



PSA AND METHODS TO OPTIMIZE THE MAINTENANCE OF SAFETY RELATED EQUIPMENT AT LAGUNA VERDE NPP

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Abstract

In this paper the most significant advances reached in the development of a project¹ to optimize the maintenance and surveillance tests of safety related equipment at Laguna Verde Nuclear Power Plant (LV NPP) are described.

The first part of this process consists of the application of risk-based results and techniques using the specific PSA Level 1 of LV. Before the use of these risk-based techniques in the generation and interpretation of results, it was necessary to perform a review of the risk criteria used in PSA applications for prioritization of maintainable components, determination of risk-based allowed outage times and surveillance test intervals, definition of component risk classes, determination of risk significances for systems and components within the scope of the maintenance rule, besides criteria used in a first approach to evaluate simultaneous inoperabilities impacting the risk. Partial results of the application of risk methods for AOTs, STIs and simultaneous inoperabilities are presented.

Also some results of the application of a selected method for maintenance optimization focused on reliability are explained. The results involve descriptions about the determination and prioritization of risk significant components, advances in the review of operational experience of a selected system to determine dominant failure modes and the comparison with those failures modeled in the LV PSA, operational experience review to assess the real times spent in maintenance activities for different types of components and, review of maintenance activities addressed to minimize the identified failure modes.

Within the regulatory assessment of the maintenance rule implementation in LV by the utility, some results of the independent work done by our regulatory staff to select those structures systems and components (SSCs) to be under the scope of the maintenance rule are presented. Also a discussion of our perspective about the establishment of performance criteria and performance goals of SSCs based on the specific LV operating experience is summarized. Finally this document includes some suggestions to make an initial evaluation of the maintenance and its effectiveness, and to define requirements of data for collecting plant data for accomplishment of the maintenance rule by the utility.

1.0 INTRODUCTION

The Laguna Verde Nuclear Power Plant (LV NPP) is located in the coasts of the Gulf of Mexico. This nuclear plant has two reactor units of the GE BWR/5 type with Mark II containment. The production capacity at full power is 654 MWe each unit. At this moment

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the Unit 2 is being refueled to begin its 3rd operational cycle and the Unit 1 is operating on its 6th cycle. For the Unit 1 a PSA level 1 has been completed and the level 2 is in regulatory assessment phase. The PSA level 1 will be applicable to the Unit 2 after a comparative analysis to account for design differences between both units.

The following section contains a description of the methodology that is being structured to improve the LV operation through the maintenance optimization. The methodology is conformed by three major parts. The first one includes the use of risk-based techniques to analyze allowed outage times for equipment out of service (AOTs), surveillance test intervals (STI) and an approach to assess risk critical plant configurations due to simultaneous component inoperability. The second part is the application of a method to optimize the maintenance focusing on reliability techniques. The third part deals with the implementation process of the maintenance rule at LV by the utility and the regulatory point of view. The enrichment of this work is given by the inclusion of LV operational experience.

2.0 METHODOLOGY DESCRIPTION

The Figure 1 shows schematically the methodology to follow in the application of the techniques to optimize the maintenance and surveillance tests, including risk information, a Reliability Focused Maintenance (RFM) method and Maintenance Rule interactions. Each part is briefly described in the next subsections.

2.1 Allowed Outage Times (AOTs)

Basically the AOTs included in technical specifications (TS) are employed to perform activities of preventive maintenance (PM) or corrective maintenance (CM). During the AOT for a component, the lost of function of the component has a risk impact. The quantification of the AOT risk contribution (r) gives the accumulated risk over the allowed time d [2],

$$r = \Delta R \times d$$

where: ΔR is the risk increase associated to the unavailable component,
 d is the time duration of the unavailability and,
 r is the AOT risk contribution

Instead of perform only a ranking of the AOT contributors, a separation into classes may be done: Class 1 or Unacceptable risk contribution; Class 2 or Medium risk contribution; and Class 3 or Unimportant risk contribution.

With the risk classification it is possible to identify class 1 AOTs, to search for interactions with other component AOTs, tests, alignment checks, or a detailed analysis to modify the AOT with high risk contributions. The class 3 AOTs can be used to relax AOTs for the associated components in conditions of exception to TS or even for TS permanent changes. The class 2 can be considered to interact with class 1 or class 3. This strategy for the management of AOTs has a strong relationship with configuration control. By other side, imposing a limit to the risk contribution of an AOT, a risk-based AOT can be calculated, $d_{\max} = r_{\max}/\Delta R$. Then the risk-based AOT can be compared to the real time duration of maintenances and to the AOT established in the TS.

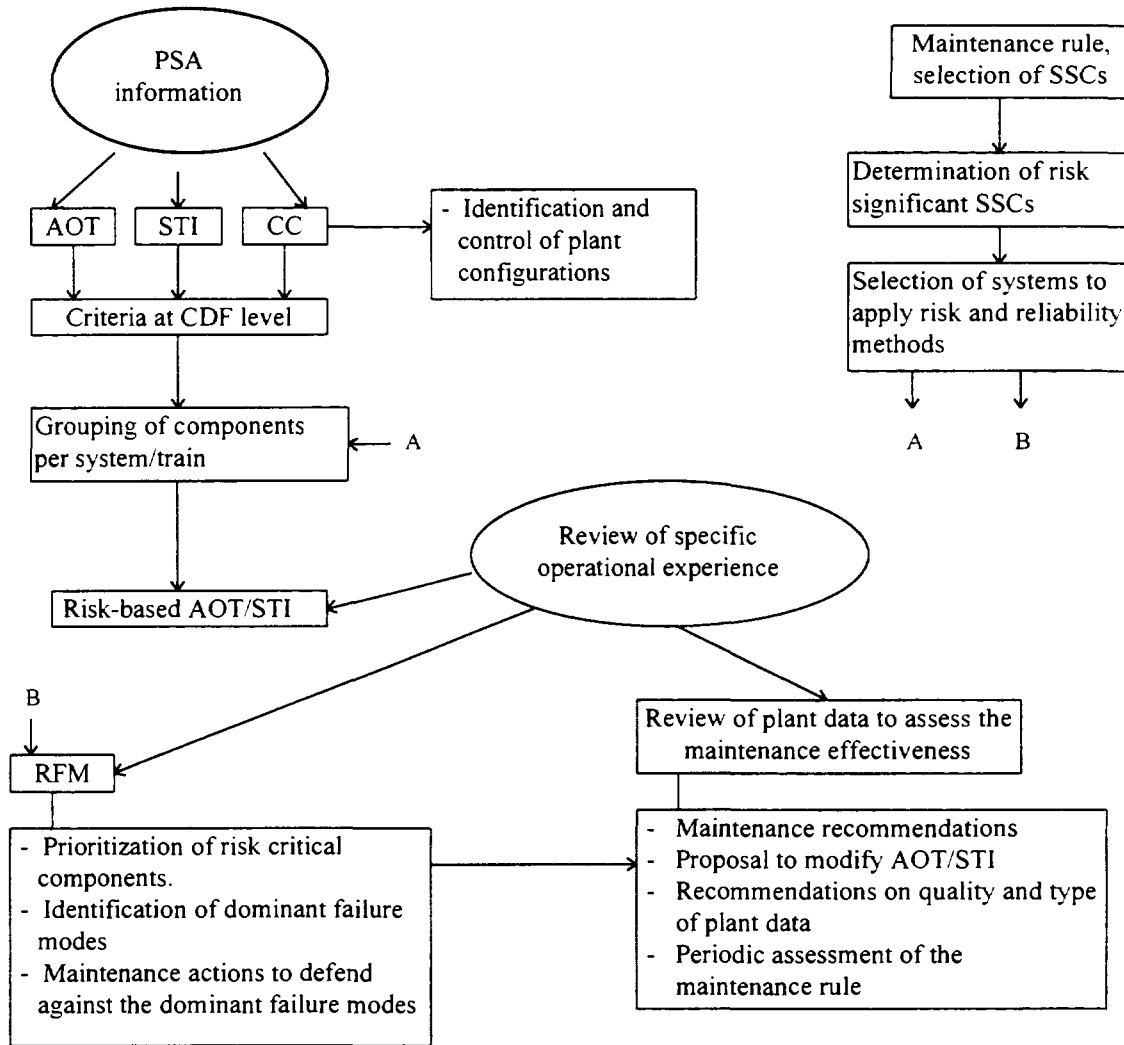


FIG. 1. Integrated strategy to optimize maintenance and surveillance testing

2.2 Surveillance Test Intervals (STIs)

The analysis of STIs is based on the risk contributions arising from failures occurring between tests and detected at the moment of the test [2]. The STI risk contribution of a component is given by

$$R_D = \frac{1}{2} \lambda T \cdot \Delta R$$

Where ΔR is the risk increase when the component is found failed at the moment of the test, λ is the standby constant failure rate and T is the STI. Similar to the AOT risk contributors, the STIs can be classified and setting a limit to the risk contribution,

$$T_{max} = \frac{2 \cdot R_{Dmax}}{\lambda \cdot \Delta R}$$

In the determination of risk contributions it is possible to extend the analysis to include all the components tested in a specific test of a system. In this case the risk contribution for n components involved by the test is

$$R_D = \sum_{i=1}^n \lambda_i \cdot T \cdot \Delta R$$

2.3 Configuration Control (CC)

Configuration control is the management of combinations of components simultaneously inoperable, to control the risk and assure a safety plant operation. Similar to the concepts used in AOTs, in configuration control the risk contributions $r = \Delta R \times d$ are considered [2], [3], where ΔR is the risk increase caused by the simultaneous inoperability and d is the time duration for the configuration. Also the configurations can be classified in terms of their risk contributions as Unacceptable, critical and marginal, where marginal is a term used to identify risk insignificant configurations that can be significant depending on the time duration allowed to exist. A maximum time duration can be calculated if a limit to the risk contribution of a configuration is imposed, $d_{\max} = r_{\max} / \Delta R$.

2.4 Reliability Focused Maintenance

The RFM method for maintenance optimization is in essence a risk-based method to identify critical components to focus maintenance activities. The method begins with the identification of risk-critical components and continues with the determination of dominant failure modes of the critical components. Finally a detailed assessment of the maintenance is needed to address maintenance activities to avoid or minimize the dominant failure modes. The Figure 2 shows a summary of the general process of the RFM method. More details about variants of the method can be found in [4]. The shown method was selected because the convenience to cover maintenance rule aspects addressing the specific operational experience, besides the interactions with the risk significant failure modes from the PSA modeled components.

As it will be seen in section 3, the determination of the risk critical or significant components involves only the systems and components modeled in the LV PSA level 1 using the typical risk importance measures, and for purposes of the maintenance rule, other systems not modeled in PSA can be classified as risk significant through an analysis to search for a relationship to systems modeled in PSA. The determination of dominant failure modes is performed from a review of the specific operational experience of a selected set of components, and the maintenance recommendations are reviewed to conclude if the present maintenance programs tend to avoid the identified failure modes, or those programs need to be improved.

2.5 Maintenance Rule

The Maintenance Rule regulation [5] has been required to the utility for its implementation to the LV NPP. With the aid of the NUMARC 93-02 [6] guidelines and [7], our regulatory staff made a selection of structures, systems and components (SSCs) to be under the scope of the rule. This selection was used to evaluate the selection made by the utility. As established in the 10CFR50.65, the required SSCs are the safety related SSCs and

those non safety related that help to mitigate transients and accidents, are within emergency operating procedures, those SSCs that can cause a scram or actuation of a safety related SSCs, and those that avoid a safety related SSC to fulfill its intended function. The scope of the present project is to cover only safety related SSCs. After the selection, specific criteria are applied to determine risk significant SSCs.

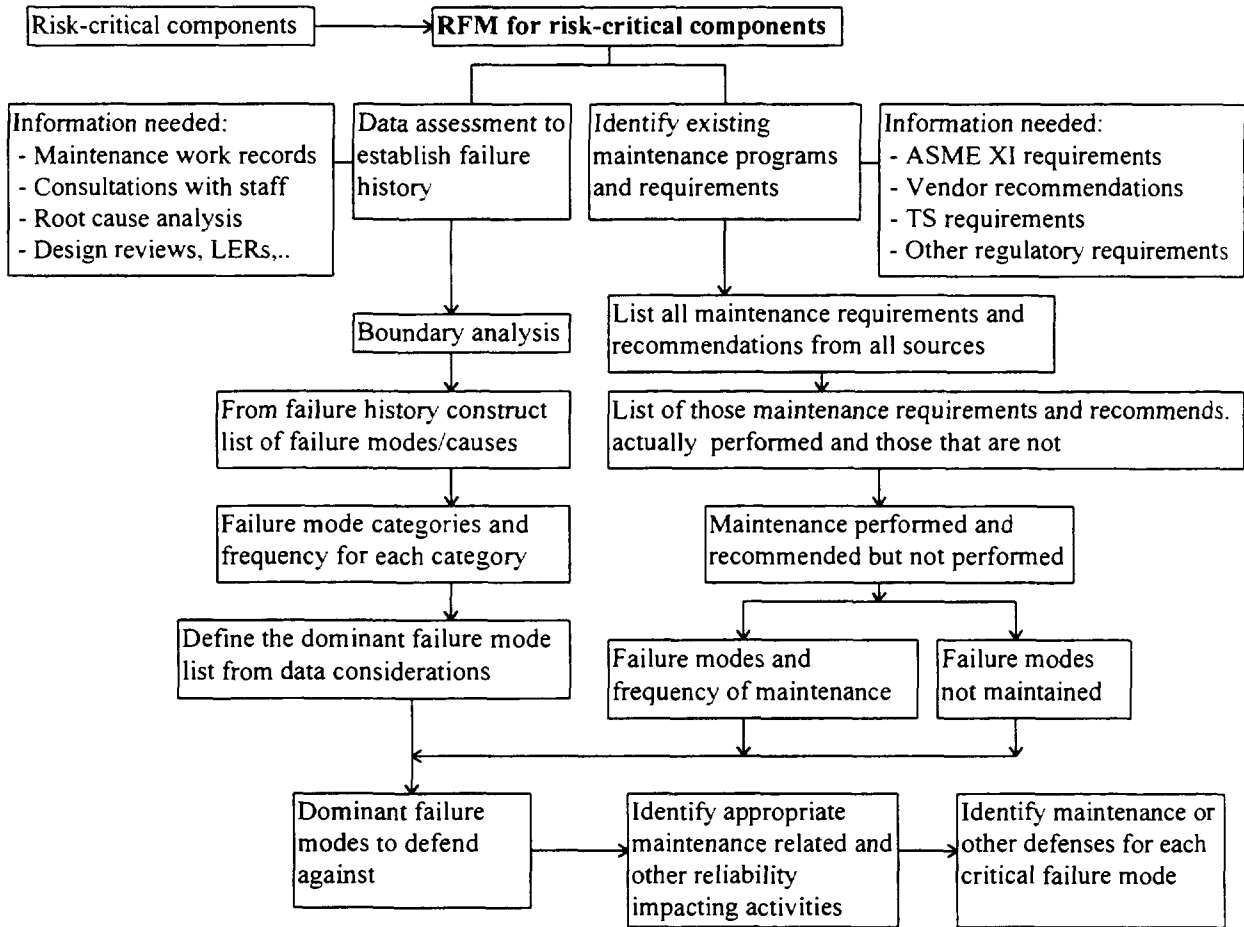


FIG 2. Summary of the general process for Reliability Focused Maintenance.

3.0 PRELIMINARY RESULTS

Before the generation of results based on risk techniques for AOTs, STIs, configuration control and identification of risk significant SSCs, the following risk criteria were selected to use in the PSA applications:

Table 1. Criteria for classification and maximum risk contributions [8].

	AOT	STI	Configuration Control
Unacceptable	$1E-06 \leq r$	$1E-06 \leq R_D$	Unacceptable $1E-02 \leq \Delta R$
Medium	$1E-08 \leq r < 1E-06$	$1E-08 \leq R_D < 1E-06$	Critical $1E-04 \leq \Delta R < 1E-02$
Unimportant	$r < 1E-08$	$R_D < 1E-08$	Marginal $\Delta R < 1E-04$
	$r_{max} = 1\%CDF$	$R_{Dmax} = 1\%CDF$	$r_{max} = 1\%CDF$

Table 2. Criteria to select risk significant structures, systems and components [6].

<p>A SSC is risk significant if:</p> <ul style="list-style-type: none"> • its risk importance RRW contributes to the 99% of the accumulated RRWs, or its RRW exceeds the 0.5% of the baseline CDF. • appears in the ranked minimal cutsets accounting for the 90% of the baseline CDF • its risk achievement worth RAW shows at least the doubling of the baseline CDF

Table 3. Risk results for the AOTs of RHR-A equipment.

Residual Heat Removal System - A					
Equipment	ΔR	Class	TS AOT (days)	d_{max} (hours)	d_{max} (days)
Heat exchanger	4.37E-06	3	3*, 7	2982	124
Moto-pump	6.29E-06	3	3, 7	2070	86
HX & moto-pump	7.75E-06	3	3, 7	1680	70
HVAC pump room	1.35E-06	3	7	9616	401

* 3 days for the shutdown cooling mode.

Table 4. Results of components grouping for systems risk analysis with IMPOSUB

HPCS				RCIC			
AOT: 14 days.				AOT: 14 days			
Equipment	ΔR	r	d_{max} (hrs)	Line	ΔR	r	d_{max} (hrs)
Electrical	5.742E-04	2.202E-05	23	Steam	3.279E-04	1.258E-05	40
CV'S & XV'S	5.895E-04	2.261E-05	22	Suction/Pool	2.940E-04	1.128E-05	44
Pump	5.795E-04	2.223E-05	23	Suction/CST	2.490E-04	9.551E-06	52
Maintenance	5.752E-04	2.206E-05	23	Common line	1.300E-04	4.986E-06	100
MOV's	5.213E-04	2.000E-05	25	Injection	3.970E-04	1.523E-05	33
O. Restr.	5.765E-04	2.211E-05	23	Condensate	1.596E-04	6.122E-06	82
HVAC	5.514E-04	2.115E-05	24	Turbine-Pump	2.501E-04	9.593E-06	52
Suppression Pool	3.723E-04	1.428E-05	35	Testing line	2.160E-05	8.285E-07	603
Filter (CST)	1.900E-06	7.288E-08	6856				

Table 5. Preliminary results for STI risk calculations.

HPCS			RCIC		
Components	TS STI (days)	Risk-based STI (days)	Components	TS STI (days)	Risk-based STI (days)
Pump, Valves V2 & V3, MOVs 8187 & 8169, Strainer.	92	91	Pump, Valves V1, V2 & V44, MOVs 8132 & 8100, Strainer.	92	83
LPCI-A			RHR-A		
Components	TS STI (days)	Risk-based STI (days)	Components	TS STI (days)	Risk-based STI (days)
Pump, MOVs 8221, 8204, 8226 & 8219, Strainer.	92	368	Pump, MOVs 8226 & 8219, Strainer.	92	366

3.1 Allowed Outage Times

In order to support the analyses for the risk impact due to the inoperability of components, the package R&R [9] was used for the development of a computer program to calculate risk importances of equipment and components. The code was named IMPOSUB [10] because of its particular ability to subsume non-minimal cutsets resulting when an unavailability is set to a true state.

The Table 3 above presents the results for the analysis of the AOTs for the RHR system. The TS AOT for this system is 7 days, but particularly for the suppression pool cooling mode the TS limit the AOT to 3 days. The most restrictive risk-based AOT of 70 days is quite longer than the TS AOTs. The long risk-based AOT for the heat exchanger results because of a redundancy in the cooling modes and two redundancies in low pressure injection. Jointly with deterministic analysis these results are being used to evaluate a solicitude of the utility to change the 3 days AOT to 7 days. Table 4 shows the results obtained for unavailability of emergency system components as pumps, valves, filters, etc., and for types of lines in a system, i.e., suction, injection, etc. In the same table appear the risk-based AOTs associated with the inoperability of each component.

The computed risk-based AOTs need to be improved by effects like the risk decrease effect due to testing or verification of operability of redundant components and common cause failure considerations

3.2 Surveillance Test Intervals

Table 5 shows the results for STI risk contributors, mainly for tested components in trains during power operation not providing water to the reactor vessel. Also the table contains the results for risk-based STIs and the present STIs required by TS.

For the HPCS and RCIC systems, practically the risk-based STIs are the same as those required by TS. Because of the lower risk importance of the LPCI-A and RHR-A systems their corresponding STIs are greater than the times required by TS.

Table 6. Different classes of risk configurations.

CONFIGURATION	$\Delta R(/yr)$	d_{max} (hours)	CLASS
DG-1A unavailable for maintenance RRA-FN-002 there is no signal to start	1.02E-02	1.3 hours	Unacceptable
Battery set 1A125 lost of function RRA-FN-002 unavailable for maintenance	1.00E-02	1.3 hours	Unacceptable
AC-I-141A1C unavailable for maintenance SLC manual valve V-9 open	1.06E-04	5 days	Critical
RCIC MV-8100 fails to remain open SLC manual valve V-9 open	1.01E-04	5 days	Critical
RRA-FN-001 unavailable for maintenance SLC manual valve V-9 open	9.81E-05	6 days	Marginal
AC-I-141A1C unavailable for maintenance SLC-P-001 unavailable for maintenance	3.92E-05	14 days	Marginal

3.3 Configuration Control.

Through the application of a simple process to generate possible combinations of unavailable equipment and verification of existence of such a combinations, the results of some existing configurations were obtained and they appear in table 6.

In table 6 it is observed the maximum time to allow a configuration to be present. If this time is exceeded, the configuration risk contribution will exceed the 1% of the baseline CDF, taken as risk criterion. The configurations identified have not been analyzed from an operational standpoint because it is necessary first to review the criteria to select components as candidates to form configurations.

3.4 Reliability Focused Maintenance

The determination of risk critical systems and components was carried out with the application of the criteria shown in Table 2 to the main results of the LV PSA. The process consisted with the obtainment of a list of components which were used to generate a list of risk significant systems. This first list covered the systems modeled in the PSA in an explicit way. An analysis of the initiating events was perform to include some systems not considered in an explicit way. In order to finalize the list for maintenance purposes some others methods were used by the utility to assign risk significances to the systems not explicitly modeled in PSA. The Table 7 shows some risk-critical safety related systems that are related to the PSA whether explicit or implicitly. This type of list contains systems selected for this project and for maintenance rule purposes.

Table 7. Examples of risk significant systems.

SYSTEM	DESCRIPTION	TYPE OF MODELING
R62	125 VDC Power Distribution	Implicit
E12	Residual Heat Removal System	Explicit
B35	Reactor Recirculation Control System	Implicit
E51	Reactor Core Isolation Cooling	Explicit
X60	DG Area Vent. and Air-conditioned system	Implicit
E22	High Pressure Core Spray System	Explicit
C72	Reactor Protection System	Implicit
P41	Nuclear Service Water	Implicit
N61	Removal of Air from the Main Condenser	Implicit

From the SSCs selected by CNSNS during the assessment of the maintenance rule a safety related system was selected to apply the method of RFM. This system is the Residual Heat Removal system (RHR). Nevertheless the RHR is a system of medium risk importance in the classification, it was selected for a first approach in the application of the defined RFM method because it has several operational mode, with two redundant loops and a loop dedicated to low pressure injection.

An initial technical visit was carried out to LV just to know the type, quality, location and control of the information generated by the distinct plant areas. A second visit had the intention to get information about of failure data for the RHR system. For this purpose the

surveillance and maintenance records were reviewed taking into consideration the impact of the failures on the functionality and operability of the system. In order to classify the failures they were categorized as

Primary Failure (PF): Failures leading to a loss of the safety function,

Secondary Failure (SF): Failures leaving the components in a degrade state, but the safety function is not lost.

Maintenance Failures (MF): Errors occurred during the execution of maintenance.

Maintenance Recommendations (MR): Deficiencies identified in procedures, practices, recommended frequencies and tests.

For convenience in the analysis of the identified failures, these were separated by engineering disciplines: mechanical, electrical and instrumentation and control. The Table 8 includes the most important failure events found in the review and analysis of maintenance and surveillance records since 1991 up to the first third of this year. The failures shown are mainly those considered PF and the last two events classified as MF and MR.

Table 8. Dominant failure modes found in the review of the maintenance history of the RHR system.

DATE	COMPONENT	AREA	TIME (H)	DESCRIPTION
92-09-02	DPIS-N012B	I&C	4	Spurious Signal to initiate the shutdown cooling mode
92-10-03	B35-PS-018A	I&C	3	Pressure switch out of tolerance, high signal causes system isolation.
92-10-19	MV-8248	Mec	8	Failure to open in shutdown cooling mode.
94-03-10	MV-8202A	Elec	8	Minimum flow valve, failure to open.
95-09-28	PS-N019A	I& C	4	Pressure switch out of tolerance, high signal causes system isolation.
96-01-22	MV-8294B	Mec	2	Failure to open totally (40%).
96-03-11	PS-N033A	I&C	1	Pressure switch out of tolerance.
96-06-19	PS-N033A	I&C	1	Pressure switch out of tolerance.
96-10-23	1-MCC-1B1-C	Elec	10	Thermic relay damage. Failure to control MV-8202B
95-09-23	AV-8206B	Elec	8	Valve actuator, lack of lub. Failure to open.
96-12-01	MV-8210B	Mec	?	Limiterque switch misinstalled giving failure in the position indication.

In the final step for classification of failures, the analysis of the information was completed with consultation of other sources like the licensing event reports, plant databases and periodical reports from the plant's systems engineering area. The identified dominant failure modes were compared with failure modes modeled in the PSA for this system. The only conclusion from this comparison is that at least for this system the failure mode "Permanent signal to close" is not considered in the system's fault tree model for the failure modes of the valves MV-8248 and MV-8247. This type of failure cause a lost of shutdown cooling mode because the failure of pressure instruments.

The events classified as secondary failures are in evaluation phase because almost all these events are from internal and external leakage. The criteria to select them as failures were to consider failures in components modeled in PSA and that the failure cause a system inoperability, or violation of the technical specifications.

The next task is to perform an evaluation of maintenance programs and surveillance requirements related to the identified critical components of the RHR system. It is intended that this evaluation will cover maintenance activities carried out and those not performed but recommended by the vendor. The corresponding results will serve to identify maintenance activities needed for minimization of the found critical failure modes.

3.5 Maintenance Rule

This section describes the relationship between the present project and the implementation of the maintenance rule required to the utility. The maintenance rule covers the systems mentioned in section 2.5 while this project intends to prove its own methodology on safety related systems.

It is considered that for the satisfactory accomplishment of the maintenance rule it is necessary to have an adequate establishment of performance goals and performance criteria for the SSCs to be evaluated through the effectiveness of their maintenance. An adequate performance goals setting can be achieved from the specific plant data and compared to the wide industry to establish goals and criteria. In this way, for the maintenance rule not working at full implementation can give some benefits to make an initial evaluation of the maintenance by means of a plant data review for the determination of the initial status and setting of the initial performance goals. Then in a following evaluation of maintenance the initial settings can be compared.

Another objectives of the two technical visits to LV were the determination of the usefulness of existing plant data to require the licensee an initial assessment of the maintenance for its effectiveness, to start the maintenance monitoring and periodic assessments; and the demonstration of the usefulness of existing plant data to define performance goals and criteria, for instance, number of failures, reliability, and unavailability for risk significant components. Although it is true that it is necessary to have a compilation data system to fulfill the compromises with the rule by the utility, it is considered that the present plant data information is spread but it has enough quality to be used for an initial maintenance assessment. For maintenance rule purposes, also a series of requirements and recommendations are being prepared about the level of detail and type of data to have a satisfactory accomplishment of the rule by the utility. In this sense it is strongly suggested to review the document referenced in [11] to get insights about what type of plant data are the most recommended for maintenance rule objectives.

4.0 CONCLUSIONS

Although the integration of risk and reliability methods is in its first approach and in experimenting phase through its practical application, it is noted that it is possible to optimize maintenance and surveillances mixing risk results of AOTs and STIs with data from operational experience used in the application of the RFM method to risk significant systems. Then, it is expected to integrate risk information to the results from RFM and maintenance rule.

The risk analysis of AOTs, STIs, and plant configurations need to be improved in the use of the computational processes and to consider assumptions like testing and alignment of redundant components and modifications for common cause failure events.

In order to conclude the definition of strategies to follow in the RFM method, it is necessary to complete the application of the method to the selected system. The final strategy will serve to improve the application of the method to other systems or groups of components.

The deficiencies found in the quality and type of existing data in LV NPP do not make impossible the application of the present methodology to another systems, to the contrary, they give the opportunity to define data requirements to accomplish successfully with the maintenance rule regulation. In a future this data requirements will serve for reassessment of system reliability analyses.

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