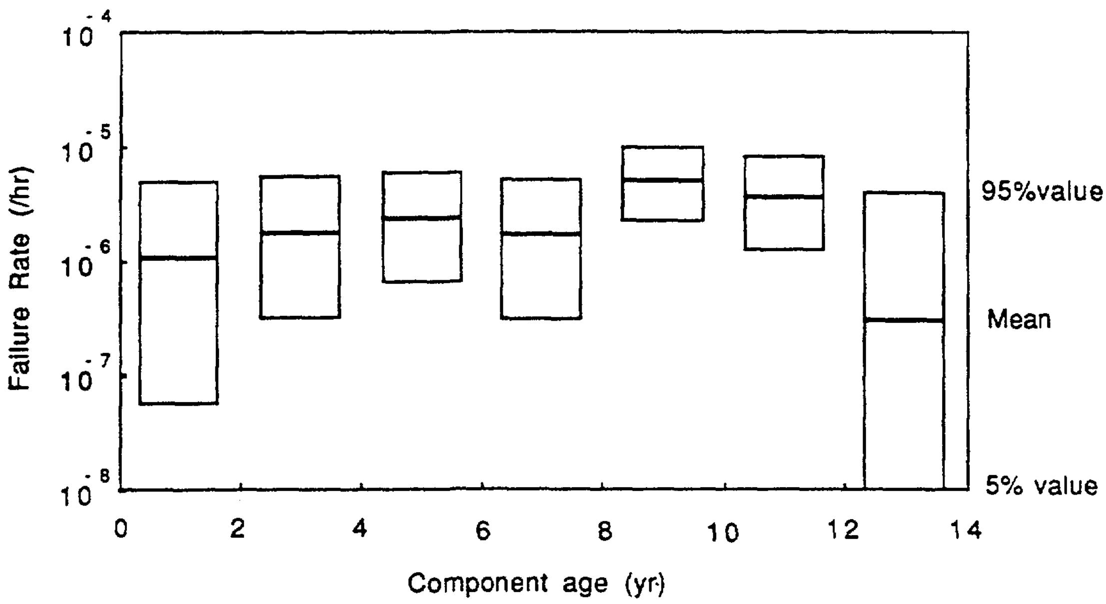

Fig. 3 Time trend of failure rate for sodium valve

occurrence of the events. The inspections are preceding, but maintenance was not performed for five events. The others experienced the maintenance such as clean-up, grease supply, exchange of parts or overhaul. The preceding maintenance for nine events is effective to reduce component age whereas inspection does not reduce component age but verifies the component available.

The failure plot curves assuming various aging reduction factor are obtained. Fig. 4 shows that the failure plot curve based on the equivalent component age assuming 60% aging reduction. Then the aging failure rate and initial failure rate is calculated from the approximation equation. They are compared with the observed value for the early component life, when the component is not experienced a maintenance. The results are shown in Fig. 5. The points for the age reduction factor of 0.5 and 0.6 are close to the observed one. This means the current maintenance work substantially reduces the component age by 50% to 60%.

The proposed method estimates the age reduction factor of 60% in the case of the above example. Then, the potential of maintenance improvement related to the aging remains 40%. It is observed that critical parts of aging-related event are extension rods, diaphragms,

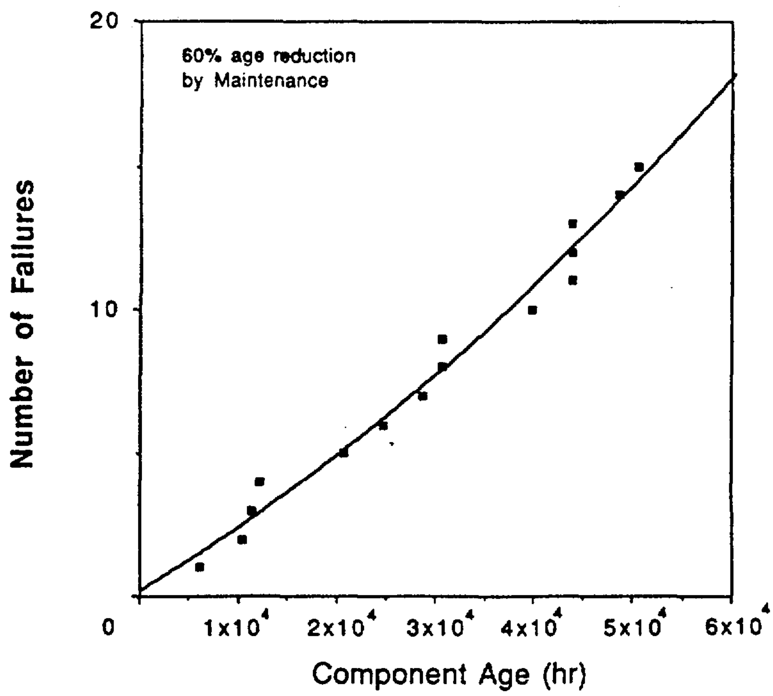

Fig. 4 Result of Failure Plot Curve based on Assumed Age Reduction

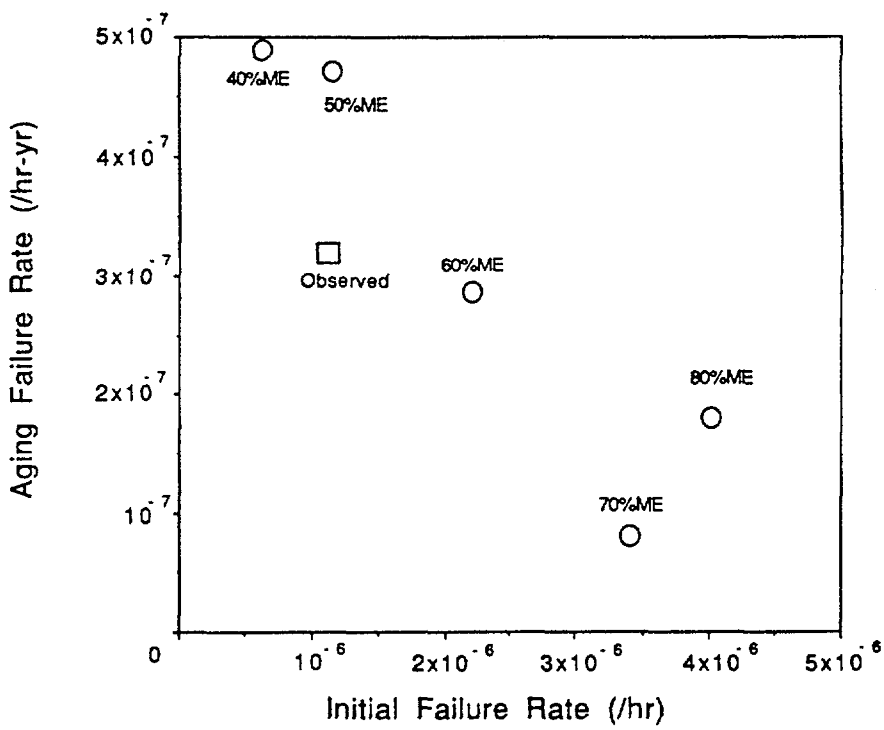

Fig. 5 Estimated aging failure rate and initial failure rate

and limit switches. One-third of aging related events are detected in a degraded state which still has functional capability. This indicates that inspection works are as useful as maintenance works to maintain the availability.

Conclusion

At present the significant aging effect is not observed for a limited operating experience of fast reactor system. Although the potential of degradation due to aging is observed, the maintenance activity is effective to prevent from the deterioration of component reliability. The method estimating maintenance effectiveness is presented and applied for the LMFBR-specific component. The result shows a prospect that maintenance effects are quantitatively calculated in the form of equivalent age reduction factor. The quantitative index for maintenance effects can be utilized for evaluation of maintenance method such as maintenance type and maintenance interval.

References

(1) Nakai, R. et al., "Development of FREEDOM/CREDO database for LMFBR PSA," IAEA Technical Committee Meeting on Evaluation of Reliability Data Sources, 1988.

(2) Vesely, W. E., "Risk Evaluations of Aging Phenomena: The Linear Aging Reliability Model and Its Extension," NUREG/CR-4769, EG& G Idaho, 1987.

LIST OF PARTICIPANTS

BELGIUM

Mr. L. Geraets
Belgatom
Avenue Ariane 7
1200 Brussels

Mr. P. Coenraets
Electrabel
Power Station of Tihange
Avenue de L'Industrie, 1
4500-Huy

CANADA

Mr. J. Krasnodebski
Ontario Hydro
700 University Avenue
Toronto, Ontario M5G 1X6

Mr. B.J. Ferguson
Ontario Hydro
Bruce Nuclear Generating Station 'A'
PO Box 3000
Tiverton, Ontario N0G 2T0

CHINA

Mr. X.J. Ou
GNPJVC
c/o EDF
Centre National d'Equipment Nucléaire
1 avenue du General de Gaulle
BP 309, 92142 Clarmart Cedex
Paris

Mr. Z.F. Zhang
GNPJVC
c/o EDF
Centre National d'Equipment Nucléaire
1 avenue du General de Gaulle
BP 309, 92142 Clarmart Cedex
Paris

CZECHOSLOVAKIA

Mr. H. Hasler
Nuclear Power Plant Temelin
373 05 Temelin

Mr. P. Andrasko
SEP-EMO
Nuclear Power Plant Mochovce 935 39

FRANCE

Mr. P. Kaplan
COGEMA/Etablissement de la Hague
BP 508
50105 Cherbourg Cedex

Mr. D. Pageron
COGEMA/Etablissement de la Hague
BP 508
50105 Cherbourg Cedex

Mr. H. Sanchis
COGEMA/Etablissement de la Hague
BP 508
50105 Cherbourg Cedex

Mr. P. Coursier
GAME Ingeneering
Immeuble CAMPUS
6 rue Jean-Pierre Timbaud
78182 St. Quentin en Vvelines Cedex

Mr. J.P. Jacquot
EDF
Department S.D.M
6 Quai Watier
78400 Chatou

Mr. G. Zwinglestein
EDF
Service de la Production Thermique
Quartier Michelet - Immeuble PB 26
13-27 Esplanade Charles de Gaulle 92060
Paris-la Defénse

GERMANY

Mr. G. Philippi
TUV Sudwest e.V
Dudenstrasse 28
6800 Mannheim 1

Mr. M. Scholz
Preussen Elektra Aktiengesellschaft
Kernkraftwerk Stade
Postfach 17 80
W-2160 Stade

HUNGARY

Mr. G. Timar
Paks Nuclear Power Plant
H-7031 Paks Pf 71

Mr. Z. Kiss
Paks Nuclear Power Plant
H-7031 Paks Pf 71

IRELAND

Mr. V. Ryan
ESB
Lower Fitzwilliam St.
Dublin 2

ITALY

Mr. A. Eramo
ENEA/DISP
Via Vitaliano Brancati 48
Rome

JAPAN

Mr. R. Nakai
Systems Analysis Section
O-Arai Engineering Centre
PNC, 4002 Narita, O-Arai
Ibraki, 311 13

Mr. K. Ohta
NUPEC, 8th Floor, Fujita Kanko Toranomon Bldg.
17-1, 3-Chome Toronomon Minato-ku
Tokyo 105

Mr. M. Hirata
Toshiba Corporation
8 Shinsugita
Isogo-ku
Yokohama

Mr. S. Shimizu
Toshiba Corporation
4.1 Ukishima-cho
Kawasaki-ku
Kawasaki 210

Mr. I. Takekuro
London Office
Tokyo Electric Power Co.
Norfolk House
31 St. Jame's Square
London SW1Y 4JJ, UK

KOREA, REPUBLIC OF

Mr. T.W. Kim
Korea Atomic Energy Research Institute
(KAERI)
PO Box 7, Daeduk-Danji
Taejon, 305-606

Mr. T.J. Lim
Korea Atomic Energy Research Institute
(KAERI)
PO Box 7, Daeduk-Danji
Taejon, 305-606

NETHERLANDS

Mr. B. Heynen
NPP Borssele
Electriciteit Productie Maatschappij
Zuid Nederland
PO Box 130
4380 AC Vlissingen

Mr. C. Witteman
GKN
Nuclear Power Plant
Waalbandijk 112 a
6669 MG Dodewaard

PAKISTAN

Mr. J.A. Hashimi
Embassy of Pakistan
Hofzeile 13
1190 Vienna

POLAND

Mrs. E. Hajewska
Institute of Atomic Energy
05-400 Otwock-Swierk

SPAIN

Mr. R. Fernandez
Nuclenor
Herman Cortes 26
39003 Santander

Mr. J. Gonzales
Nuclenor
Herman Cortes 26
39003 Santander

Mr. J.A. Izquierdo
Central Nuclear de Cofrentes
46625 Cofrentes
Valencia

SWITZERLAND

Mr. L. Nedelko
Kernkraftwerk Leibstadt AG
CH - 4353 Leibstadt

Mr. H. Millat
Nordostschweizerische Kraftwerke AG
Nuclear Power Plant Beznau
CH - 5312 Dottingen

SWEDEN

Mr. Per-Olaf Sanden
Swedish Nuclear Power Inspectorate
PO Box 271 06
S-102 52

Mr. H. Gunnarsson
Safety and Reliability
S-205 09 Malmo

Mr. L. Gomersson
Ringhals Nuclear Power Plant
S-430 22 Varobacka

UNITED KINGDOM

Mr. I.C.D. Stewart
Nuclear Electric PLC
Sizewell B Power Station
Leiston, Suffolk IP1G 4WR

Mr. B. Horne
Nuclear Electric PLC
Barnett Way, Barnwood
Gloucester, GL4 7RS

Mr. R. Mottram
Scottish Nuclear Ltd
14a Meadowfoot Rd.
West Kilbride
Ayrshire
Scotland KA23 9BX

Mr. M. Jenkins
Scottish Nuclear Ltd
Minto Building
6 Inverlair Avenue
Glasgow G44 4AD

Mr. P. Welsh - (Chairman of the Meeting)
Dungeness A Nuclear Power Station
Romney March
Kent TN29 9PP

Mr. C. Davis
Nuclear Electric PLC
Heysham, PO Box 4
Morecambe, Lancs LA3 2XQ

Mr. B.R. Spriggs
Nuclear Electric PLC
Heysham, PO Box 4
Morecambe, Lancs LA3 2XQ

UNITED STATES OF AMERICA

Mr. L.W. Owsenek
PRC Engineering Systems Inc.
12005 Sunrise Valley Drive
Reston
Virginia 22091

Mr. W.D. Midgett
PRC Engineering Systems Inc
12005 Sunrise Valley Drive
Reston
Virginia 22091

Mr. E.W. Brach
US Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Mail Stop WFN 10 A 19
Washington, DC 20555

Mr. N. Bloom
Southern California Edison Company
PO Box 129
San Clemente
California 92674

Mr. E.V. Lofgren
Scientific Applications International Corp
1710 Goodridge Drive
McLean VA 22102

Mr. R.M. Sigler
NE-73
Office of Nuclear Safety Policy and Standards
US Department of Energy
Washington, DC 20585

Mr. D.D. Barnard
Life Cycle Engineering Inc
PO Box 300001
1 Poston Rd., Suite 300
Charleston, SC 29417

Mr. D. Sonnett
Life Cycle Engineering Inc
PO Box 300001
1 Poston Rd., Suite 300
Charleston, SC 29417

Mr. G. Allen
EPRI
3412 Hillview Avenue
PO Box 10412
Palo Alto, CA 94303

Mr. J. Gaertner
ERIN
2175 N. California Blvd.
Suite 625
Walnut Creek, CA 94596

THE RUSSIAN FEDERATION

Mr. V.D. Gourinovich
All Union Institute for Nuclear Power Plants
Ferganskaya 25
109507 Moscow

Mr. V.V. Nikolaev
Ministry of Atomic Energy
Moscow

YUGOSLAVIA

Mr. V. Dirnbek
KRSKO NPP
Vrbina 12
68270 KRSKO

Mr. Z. Zec
KRSKO NPP
Urbina 12
68270 KRSKO

Mr. L. Fabjan
"Jozef Stefan" Institute
Jamova 39
PO Box 100
61111 Ljubljana

INTERNATIONAL ORGANIZATIONS

WANO

Mr. V.R. Hoensch
World Association of Nuclear Operators
WANO - Paris Centre
35 avenue de Friedland
FR - 75008 Paris
France

OECD/NEA

Mr. G. Ishack
OECD/NEA
Nuclear Safety Division
38 boulevard Suchet
75016 Paris
France

IIASA

Mr. B. Wahlstrom
IIASA
Schlossplatz 1
A-2361 Laxenburg

IAEA

Mr. F. Niehaus, Head, NENS-SAS
Mr. V. Tolstykh, NENS-SAS
Mr. J.P. Bemer, NENS-NOSS
Mr. B. Moore, NENS-NOSS
Mr. H. Seki, NENS-NOSS
Mr. B. Tomic, NENS-SAS - Scientific Secretary

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