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Monitoring the effectiveness of maintenance programs through the use of performance indicators

Summary Report

Povilas VAISNYS, Paolo CONTRI, Claude RIEG & Michel BIETH

DG JRC – Institute for Energy

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Executive Sumary

This Report summarizes the preliminary results of Task 5 of the IE activities under the SENUF initiative. The purpose of Task 5 was to prepare the preliminary set of maintenance related performance indicators to be used by nuclear power plants in their self evaluation practice and which can be used also as an objective criterion for benchmarking purposes. As an outcome of Task 5 activities, quantitative indicators were selected and a maintenance performance monitoring framework was proposed. The proposed framework includes the maintenance performance monitoring system, which defines the hierarchical structure of the performance indicators distributed in several hierarchical levels in accordance with the breaking of the maintenance process into the single elements.

The proposed system is the result of the activities carried out for the fulfillment of Task 5. To develop a maintenance monitoring system, a broad research was carried out. The objective of the research studies was to analyze the current status in the evaluation of the maintenance effectiveness and efficiency by means of the selection of quantitative indicators. The studies were extended not only to the nuclear industry, but also to other industrial sectors with advanced maintenance strategies and advanced systems for maintenance performance evaluation. The major part of the analyzed sources is presented in the list of References to this Report. In particular, useful information was found in the study of maintenance performance indicators for the Swedish Railroad System [32]. Practical examples of the application of maintenance performance indicators to petrochemical facilities provided useful guidance in the selection of most suitable key performance indicators [4].The experience of nuclear industry in the utilization of WANO performance indicators as well as the experience of the IAEA in the development of the framework for the operational safety performance indicators system was also thoroughly examined. In particular the experience of the IAEA [6] was very useful since the developed system of performance indicators was validated at some nuclear power plants and feedback was received from the validation studies. Useful experience of the application of performance indicators at nuclear power plants was also found in the regulatory practices of STUK (National Regulatory authority of Finland) [11] and Paks NPP in Hungary [9]. The information contained in the questionnaire on ‘Advanced Strategies to optimize maintenance’ distributed at the nuclear plants participating to the SENUF network [8] was also thoroughly analyzed. At last, the latest developments of the Society for Maintenance and Reliability Professionals [14] significantly contributed to the selection of performance indicators suitable for the maintenance evaluation in the nuclear industry.

As an outcome of the study of the operational experience, a maintenance performance monitoring system was proposed. The system consists of three hierarchical levels. On the top of a hierarchical structure is the *Maintenance*

Excellence, from which the *attributes* of the maintenance program are developed. It is assumed that the maintenance monitoring system is established at the power plant with the aim to achieve the maintenance excellence, by removing existing or potential deficiencies.

Three attributes associated with the excellence of the maintenance program are proposed as a higher level of this structure. They are: preventive character of maintenance, maintenance management and maintenance budget.

Using the attributes as a starting point, some *key performance indicators* were derived at the second level of the hierarchical structure. Eight key performance indicators were proposed to cover the key aspects of maintenance. Finally each key performance indicator is supported by a set of specific indicators representing the measurable metrics of the maintenance program. In total forty-three (43) specific indicators were selected to cover all aspects of the maintenance program for nuclear power plants.

The results presented in the report are the initial step in the development of the framework for the monitoring of the maintenance efficiency using measurable performance indicators. As a further step, pilot studies should be initiated in order to validate the applicability, usefulness, and viability of the approach for the implementation of the proposed system of maintenance indicators at nuclear power plants.

It is expected that the pilot studies would provide feedback on whether this approach can be used to develop the system of maintenance performance indicators that would meet the needs of SENUF operating nuclear power plants. The findings, insights, lessons learned, and recommendations from all the SENUF members would be welcome and extremely useful to implement this approach as a first step in the SENUF nuclear utilities and later in the other EU nuclear power plants.

The Report provides recommendations for the further steps in the implementation of the proposed maintenance performance indicators system. These recommendations are based on the experience in nuclear industry, in particular the feedback from the application of IAEA operational safety performance indicators.

As further steps in the development of the maintenance performance indicators a discussion of the main results with the SENUF members is recommended. In particular the following items should be addressed:

- The proposed maintenance performance indicators and the framework as a whole;
- Practical items related to the validation studies for the proposed performance indicators;
- Action plan for the further steps in the development of proposed system of performance indicators.

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1 Introduction

1.1 Background

The SENUF (Safety of Eastern European type Nuclear Facilities) network, as a new European initiative integrated into the JRC/IE's existing nuclear safety related SAFELIFE framework, was established in 2003 [1, 2] to facilitate the harmonization of safety cultures between the Candidate Countries (CCs) and the European Union (EU), the understanding of needs to improve the nuclear safety in CCs, and the dissemination of JRC-IE nuclear safety institutional activities to CCs.

Primarily the SENUF activities are focused on those operational areas that are critical for plant life management of ageing nuclear power installations in EU and CC countries. In particular the maintenance activities at nuclear installations have been recognised as an important contributor to the safety of ageing nuclear power plants. Therefore, a series of research tasks within the SENUF framework addresses advanced maintenance methods and relies on the activities of the SENUF network.

The main SENUF activities in the maintenance field are focused on the following items:

- Review and identification of the maintenance issues critical for safe operation of nuclear power plants;
- Promotion of advanced maintenance methods and proven practice for nuclear power plant systems, structures and components, in particular those important for safety;
- Support to the implementation of advanced maintenance approaches, including implementation of preventive (condition based) maintenance as well as preventive mitigation measures;
- Evaluation of the advanced risk informed maintenance approach and provision of assistance in its implementation.

To coordinate the SENUF activities on maintenance, the Working Group on 'Safety of Nuclear Facilities in Eastern Europe dedicated to Nuclear Power Plant Maintenance' (SENUF-WG-NPPM) was established [1].

The SENUF activities are organized as a series of specific tasks addressing the key aspects of maintenance programme. In particular the Task 5 of the SENUF workplan for 2006 was dedicated to the monitoring of maintenance performance through the use of appropriate performance indicators.

The purpose of Task 5 was to propose some performance indicators that can be used by nuclear power plants for the evaluation of their own maintenance programmes as well as for benchmarking purposes. The experience accumulated in the nuclear industry and other industries in monitoring the performance by means of quantitative indicators was taken into account. Moreover, the experience at the international level in the development of performance indicators (WANO, IAEA, etc.) was analysed. It was found that some specific performance indicators developed by WANO and the IAEA can be useful also for the evaluation of maintenance performance.

As a first stage of the Task 5, a list of indicators and their definition was developed, and an exercise of their validation in a two-three year period was planned to be implemented by selected SENUF members, to evaluate their adequacy and viability. After these phases, a final list of maintenance performance indicators will be proposed to the engineering community at large.

1.2 Objectives

The objective of the Report is to describe the results of the research carried out in the year 2006 in the framework of the SENUF program. The first task of this report is to discuss the subject of monitoring maintenance effectiveness through the use of performance measures. The second task of this report is to describe the system of maintenance performance indicators based on the best operational practices in the nuclear industry and the other industries. The last but not least task of this report is to provide some guidelines for the implementation of the proposed system of maintenance performance indicators to specific nuclear power plants.

1.3 Document structure

The report consists of six Sections. Section 1 presents the background information on the SENUF activities and establishes the link between the previous SENUF activities and the research carried out within the Task 5. Section 2 introduces the subject of performance monitoring by using the performance indicators. Section 3 concerns the experience in the establishing different systems of performance indicators. Section 4 is dedicated to the application of performance indicators to the monitoring of maintenance programme. Section 5 presents the proposal for the establishing the system of performance indicators for the maintenance. Finally Section 6 provides recommendations and guidance on the implementation of the system of maintenance performance indicators to the operational practice of nuclear power plants.

2 Monitoring management effectiveness through the use of performance measures

2.1 Measurement of performance

A safe and economic operation of a nuclear power plant in today's environment requires the application of high-performance systems and equipment as well as intelligent operational practices. Inadequate efficiency of operational management programmes, insufficient reliability, and low availability will prohibit safe and economic operation. Moreover, excellent safety is a prerequisite set by society and legislation. The performance of the power plant systems and equipment has to deliver the load and power demand of the customers in the most safe, reliable and efficient manner with minimal environmental impact. This means that power plant equipment and systems remain in the most optimum condition requiring professional maintenance, operational evolutions and business practices. All professional and successful organizations utilize defined indicators to measure in meeting their mission on a continuous basis.

Measures of performance have been used by management for long time to review current operational capabilities [4]. Such measures have been used to assess both departmental and corporate performance, as well as trend performance achieved against established goals and objectives. In many industrial facilities, these measurements are related to safety (number of incidents), environmental (number of releases), costs (percentage of departmental budgets used), and production (comparison of actual vs. targeted production output). These measures are needed in order to determine not only if resources and costs have been managed for the safe and economical operation of the plant, but also whether the assets or plant remain in good health. Clearly, these measures provide assurance that asset policies in place today do not limit capabilities for tomorrow. If the performance of a function is not being measured, the management of the function is less effective.

It is a good practice to regularly provide management with accurate information regarding key performance indicators. Such information should be measurable and used to assess performance and identify areas requiring management attention. Overall indicators relevant to performance of organization, indicators to measure progress in achieving goals and objectives, and specific indicators for monitoring current performance problems and performance in specific functional areas are the common practice in the many industries. Information is presented in a way that provides ready recognition of trends and comparison of actual versus expected results and, where appropriate, clearly indicates corrective action and the results of these actions. For most quantitative indicators a graphic format is preferable to show comparisons between actual results, plant goals, and overall industry progress over a period of time. Quantitative indicators are usually presented in a way that shows a significant time period, such as 12 to 36 months, to support more meaningful analysis of performance trends. Where data is subject to wide variations over time, averaging techniques are used to smooth the data and facilitate the identification of trends. Monitoring reports based on quantitative indicators are issued on a periodic basis. In most cases, updating quantitative indicators monthly has been found to be most effective.

Indicators can be used effectively by a specific utility as a management tool to assess the trend of performance within a given indicator or set of indicators. However, it should be admonished that there are individual plant variations that make absolute comparisons misleading, even for plants with the same licensee. There is also common understanding between the operating organizations and regulators that the comparison of plant-specific indicators to industry averages can be misleading.

The inclusion of quantitative performance indicators that are defined nationally or internationally (e.g. those defined by WANO) also allows the organization and individual plants to benchmark their performance against national and international standards.

Performance measures are in particular useful if the organization implements the changes into the organizational structure or the management programmes. If the utility or nuclear power plant is planning change the maintenance strategy moving from reactive maintenance to proactive one and employs best maintenance practices, this activity should be well supported by the top management. Continued journey to the new strategy needs continued support of the management and this support will need justification. The top management wants something tangible to gain further commitment from them. There is need for tangible evidence in the form of objective performance facts.

One more aspect should be taken in consideration when dealing with performance indicators. They should not be considered just a measure/demonstration of success but should be used as a tool to manage successfully. The utilities should utilize performance indicators to identify opportunities for improvement rather than measures of success or failure.

In order to define a complete set of performance measures, organization must ensure that simple, workable measures are in place. Selecting the right measures is vital for effectiveness. Even more important, the metrics must be built into a performance measurement system that allows individuals and groups to understand how their behaviors and activities are fulfilling the overall corporate goals. The metrics provides a tangible evidence of performance in the form of objective performance facts. Metrics in this context is just a term meaning ‘to measure’ (either a process or a result). Combining several metrics yields indicators, which serve to highlight some condition or highlight a question that has to be answered to. **Key performance indicators (KPI)** combine several metrics and indicators to yield objective performance facts [5]. KPI should combine key metrics and indicators to measure maintenance performance in long time perspective.

Metrics can be twofold item. Metrics are essential for establishing goals and measuring performance. When properly used at the nuclear facilities, indicators are a valuable tool for operating nuclear power plants safely maintaining the reliability and availability of the plant systems and components at the required level. When used improperly, undue pressure may be applied to plant personnel resulting in management or manipulation of the indicators, rather than performance assessment. In fact, improper use of operational safety performance indicators can result in actions that are not in the best interests of reactor safety [6]. Metrics chosen or combined erroneously can produce misleading indicators that gives incorrect and/or low performance measures. Inaccurate measures may lead to inadequate management decisions. For example, it is understood that component reliability by itself is not a good indicator of maintenance performance. The reason is that component reliability may be an indicator not only of maintenance performance but also of a design, manufacturing, or operating problem.

A numerical value of any individual indicator may be of no significance if treated in an isolated manner, but may be enhanced when considered in the context of other indicator performances. On the other hand, specific indicator trends over a period of time can provide an early warning to plant management to investigate the causes behind the observed changes. In addition to monitoring the changes and trends it may also be necessary to compare the indicators against identified targets and goals to evaluate performance strengths and weaknesses. Each plant needs to determine which indicators best serve its needs. Selected indicators should not be static but should be adapted to the conditions and performance of the plant with consideration given to the cost benefit of maintaining any individual indicator.

There are other more general measures of performance that, whilst providing more qualitative information, are an important adjunct to numerical indicators. For example, observations of the behaviour of plant personnel can give an indication of how safely they actually carry out work and comply with procedures and good practices. Observing plant personnel performing work in the field and their interactions with supervisors and managers can provide insight into the safety culture at a plant. Such measures can be supplemented by surveys and interviews into the attitudes of staff. Although these tend to reveal what people think rather than how they act, properly conducted surveys and interviews can provide an accurate impression of the level of safety culture at a plant.

It should also noted that specific indicators to address organizational attitude may enhance the performance monitoring framework. Indicators related to industrial safety attitude and performance, staff welfare, and environmental compliance, while not contributing directly to issues of operational performance, may be valuable in some environments as measures of the overall organizational attitude.

2.2 Leading and lagging performance indicators

Depending on values of performance indicators they can be classified as either **leading** or **lagging** indicators. Most conventional quantitative indicators measure historical performance (they are often referred to as 'output' or 'lagging' indicators) and thus their predictive capacity arises from extrapolation of trends or comparisons with past performance. The WANO performance indicators are typical examples of lagging indicators. The **leading** indicators are forward looking indicators which measure positive efforts to improve performance. Leading indicators are metrics that are task specific. They respond faster than results metrics and are selected to indicate progress towards long term objectives. Leading indicators are indicators that measure and track performance before a problem arises. They are particularly valuable, although they are recognized as being more difficult to develop and measure objectively. The best performance measurement systems contain a mix of lagging and leading indicator. The IAEA experience in the development of operational safety performance indicators shows that the indicators chosen to support an operational safety monitoring programme should include a combination of indicators that reflect actual performance (lagging indicators), and those that provide an early warning of declining performance (leading indicators).

Some indicators can be either leading or lagging depending on the context of their application. One example of such indicators is the *schedule compliance* (see pg.46). It is a lagging indicator of the efficiency of the scheduling process and a leading indicator for *Wrench time* (pg.49).

3 Different systems of performance indicators

3.1 WANO performance indicators

The nuclear industry accumulated a great experience in the development and use of performance indicators in different fields of operation of nuclear power plants. In the nuclear industry the introduction of performance indicators enables an operating organization to set performance targets and to trend performance for the organisation as a whole, for individual nuclear power plants and, where feasible, for organizational units within a plant. The well known WANO Performance Indicator Programme supports the exchange of operating experience information by collecting, trending and disseminating nuclear plant performance data in 10 key areas [7]. The data is gathered for set of quantitative indicators of plant performance in the areas of nuclear plant safety and reliability, plant efficiency, and personnel safety.

Many NPP operators have developed their own output performance indicators; however they are mainly based on the 'top level' performance indicators established by WANO, such as:

- unit capability factor,
- unplanned capability loss factor,
- unplanned automatic scrams per 7000 hours critical,
- safety system performance,
- thermal performance,
- chemistry index,
- collective dose,
- volume of low-level solid radioactive waste produced,
- industrial accident rate,
- fuel reliability.

WANO performance indicators are intended principally for use as a management tool by nuclear operating organisations to monitor their own performance and progress, to set their own challenging goals for improvement, and to gain additional perspective and performance with reference to that of other plants. These indicators are summoned to encourage emulation of the best industry performance. They should also further motivate the identification and exchange of good practices in nuclear plant operations.

In the past the nuclear industry has often looked upon safety and production as conflicting objectives. However, the operating experience developed over the past thirty years has led the industry to understand that this is not so. In fact, plants with excellent safety records also tend to be good performers. Therefore, a complete set of parameters to monitor NPP performance should include both safety and economic performance indicators. The performance monitoring programme is helpful in justifying plant improvement programmes and their costs.

The performance of the power plant is the result of common effort of many management programmes established at the plant to ensure safe and economic operation of power plant. Figure 1 shows the interrelation between the NPP performance and the operational management programmes which are contributing in the operational performance of NPP. On the top of this hierarchical structure is the overall performance of power plant represented by the WANO performance indicators.

To achieve a high level of NPP performance it is important to ensure a high quality of the operational management programmes. The root cause of the performance decline at nuclear power plant is usually related with deficiencies at the low management level, the level of specific operational management programmes, such as maintenance, training and qualification, provision of industrial safety, radiation protection, and so on. It is obvious that the maintenance programme affects such WANO performance indicators as unity capability factor and unplanned capability loss factor. The safety system performance indicator can be used to monitor the effectiveness of maintenance practices in managing the unavailability of safety system components. The high level of thermal performance indicator reflects emphasis on thermal efficiency and attention to detail in maintenance of balance-of- plant systems. On the other hand it is clear that the WANO performance indicators are not appropriate for use as the sole indicators of maintenance-effectiveness because of the number of non-maintenance related factors included in them. The other reason why WANO indicators are not very useful in measuring the effectiveness of the activities at the lower hierarchical level is that they are *lagging* indicators, which reflect actual plant performance and do not capture lower level problems that affect the plant performance processes[1]. The overall NPP performance is dependent on the performance of several operational management processes established at the plant. WANO performance indicators are in such a way dependent on the performance of separate operational management programmes, such as maintenance, conduct of operations, technical support, radiation protection, training and qualification, fuel management, etc. Variation of WANO performance indicators is the reflection of the changes in the performance of specific management programmes contributing into the overall plant performance. Increased value of the unplanned capability loss factor indicates important plant equipment is maintained inadequately, with low reliability and may be there are many outage extensions. A low trend of these indicators may be attributed to the poor maintenance performance. On the other hand low values for the WANO indicators may also be the result of inadequate operations or mishaps in the training and qualification programme.

So trending the WANO performance indicators is not sufficient to monitor the performance of specific operational programmes. On the other hand high

[1] Some WANO performance indicators can be used as a low level performance indicators based on the specific hierarchical performance indicators structure. For example in the IAEA performance indicators system [6] Fuel reliability (WANO performance indicator) is used as a specific indicator to support the strategic indicator State of the barriers, which in it's turn is derived from he overall indicator State of SSC (Structures, systems and components). On the other hand, use of Unit Capability Factor (WANO) and Unplanned Capability Loss Factor (WANO) to support the strategic indicator Forced Power reductions in the IAEA performance indicators system and outages is a point at issue.

level of the overall performance of a nuclear power plant can be achieved only as a result of high quality of all contributing operational management programmes, such as maintenance, conduct of operations, training, technical support, etc.

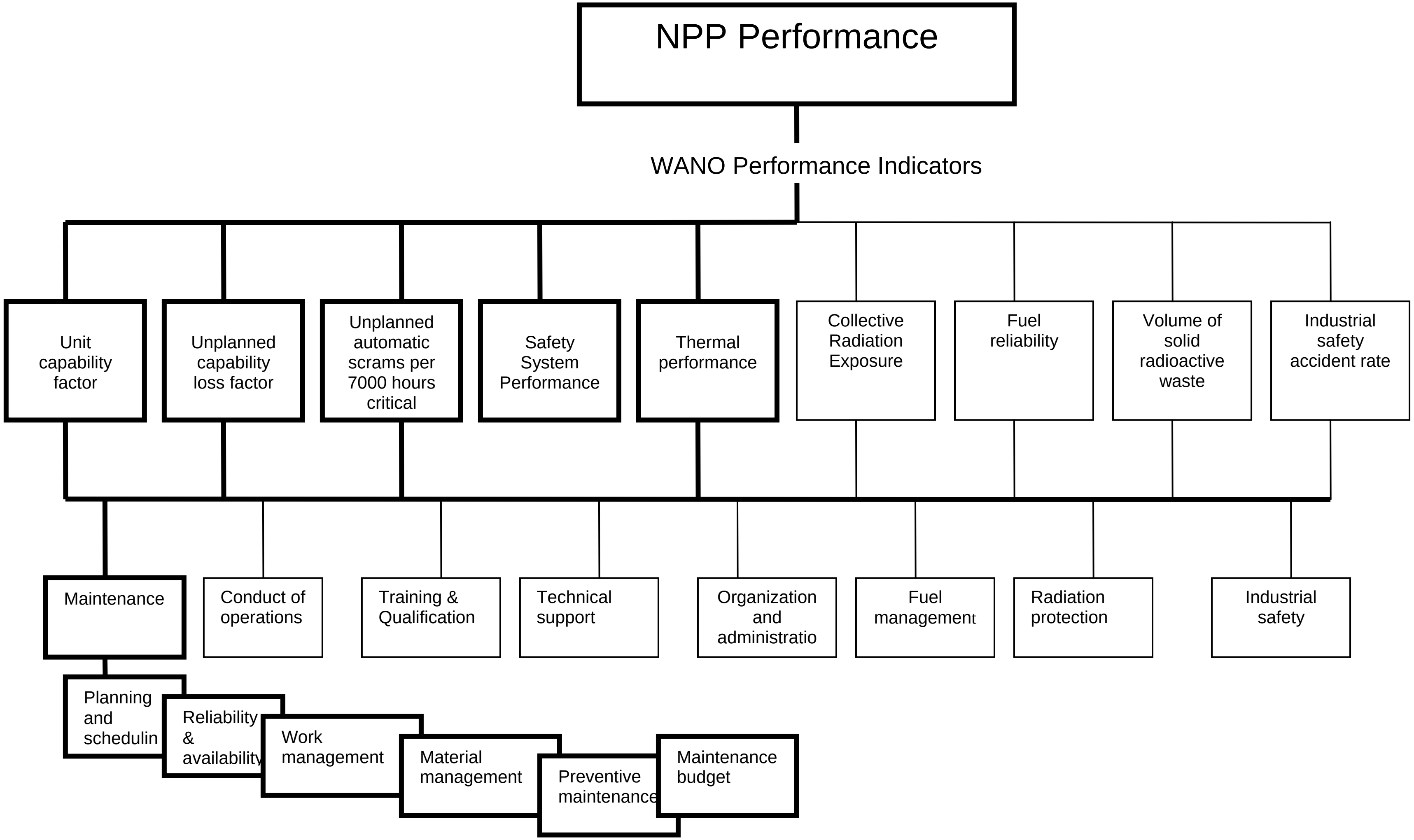

Figure 1 Contribution of operational management programmes into the NPP performance

3.2 The IAEA approach in the development of operational safety performance indicators

During four years (1996-1999) the International Atomic Energy Agency (IAEA) developed a comprehensive framework for the monitoring of the nuclear power plant operational safety performance [6]. By identifying the attributes of operational safety, objective measures of operational safety performance were developed and proposed for the validation in pilot plant studies.

The development of the IAEA framework is based on the concept of nuclear power plant safety performance. To ensure a reasonably complete set of operational safety indicators, a hierarchical structure was developed in which the top level is operational safety performance, the next level is presented by operational safety attributes, from which a set of operational safety performance indicators are drawn.

In defining the key attributes, it was necessary to determine the key elements associated with plants that operate safely. Three important aspects were addressed –nuclear power plant normal operation, nuclear power plant emergency operation, and the attitude of nuclear power plant personnel towards safety. On this basis three key attributes were chosen that are associated with plants that operate safely:

- Plants operate smoothly;
- Plants operate with low risk;
- Plants operate with a positive safety attitude.

Because these attributes cannot be directly measured, the indicator structure was expanded further until a level of easily quantifiable or directly measurable indicators was identified. The IAEA approach to monitoring NPP operational safety performance is shown in Fig. 2.

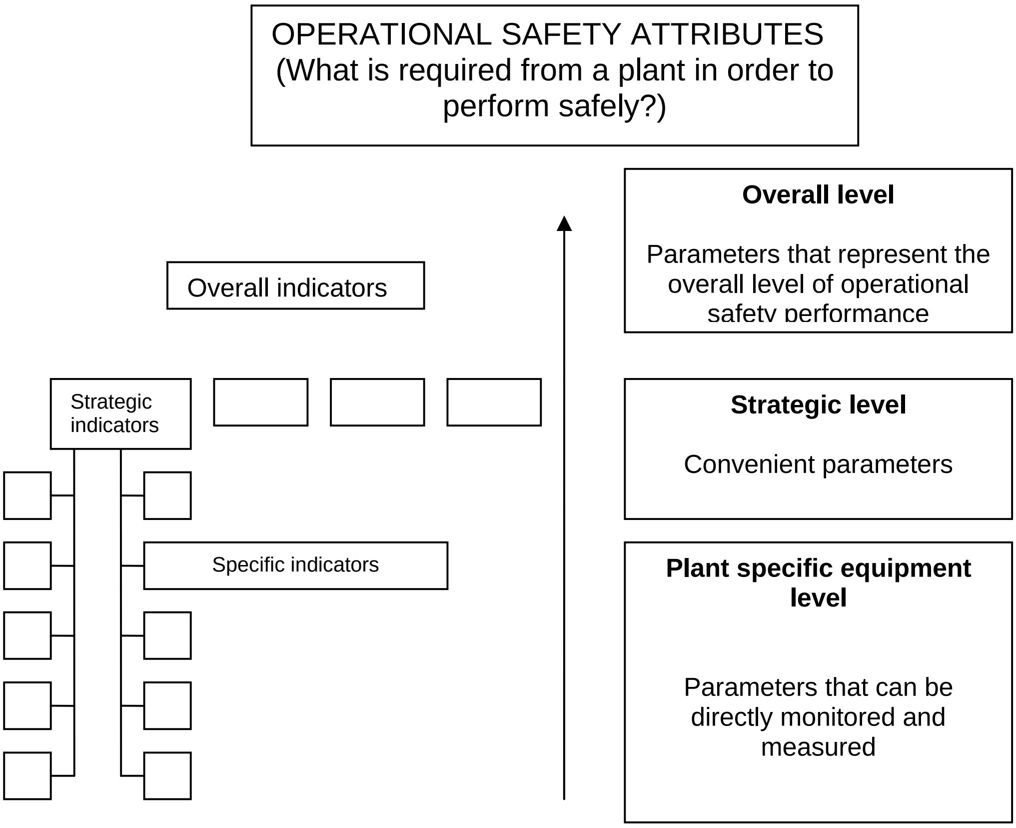

Figure 2 IAEA approach to monitoring NPP operational safety performance.

Using the attributes as a starting point for indicator development, a set of operational safety performance indicators was identified. Below each attribute, overall indicators were established. Associated with each overall indicator was a level of strategic indicators. Finally, each strategic indicator was supported by a set of specific indicators, most of which are already in use in the industry.

The overall or key indicators were envisioned to provide overall evaluation of relevant aspects of safety performance. Strategic indicators were intended to provide a bridge from overall to specific indicators. Specific or plant specific indicators represent quantifiable measures of performance. Specific indicators were chosen for their ability to identify declining performance trends or problem areas quickly so that after proper investigation, management could take corrective actions to prevent further performance degradation.

The hierarchical structure of the IAEA framework for operational safety performance indicators is presented in Fig. 3.

In the original conception of this design, there was no intention to propose an aggregation of data from lower levels (specific indicators) to obtain a quantifiable value for the higher levels indicators (strategic and overall indicators). The intention was to use quantitative information provided by specific indicators to analyse performance trends relative to established goals. Evidence of declining performance would then be utilized to develop a qualitative indication of performance at higher levels. However, some of the plants participating in the pilot studies chose to assign quantitative values to each specific indicator, based on performance relative to the goal. These values were then aggregated by some means to derive a quantitative value for the higher level indicators and attributes.

Figure 4 shows the example of hierarchical structure of performance indicators for the operational attribute ‘Plant operates smoothly’. For the demonstration of the smoothness of the plant the following overall indicators have been chosen: operating performance, state of SSC (structures, systems and components), and events.

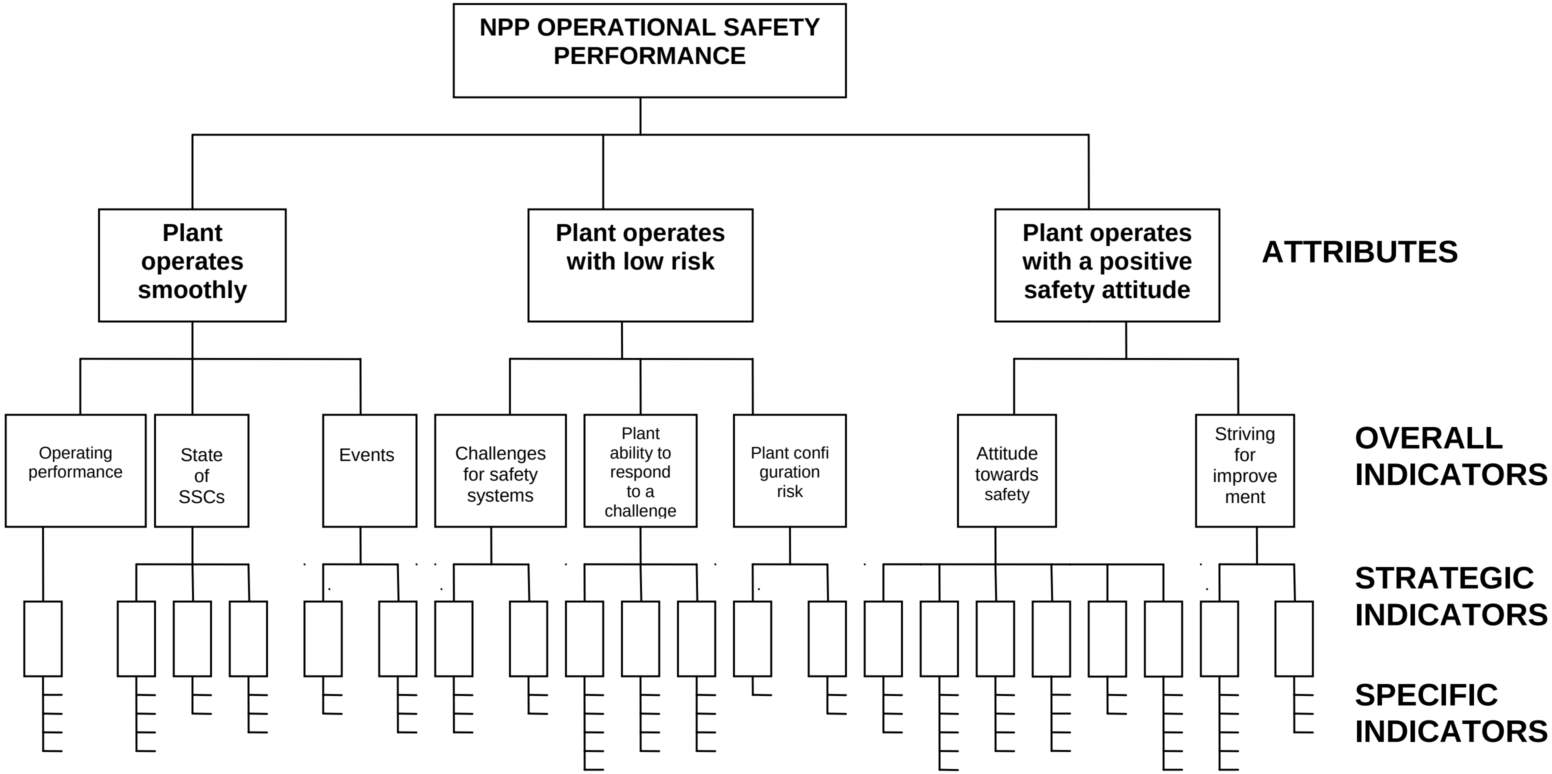

Figure 3 IAEA operational safety performance indicator framework

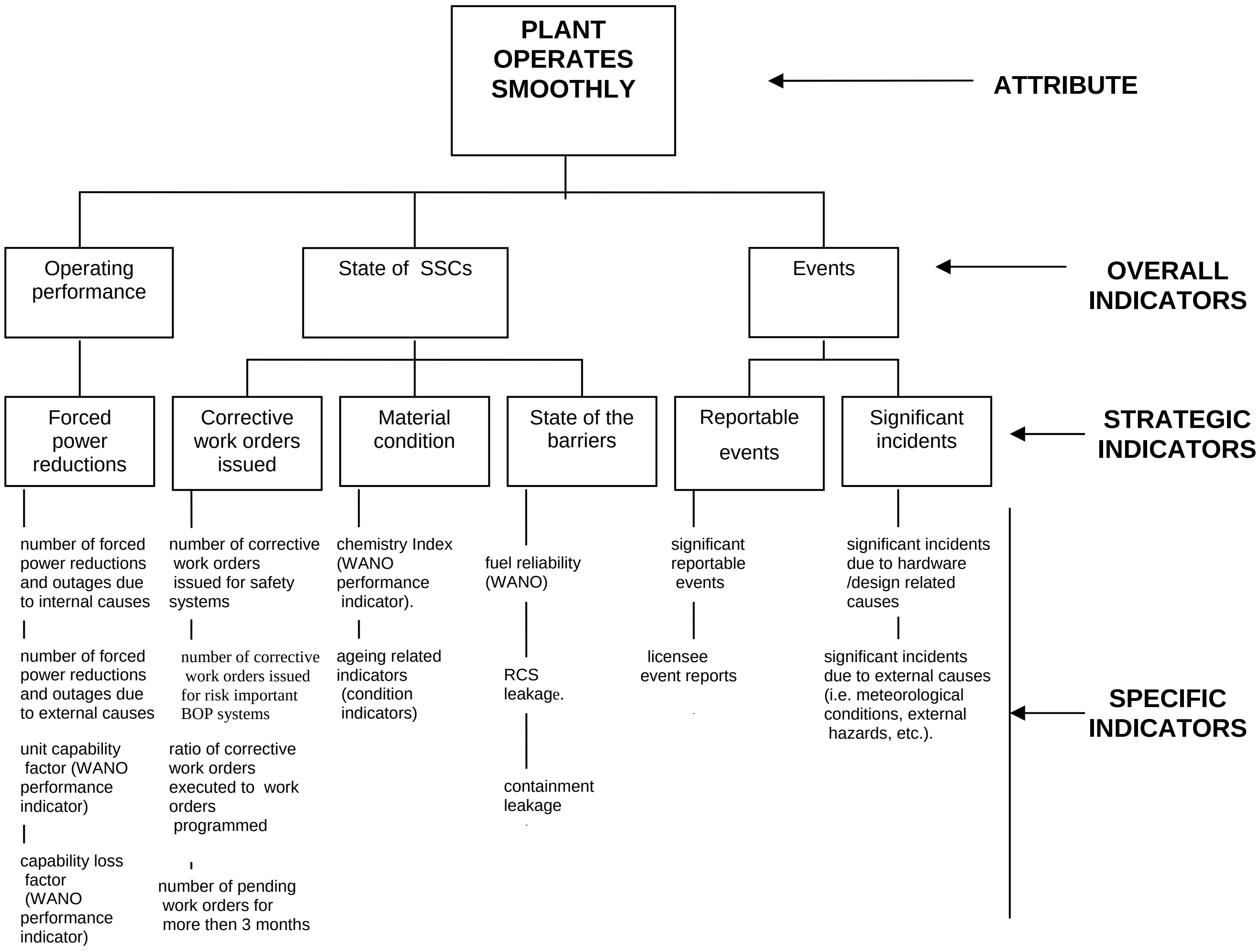

Figure 4 Hierarchical structure of performance indicators for the operational attribute 'Plant operates smoothly'

3.3 Lesson learned from the IAEA experience in the development of operational safety performance indicators

The IAEA experience in development of operational safety performance indicators including the validation studies at some power plants showed the viability of IAEA framework for the monitoring of operational safety performance. The plants involved in the pilot validation studies recognized the inherent value of the IAEA concept and framework, and in their evolutions maintained the overall hierarchical organization of indicators.

However the practical validation process showed that at the plant level the specific adaptation of the proposed IAEA framework is required in order to produce an effective management tool. Although the overall framework was considered effective, each participating plant has felt the need to introduce plant specific adaptations to suit individual data collection systems, plant characteristics, etc.

In fact the model proposed by IAEA provided a starting point for further development of the site specific performance indicator system which required from each power plant to review and evaluate the original indicators and a system as a whole. Additional effort was needed in indicator selection, definition and goal setting that helps to focus the organization on those elements that are critical for operational safety monitoring. In the course of pilot studies it was recognized that the programme development and adjustment may require the additional time and resources investment and that this process may extend over an extended period of time.

It was found that even though the process of establishing goals is a difficult task, goal development is an important step in programme development. Trends can be derived from collection of numerical data alone. However, the significance of the data and the benefit derived is enhanced by establishing meaningful goals and targets against which performance can be evaluated.

It was also found that the lower level indicators which form the basis for the plant programmes are often highly dependent upon site specific definitions and data collection systems, preventing viable comparisons on a plant-to-plant basis. Unit differences at multi- unit sites may also create difficulties in adapting this model for common use.

3.4 Experience of SENUF countries in using the maintenance performance indicators

The questionnaire on 'Advanced Strategies to optimize maintenance' developed to explore the advanced maintenance methods and approaches [8], provides limited information on the use of performance indicators for the maintenance monitoring. It is not clear from the questionnaire whether the maintenance performance indicators are used systematically, and what are the objectives of and achievements in their application. Nevertheless some preliminary comments could be drawn from this information. Table 1 presents the information available in the survey on the application of maintenance performance indicators in the SENUF Group utilities.

The survey results show that almost all power plants (six out of eight respondents) monitor the rework which is characteristic of the maintenance quality. In the majority of NPPs monitoring of maintenance effectiveness is focused on the equipment reliability and availability. Despite that reliability indicators are of considerable importance in the maintenance field, it is understood that component reliability by itself is not a good indicator of maintenance performance. The reason is that component reliability may be an indicator not only of maintenance performance but also of a design, manufacturing, or operating problem.

Ratio of preventive maintenance in the total maintenance activities is a good indicator to demonstrate the plant's preferences in the maintenance strategy. This indicator is used in almost all SENUF utilities, though in slightly different form. The average ratio of the amount of preventive maintenance to the corrective maintenance 50-85/50-15 gives impression that in some SENUF utilities there is a room to elaborate in the direction of enhancement of preventive approach in the maintenance strategy.

The Spanish utilities have in use the most complete list of maintenance related indicators, despite that the concept of the MPI is not explained in the survey information. They comprise several maintenance areas such as equipment reliability and availability, work control and the material control. It is very much speculative to draw further conclusions on the application of MPI in the Spanish utilities.

As it follows from the response to the questionnaire, KRSKO NPP developed its own maintenance performance indicators to monitor the preventive maintenance effectiveness. KRSKO NPP is planning further activities to improve the existing system of maintenance performance indicators.

Development of Safety Performance Indicators (SPI) system at Paks NPP in Hungary was completed in 2001 and the system was introduced in the safety evaluation report for 2002 [9].This system

Table 1 Maintenance performance indicators in SENUF utilities

N %	MPI	Spain	PAKS	Cernavoda	Bohunice	EMO	Krsko	REA	Ignalina
1	Number of outstanding backlogs	X			LACK OF INFORMATION	X			
2	Number of urgent and first priority orders						X		
3	Reliability of equipment	X						X	
4	Number of equipment failures	X		X					
5	Component and system availability	X							X
6	Amount of maintenance rework	X		X		X	X	X	X
7	Availability of spare parts	X							
10	Overdue of PM activities			X					X
11	MTBF (mean time between failures) by total operation, area, equipment			X					X
12	Ratio of PM activities and all maintenance activities			X					
13	Ratio of planned and unplanned maintenance					X			
14	Ratio of PM & CM activities						X		
15	Duration of repair							X	
16	Cost of repair							X	X
17	System health			X					
18	Specific work orders indicators						X		

reflect the plant safety performance on the basis of an extended range of safety related indicators. The new system was developed on the basis of the IAEA approach and comprises a four-level hierarchical structure (safety performance attributes, overall indicators, strategic indicators and specific indicators). Clear and simple definitions and goals are established for each specific indicator. The color coding system is used to track the performance indicators and display the results of performance monitoring. The development of a web based computer program to support the assessment work is in progress. The latest version of the SPI and the results for the 2004 were presented in the Safety evaluation report for Nuclear Safety Convention [10]. The safety evaluation report provides the most important safety indicators used at Paks NPP as well as the most significant information related to maintenance, inspections, utilisation of experience, and other safety related activities.

The maintenance related performance indicators in the overall safety performance indicators system at Paks NPP are allocated mainly within three overall indicators groups:

- Safety systems and components,
- Operational performance, and
- State of systems and components.

The Safety systems and components group comprises various types of scrams, failures and unavailability of ECCS discovered during the tests. Additionally, two indicators related to the specific equipment, availability of pumps and the availability of diesel-generators are also included in this group.

Specific indicators related to the unplanned shutdowns and power reductions are grouped under the overall indicator of Operational performance. This group also includes the ratio of planned time to the real duration of the outage. The third group of maintenance related indicators (State of systems and components) comprises maintenance of components classified as Safety Class Systems, ratio of preventive and total maintenance, ratio of unsuccessful safety reviews and two site specific indicators, ratio of plugged SG tubes and the foreign material intrusion.

3.5 Experience in use of performance indicators by the Regulatory Authority (STUK) in Finland

The surveillance of nuclear power plants safety by the National Regulatory Authority (STUK) in Finland was supported by the STUK safety performance indicator (SPI) system [11]. The SPI system is used to monitor the key operational processes at the power plants to ascertain that certain safety factors under scrutiny have remained at a desired level or to gain insight into possible changes and trends in the short and the long run. The aim of established safety indicators is to recognize trends in the safety-significant functions of a nuclear power plant as early as possible.

The STUK SPI system is divided into two principal groups: external indicators for the safety of nuclear facilities and internal indicators for the regulatory effort. External indicators are divided into three principal subgroups: safety and quality culture, operational events, and structural integrity. These principal subgroups comprise 14 indicator areas that are in their turn supported by 51 specific indicators (see Fig. 5).

A specific Regulatory Guide [12] defines the responsibilities and procedure for data collection and calculation of indicators as well as for assessing, reporting and utilizing these indicators. The guide describes the definition for each indicator, provides the information on data acquisition procedure, defines the functions and responsibilities of the persons assigned for the safety performance monitoring task.

The values of the plant safety performance indicators are updated quarterly and the deviations and their reasons are tracked down immediately. The results of STUK safety performance indicators, including the trends, are presented in the annual report of regulatory activities. The findings and the conclusions concerning performance indicators, as well as their justifications, are reviewed by the responsible persons and the management of STUK. The main focus is on the indicators that show a deteriorating trend. The special attitude is given to the identification of root causes of the decline and development of the measures to discontinue the trend.

As a result of the review of the STUK SPI system in 2003, the definitions of some specific indicators were modified to improve their reliability and to improve the monitoring process. The definitions of some indicators were changed also in 2004 to make them more convenient to use in the regulatory practice. Several new indicators concerning the risk-significance of events were developed. The definitions for some maintenance related indicators were also modified (failures in Tech Spec components, maintenance and repair time) as well as for the indicators related to the integrity of the primary and secondary circuits. Some new indicators have been developed for these areas. After these modifications the values of updated indicators were calculated retrospectively over the previous few years to establish the base for comparison with the performance results for 2004.

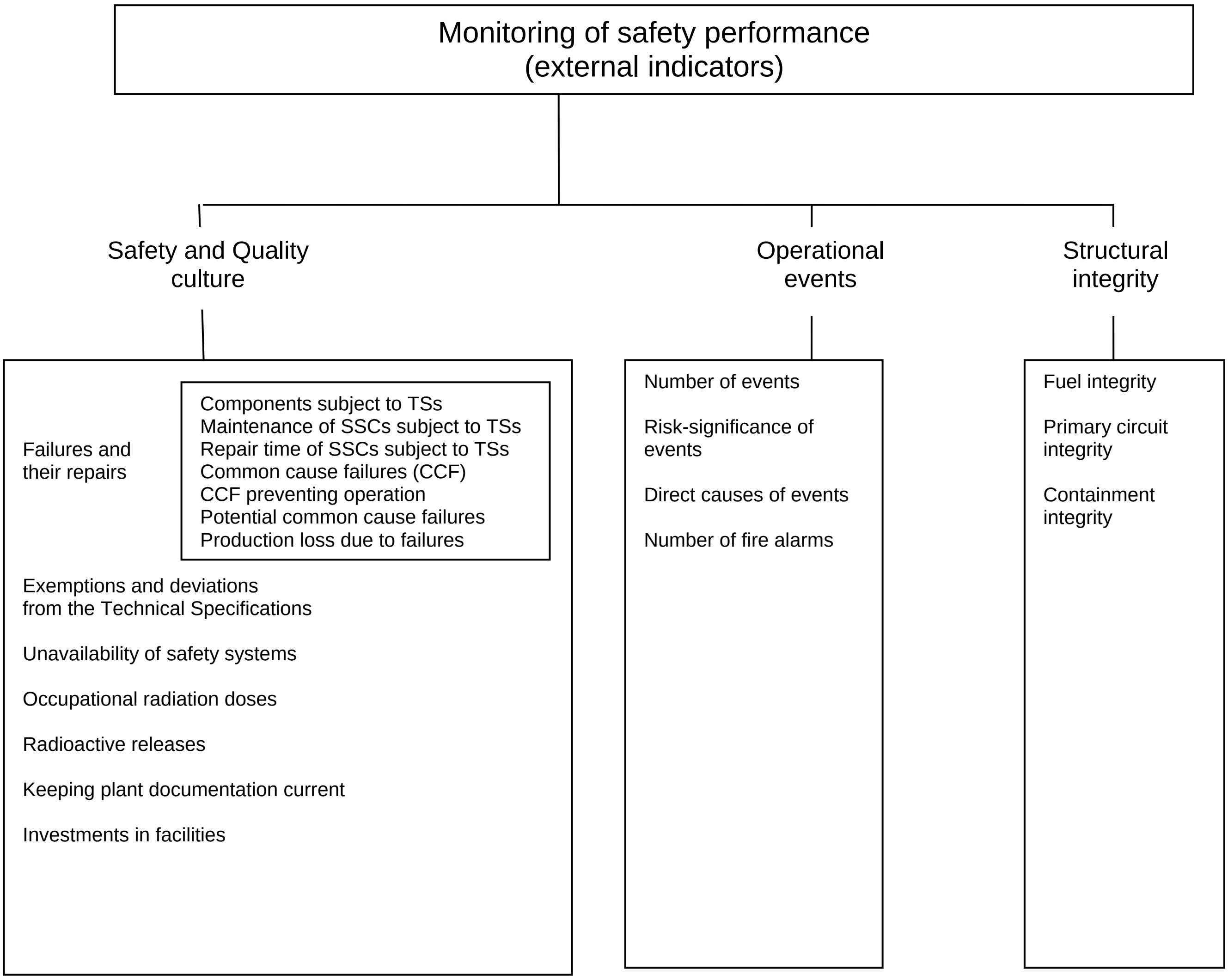

Figure 5 Structure of STUK safety performance indicators for the nuclear power plants in Finland

The STUK safety performance monitoring system includes several indicators concerning maintenance performance. The majority of maintenance related indicators are attributed to the group of failures and their repairs (see Fig.5).

The definition of the indicator Failures of components subject to the Technical Specifications is an example of the specific approach to the selected indicator (see *Establishing indicator definitions,* pg.59). In accordance to the definition the failures are divided into two groups: failures causing an immediate operation restriction and failures causing the operation restriction in connection with repair work. Even though this indicator is not unique in the nuclear industry the division of failures in two groups in such a specific manner is an approach worthy of special attention.

Based on the analysis of the maintenance related indicators for 2003 some deterioration of the maintenance performance at Loviisa NPP was identified and corrective measures undertaken to discontinue the negative trend in 2004 [11].

The advantage of the STUK safety performance system is in its completeness. It includes the indicators related to the core power plant processes (maintenance, radiation protection, radioactive releases, and maintenance of configuration control documentation), abnormal events, reliability and availability of the SSCs important to safety, structural integrity, and the investments into facilities to monitor the expenditures for plant maintenance and their fluctuations.

4 Monitoring maintenance effectiveness through the use of performance indicators

4.1 Maintenance goals and objectives

The function of the plant maintenance program is to preserve and restore the inherent safety, reliability and availability of plant structures, systems and components for reliable and safe operation. The maintenance program at a nuclear power plant covers all preventive and remedial measures, which are necessary to detect and mitigate degradation of a functioning system, structure or component or to restore the performance of design functions of a failed system, structure or component to an acceptable level. The purpose of the maintenance activity is also to enhance the reliability of equipment [13].

Maintenance in nuclear installations has specific characteristics in terms of organization and tasks. These characteristics may play a significant role in the program effectiveness and therefore in the safety implications of the maintenance related actions.

The importance of proper maintenance to safe and reliable nuclear plant operation has long been recognized by the nuclear industry. The nuclear industry is placing an increased emphasis on improving maintenance effectiveness because of its importance in improving overall plant performance. The nuclear industry demonstrates its complete commitment to the goal of improved safety and reliability through better maintenance. The industry's efforts resulted in significant progress in advanced maintenance strategies that is demonstrated by many nuclear power plants attaining world-class performance by all measurements, including industry overall performance indicators.

Economic deregulation of electricity markets in many countries has placed nuclear power plants in a new competitive environment where capital, operating and maintenance costs must be minimized. The issue is the inevitable tension between production on the one hand, and safety on the other. In the new changed environment in the energy market the ability of the nuclear utilities to realize innovative concepts are decisive to satisfy the progressive demands on competitiveness. The objective of these concepts must always be to achieve high level of performance with a minimum of expenditure. Cost effective maintenance should ensure that design-based availability and plant safety are maintained or even improved through the use of improved maintenance programs. Maintenance, with its significant influence on life cycle costs, can be the decisive key to ensure enhanced international competitiveness. Optimization of the maintenance strategy, enhancement of the maintenance efficiency and monitoring of the efficiency are becoming the key attributes to ensure the survival of nuclear utilities in the energy market.

4.2 Assessment of maintenance efficiency

To monitor the maintenance performance in an effective and objective way, the relevant measurable performance indicators should be used. These indicators should enable senior utility management to discern and react to shortcomings and early deterioration in the performance of maintenance management within the train of other business performance indicators. However, it should be borne in mind that there is no one single indicator that provides a measure of all the maintenance process. Experience has shown that focusing on any single aspect of performance is ineffective and can be misleading. More valid is the total picture presented by a complete set of indicators designed to monitor all aspects of maintenance programme. It was understood by the nuclear industry that general plant performance indicators are not appropriate for use as the sole maintenance-effectiveness indicators because of the number of non-maintenance related factors included in them. A range of specific indicators should be considered in order to provide a general sense of the overall performance of a maintenance programme and its trend over time.

The maintenance is the complex process that comprises different aspects, phases and areas. To determine maintenance strengths and weaknesses it is necessary to break the maintenance process into these areas for which we need to know performance levels. The examples of such areas are preventive maintenance, availability and reliability of safety systems, materials management, planning and scheduling, maintenance budget, work control.

4.3 Maintenance performance indicators

A numerical value of any individual indicator may be of no significance if treated in an isolated manner, but may become relevant when considered in the context of other indicator performances. For example, the indicator "number of outstanding backlogs" if considered alone can be attributed either to the poor planning and scheduling, or to the lack of resources. Analyzed together with the 'number of equipment failures', it gives more certainty about the maintenance issue. If in parallel there is a low value of the indicator 'availability of spare parts', the root cause of the maintenance issue may be the poor material resource management.

To cover broadly the maintenance area it is important to have a complete set of maintenance performance indicators available. Looking at indicators in isolation does not always provide the optimum benefit. Despite that in this report the single indicators are grouped correspondingly, at each power plant this grouping can be made site specific, based on the specific plant maintenance issues and the maintenance expert judgments (see Section 3.4).

The **leading** and **lagging** performance indicators in general are introduced in previous sections of this report (see Section 2.2). For the maintenance application, the leading indicators measure the effectiveness of the maintenance process, while lagging indicators measure results. In this report a business process approach is applied to the management of the maintenance function. This concept of process management is based on the assumption that the process itself produces the desired results and that therefore the process has to be managed and measured. This approach ensures that we successfully manage the maintenance process in order to achieve optimal levels of equipment reliability, availability and cost effectiveness. Such operating characteristics as consistently high availability or low equipment-caused forced outage rates over a number of operating cycles are indicators of good maintenance effectiveness. However, the plant material condition can degrade significantly before these indicators provide identification of degraded maintenance effectiveness, thus these indicators are not very timely. The necessity for tracking the maintenance performance indicators other than just equipment reliability and availability is to pinpoint areas responsible for negative trends (leading indicators). Examples of the leading indicators in maintenance are percentage of hours worked on proactive activities, amount of maintenance rework, compliance to schedule for preventive tasks, ratio of downtime to allowed outage time, etc. On the other hand the product of maintenance is reliability and availability of systems and components that satisfies the needs of the operations and the plant as a whole. So to measure the maintenance performance in this scale we have to use lagging performance indicators such as failure frequency (MTBF), downtime attributable to maintenance, and number of outstanding backlogs.

5 Maintenance Performance Indicators (MPI) system

5.1 MPI hierarchical structure

As a first step in the development of the maintenance performance monitoring framework, we consider the definition of the maintenance concept. It is assumed that the maintenance monitoring system is established at the power plant with the aim to achieve the maintenance excellence, by removing the existing or potential deficiencies. So on the top of the maintenance performance hierarchical structure we propose the *Maintenance Excellence,* from which we develop the *attributes* of the maintenance programme.

In defining the key attributes of the maintenance programme we have to determine the key maintenance aspects that contribute to the *maintenance excellence*. We propose three attributes that are associated with the excellence of the maintenance programme:

- Preventive character of maintenance (including predictive maintenance);
- Maintenance management;
- Maintenance budget.

Because we are not in position to directly measure these attributes, the maintenance performance indicators structure was expanded until the level of easily measurable quantitative metrics was identified. The approach to monitoring of maintenance performance is presented in Fig. 6.

Using the attributes as a starting point for indicators system development, a set of maintenance performance indicators is proposed. Below each attribute, *key performance indicators* are established. Each key performance indicator is supported by a set of specific indicators, some of which are already in use in the industry.

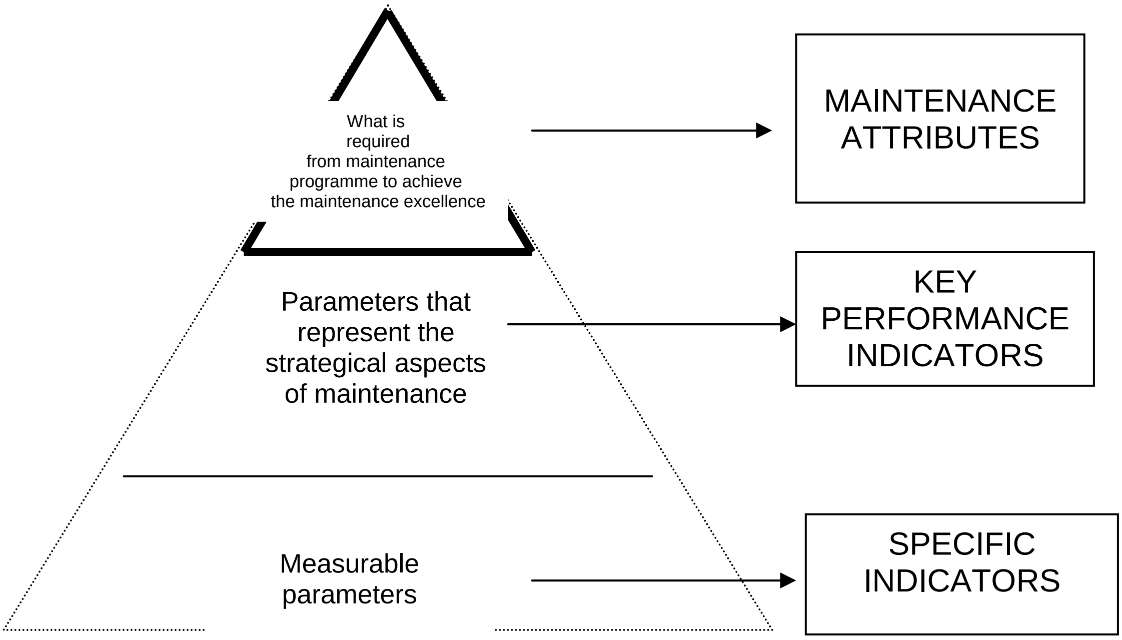

Figure 6 An approach to the monitoring of maintenance performance

The key performance indicators are envisioned to provide overall evaluation of relevant aspects of maintenance performance. Specific or plant specific indicators represent quantifiable measures of performance. Specific indicators are chosen for their ability to identify declining performance trends or problem areas quickly, so that after proper investigation the management could take corrective actions to prevent further maintenance performance degradation. Figure 7 presents the proposed framework for the maintenance performance monitoring.

In the following sections for each attribute of the maintenance programme the relevant key performance indicators and some examples of the associated specific indicators are presented. The proposed specific indicators, in no way, represent a comprehensive list of maintenance performance characteristics. The examples of specific indicators are proposed on the basis of the existing performance indicators in the nuclear industry and other industries, in particular risk related industries, proposals from the Society for Maintenance & Reliability Professionals for the best practice metrics [14], other sources available during the elaboration on this task (see the References). The main emphasis was put on the consideration of the maintenance activities with the focus on the safe operation of a power plant; therefore the economic effectiveness of the maintenance program, despite its unquestionable importance, was not developed in such a depth that is sufficient to represent all the budgetary aspects of a cost-effective maintenance program.

It is necessary to notice that despite of the fact that the proposed specific indicators were found very adequate to assist in the monitoring of maintenance attributes, it is important that each organization explores cautiously the specific features of its own power plants and the implemented maintenance methods and strategy before adopting the proposed scheme and the selected indicators.

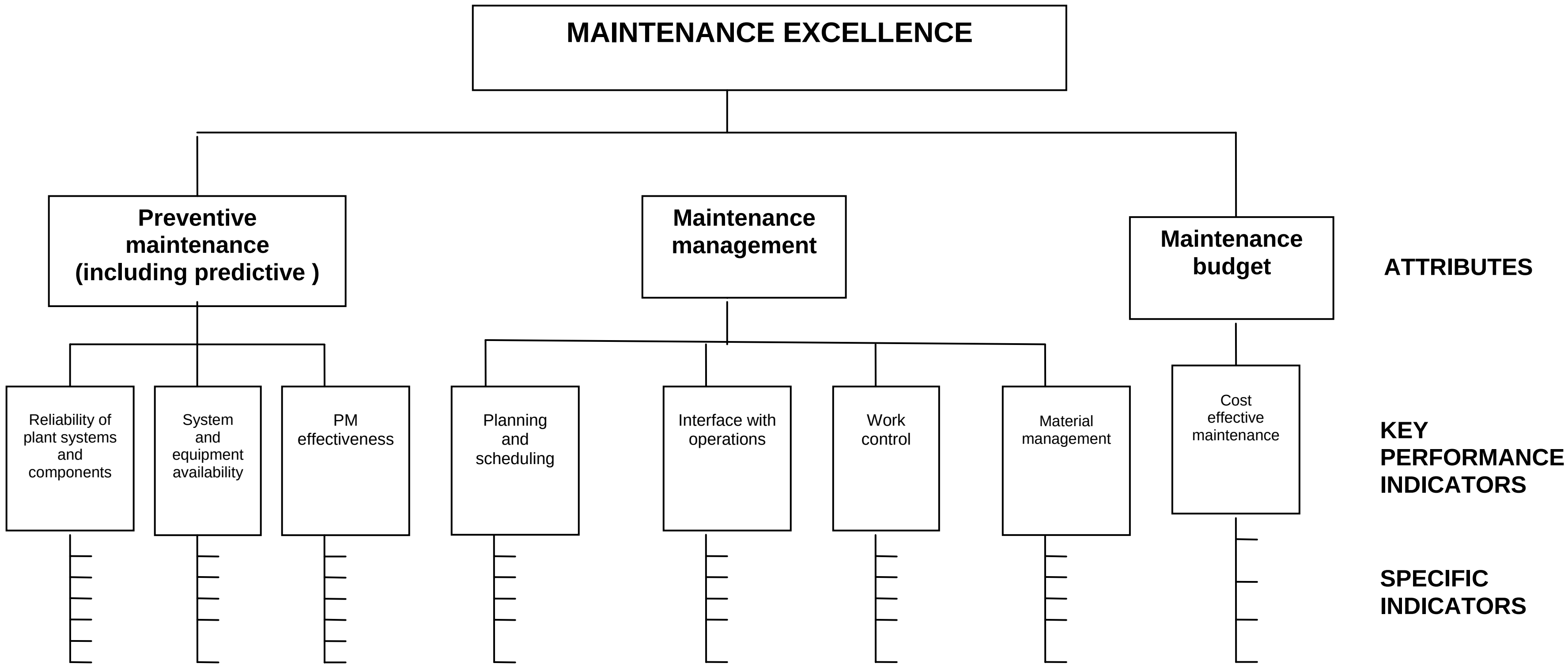

Figure 7 Maintenance performance indicators framework

5.2 Preventive maintenance (including predictive maintenance measures)

Preventive maintenance can be defined as a series of systematically planned and scheduled actions performed for the purpose of preventing equipment, system, or facility failure. Preventive maintenance programs are established at the majority of nuclear facilities to maintain equipment within design operating conditions and/or to extend equipment life. Preventive maintenance includes the lubrication programme, routine inspections and adjustments. In conjunction to the predictive maintenance measures, preventive maintenance helps to correct many potential problems before they occur. Preventive maintenance allows equipment to be repaired at times that do not interfere with production schedules, thereby removing one of the largest factors from downtime cost, increasing profitability. High level of preventive maintenance, as a matter of fact, reduces the number of outstanding orders. This is because the preventive maintenance activities can be planned in advance facilitating the control of the backlog at the reasonable level.

Preventive maintenance should be performed in particular on equipment whose failure can limit safe or reliable operation or result in forced outages. For the preventive attributes of maintenance the following three key indicators are proposed:

- System and equipment availability;
- Reliability of the systems and components;
- Effectiveness of preventive maintenance.

The performance indicators structure for preventive maintenance is shown in Fig. 8.

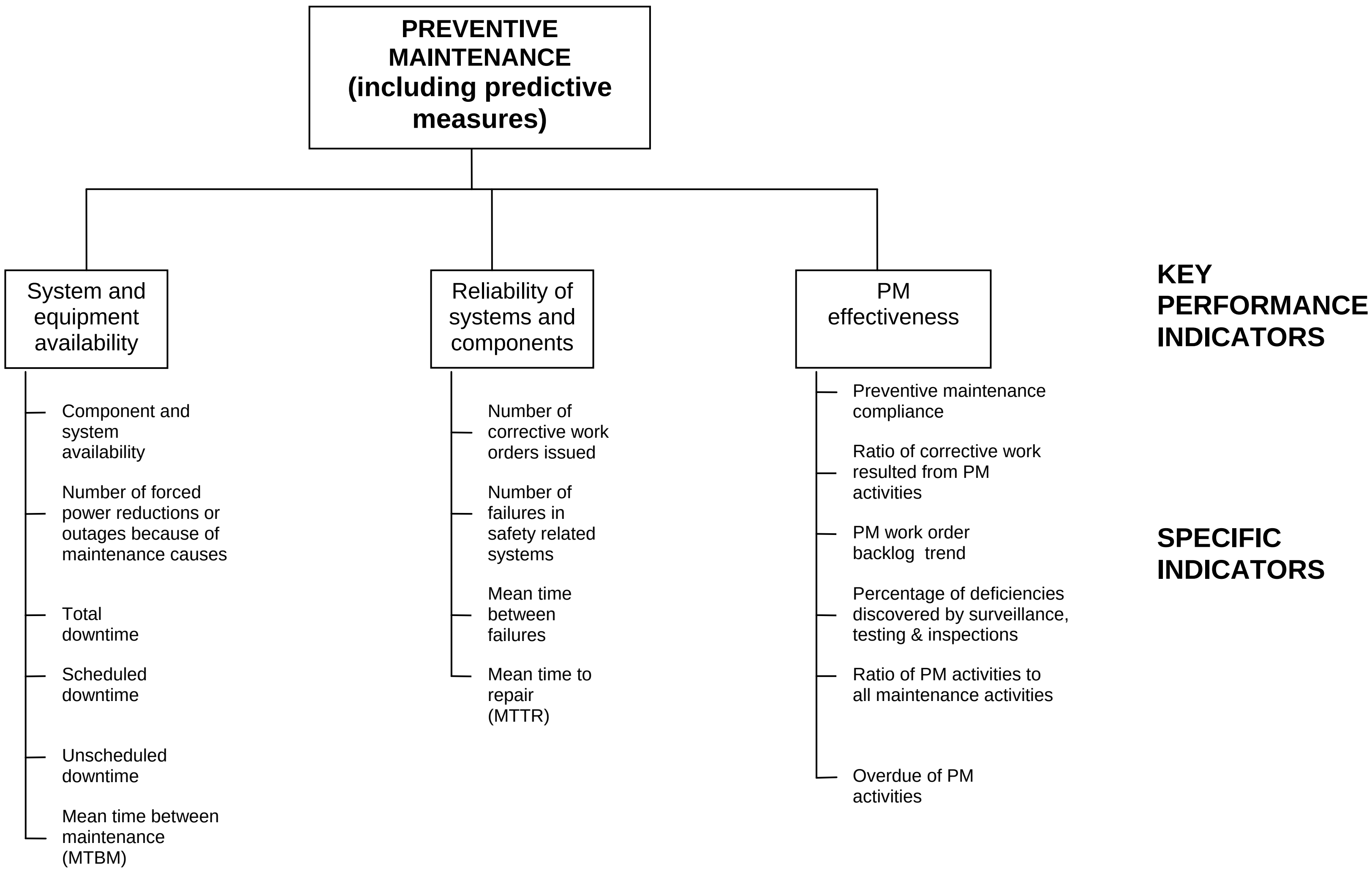

Figure 8 Performance indicators for the preventive maintenance

5.2.1 Key performance indicator: *System and equipment availability*

This key indicator is indirectly monitoring the effectiveness of preventive maintenance practices in managing the unavailability of safety system components and the plant itself. Six specific indicators are proposed to support this key indicator.

5.2.1.1 Component and system unavailability (lagging indicator)

This indicator is useful to monitor the readiness of important plant systems to perform the functions they are designed for. This indicator also indirectly monitors the effectiveness of maintenance practices, including surveillance in managing the unavailability of system components. One of the metrics of the system or component unavailability is the fraction of time that component is unable to perform its intended function when it is required to be available for service. At some power plants this indicator is defined as ***unavailability of safety system performance caused by maintenance, surveillance or inspection*****.** The indicator is usually expressed as a number of times/hours a safety system is unavailable. This indicator can be split further into three more specific indicators: *total downtime, scheduled downtime, unscheduled downtime.*

5.2.1.2 Total downtime (lagging indicator)

Total downtime is the amount of time a system is not capable of running. It is the sum of Scheduled downtime and Unscheduled downtime. This metrics allows one to evaluate the total amount of time the system or equipment has not been capable of running. The metric would be used to identifying problem areas and/or potential capacity in order to minimize downtime.

5.2.1.3 Scheduled downtime (lagging indicator)

This indicator indicates the amount of time an equipment or system is not capable of running due to Scheduled downtime, i.e., work that is on the established maintenance schedule. This metric allows evaluating the total amount of time the equipment has not been capable of running due to scheduled work. The metrics would be used to understand the impact of scheduled work on capacity and to minimize downtime.

Scheduled downtime is expressed as the sum of equipment downtime elements Identified on the maintenance schedule.

5.2.1.4 Unscheduled Downtime (lagging indicator)

Unscheduled Downtime is the amount of time when equipment or system is not capable of running due to unscheduled repairs, i.e., repairs not on the approved maintenance schedule.

This metric allows one to evaluate the total amount of time the system or equipment has not been capable of running due to unscheduled repair work. The metric would be used to understand the impact of unscheduled work on capacity and maintenance productivity in order to minimize downtime.

Unscheduled downtime can be expressed as a sum of equipment downtime elements not identified on the maintenance schedule.

5.2.1.5 Number of forced power reductions or outages due to maintenance causes (lagging indicator)

The number of forced power reductions and outages due to maintenance causes reflects the overall quality of plant maintenance, and is directly tied down to the ability of the power plant to maintain the reliability of systems, components and to operate the plant within its design limitations.

5.2.1.6 Mean time between maintenance (MTBM) (leading indicator)

Mean time between maintenance (MTBM) is the average length of time between one maintenance action and another for an asset or component. The mean time between maintenance (MTBM) includes all corrective and preventive actions (compared to MTBF which only accounts for failures). This metric is useful in assessment of maintenance effectiveness.

The metric is applied only for maintenance actions which require or result in function interruption. MTBM measures how many times a maintenance task is being performed on the asset which interrupts the function. The objective of this indicator is to minimize number of function interruptions by establishing an appropriate maintenance strategy and applying correct maintenance procedures.

The MTBM is calculated as the total operation time divided by number of maintenance actions during the same period.

5.2.2 Key performance indicator: Reliability of systems and components

The primary objective of preventive maintenance is to ensure the high reliability of the systems, structures and components important to safety. The preventive, including predictive, actions should be thoroughly planned to avoid the unexpected equipment failures. It is understood that cost of the forced repairs is higher that the expenditures for the planned preventive measures. On the other hand the extremely high level of preventive intrusions in the plant systems and equipment may lead to adverse consequences and unjustified expenses. Thorough analysis should be performed at the power plant to achieve balance between the corrective and preventive maintenance actions. The reliability focused maintenance indicators in this context can obviously contribute in the establishment of such balance.

The following examples of specific indicators are proposed for this key indicator:

5.2.2.1 Number of corrective work orders issued (leading indicator)

A high number of corrective work orders issued for safety or safety related systems may reflect potential reliability problems, but also maintenance deficiencies. High number of corrective work orders may directly affect overall plant performance and unit capability factor.

5.2.2.2 Number of failures in safety related systems (lagging indicator)

This indicator is measure of the reliability of safety related systems. It is desirable to monitor each system with its own indicator, or at least each group of systems (e.g. ECCS, emergency diesel generators, emergency feed water system, etc.)

5.2.2.3 Mean time between failures (MTBF) (lagging indicator)

There are some definitions of the mean time between failures. One of them is that MTBF is average time (expressed in hours) that a component works without failure. Also, the length of time a user may reasonably expect a device or system to work before an incapacitating fault occurs. It is the hours under observation divided by the number of failures. The other definition presents MTBF as an indicator of expected system reliability calculated on a statistical basis from the known failure rates of various components of the system. Usually MTBF is expressed in hours. These two definitions are examples of the approach that can be used by specific power plant when defining the indicator for the specific circumstances at the specific plant.

It is necessary to be cautious in application of MTBF to the failures of systems and components at nuclear power plant. The MTBF is rather ensemble characteristic than a sample characteristic and it is best determined from large populations (failures). For many systems and components at NPP the required failure rates are so low that the MTBF may substantially exceed the reasonable time of observation.

MTBF is, therefore an excellent characteristic for determining how many spare parts are needed to support 1000 similar equipment items but a poor characteristic for guiding on when to replace the component to avoid a crash of a system. MTBF is usually used for repairable assets of similar type.

5.2.2.4 Mean time to repair (MTTR) (leading indicator)

The MTTR is a measure of equipment maintainability and is defined as the mean time to repair. The difference between the MTBF and MTTR is that while MTBF measures the time between failures, MTTR measures the time between the service interruption and service restoration. MTTR includes problem diagnosis and problem repair.

MTTR is an essential parameter for system reliability studies of repairable systems. Prediction of the number of hours that a system or component will be unavailable whilst undergoing maintenance is of vital importance in reliability and availability studies. Using a maintenance prediction procedure, allows the identification of areas of poor maintainability leading to reduced system availability. Changes in maintenance procedures may then be recommended allowing an increase in a system availability. The MTTR parameter is important in evaluating the availability of repairable systems. MTTR is usually calculated as a total amount of repair time expended in a specified period (hours) divided by number of repair events in that specified period.

5.2.3 Key performance indicator: Preventive maintenance effectiveness

This key indicator is a measure of the effectiveness and efficiency of the preventive maintenance activities. This indicator helps to understand how effective the PM programme is at identifying potential failures and can be useful for the plant maintenance personnel to understand how effective their PM tasks are. In support of this key maintenance performance indicator, five specific indicators are proposed.

5.2.3.1 Preventive maintenance compliance (leading indicator)

This indicator is proposed to review on a monthly or quarterly basis the completed preventive maintenance (PM) work orders. The indicator can be expressed as a percentage of the PM orders executed on time to the total amount of the working order on a monthly or quarterly basis.

The objective of this indicator is to provide a management summary of PM work order execution and completion compliance on a monthly basis.

High values for executed on time and completed on time works indicate high level of maintenance planning and execution. As far as the frequency of PM activities are preset by the reliability requirements and the requirements in the technical specifications high PM compliance contributes in the safe operation of power plant. Knowing how quickly the PM work orders are completed, based on work order frequency and the required by date, provides a basis for evaluating whether enough time is provided to effectively plan, schedule and execute the next instance of PM work orders.

5.2.3.2 Ratio of corrective work resulted from PM activities (leading indicator)

The preventive maintenance effectiveness can be expressed as the amount of corrective work that is identified when performing PM work compared to the amount of PM work being done. The indicator should be calculated as an average for a large maintenance department. It should not be applied to a single PM task or single item.

This indicator is only one of the measures of the effectiveness of a PM programme. The best indicator of the effectiveness of PM work is the reliability of equipment. The equipment reliability is a lagging indicator. Measuring work generated from the PM work can be a leading indicator of the effectiveness of the programme, but should be used with caution [14]. This is a measure of how well preventive maintenance is identifying potential failures before they occur. The measure assumes that since a PM is in place, there is a desire to avoid the failure.

The target value for this indicator should be a mid range. Very low or very high numbers would be cause for investigation. In all cases the measure should be considered with the equipment reliability. In addition the total amount of PM work being done should be considered when evaluating the effectiveness of PM activities.

5.2.3.3 Percentage of deficiencies discovered by surveillance, testing and inspection (lagging indicator)

This indicator monitors the effectiveness of surveillance programme at the plant. It is a measure of the effectiveness of the preventive activities in identifying equipment problems before this equipment is required in real situation. This indicator is calculated as the ratio of the deficiencies discovered during the planned surveillance activities to the total amount of the deficiencies discovered on the annual basis.

5.2.3.4 Ratio of PM activities to all maintenance activities (leading indicator)

This metrics indicates the prevailing maintenance strategy at the power plant. As the ratio of preventive maintenance work orders to corrective maintenance orders increases, plant management may be able to measure a shifting towards planned maintenance and away from emergency maintenance.

Preventive maintenance activities as a percentage of total maintenance activities monitor the ratio of preventive maintenance (PM) work to corrective work orders. It is expected that the use of this indicator will increase PM activities as a percentage of maintenance work. Since inadequate scheduled maintenance results in unscheduled failures/downtime, it is expected that increased PM activities will eventually decrease emergency/unscheduled repair work orders.

Another version of this indicator, the *Ratio of PM activities to CM activities,* except of the meaning presented above, is often used for the optimization of the equipment replacement interval before equipment fails. Analysis of the effect of the corrective/preventive cost ratio on the optimum replacement interval shows that as the cost ratio increases, the optimum replacement interval decreases. This is an expected result because the corrective replacement costs are much greater than the preventive replacement costs. Therefore, it becomes more cost effective to replace the component more frequently before it fails.

5.2.3.5 PM work order backlog trend (leading indicator)

The objective of this indicator is to manage PM work order backlog. This indicator is a measure of all active PM work orders in the system. It is historically trended using the required by date of the work order and comparing this to today's date +/- 14 days. Using this guideline, all active PM work orders are segregated into categories 'Overdue', 'Current' and 'Future', according to a predetermined calendar based formula, and plotted as a function of time. The graphical representation allows the maintenance manager to identify trends in non-compliance and effectiveness of backlog reviews.

5.2.3.6 Overdue of PM activities (leading indicator)

The preventive maintenance performed in due time ensures high reliability of the equipment and system, in particular that is safety related or affects the unit capability factor. High number of overdue PM work is evidence of poor planning or inadequate attitude of plant management.

The proposed indicator is a measure of PM work orders that are past the required by date (i.e., overdue). It can be expressed as a percentage:

PM work orders overdue (%) = [(Today's date – Required by date) / PM frequency (days)] x 100.

The PM work orders that are determined to be overdue can be rank ordered to determine those work orders that are the most overdue, and which can be focused on for corrective action.

This metric helps plant management to identify work execution opportunities and implement duly necessary corrective measures.

5.2.3.7 Other indicators

Some utilities use in their performance monitoring practices the indicator *Percentage of man-hours used for the equipment modification.* This indicator can be useful in the demonstration of the utility's specific preventive maintenance strategy which is oriented to the implementation of modifications.

5.3 Maintenance management

An appropriate maintenance management controls should be established at the plant to ensure that the objectives of the plant maintenance program are fulfilled. A comprehensive work planning and control system applying the defense in depth principle should be implemented so that work activities can be properly authorized, scheduled and carried out by either plant personnel or contractors, in accordance with appropriate procedures, and can be completed in a timely manner. The maintenance management system should ensure the allocation on and off the site of the resources necessary to efficiently accomplish the maintenance activities. It should be also ensured that adequate maintenance personnel is available and on call to provide urgent remedial maintenance as necessary. Effective coordination should be established among different maintenance groups and among the different departments of the plant. Well-planned, properly scheduled, and effectively communicated maintenance activities accomplish more work, more efficiently, and at a lower cost. This work will disturb operations less frequently, and be accomplished with higher quality, greater job satisfaction, and higher organizational morale than jobs performed without proper preparation. Maintenance planning, scheduling and coordination focuses on and deals specifically with the preparatory tasks that lead to effective utilization and application of maintenance resources. To reflect the maintenance management aspects we propose the following key indicators:

- Planning and scheduling;
- Interface with operations;
- Work control;
- Material management.

The structure of the performance indicators to reflect the maintenance management is presented in Fig. 9.

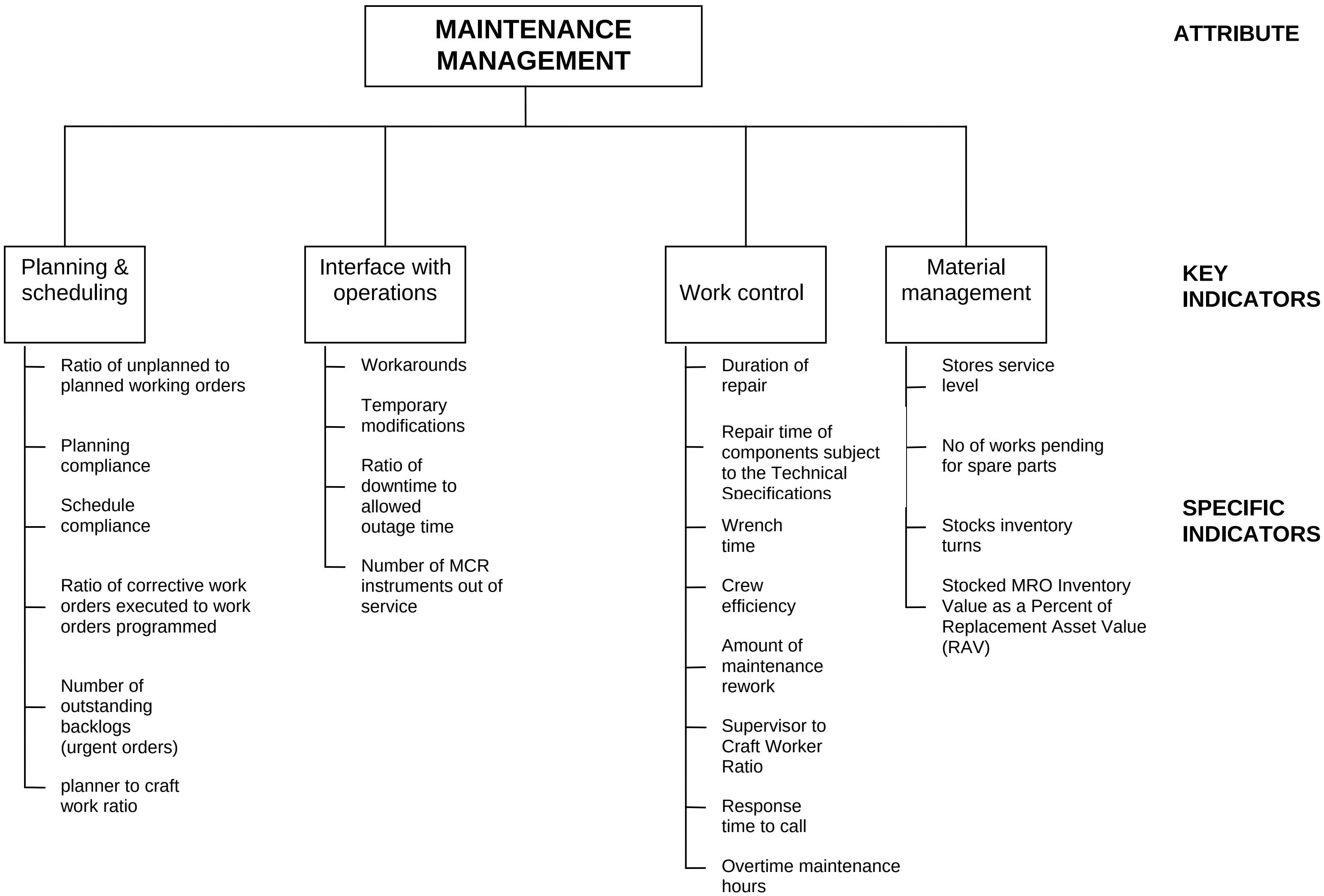

Figure 9 Indicators structure for the maintenance management

5.3.1 Key performance indicator: Planning and scheduling

The work planning system should maintain high availability and reliability of important plant structures, systems and components. Maintenance planning and scheduling is often broken down into several sub-processes such as backlog management, prioritization of work, scheduling of maintenance work, coordination of maintenance schedule and operations schedule, planning of maintenance jobs, recording of work order history, and follow up by key performance indicators. So performance indicators in this area should reflect each and every one of these maintenance processes mentioned above. Maintenance planning and scheduling is often viewed as the center of maintenance management, since other processes such as preventive maintenance, materials management, and other processes are dependent on the planning and scheduling process to work. The following specific indicators were identified to support planning and scheduling of maintenance.

5.3.1.1 Ratio of unplanned to planned working orders (leading indicator)

Low level of this indicator indicates good preventive maintenance management at the plant. Moreover this indicator is witnessing the good balance in establishing the periodicity of preventive maintenance actions.

5.3.1.2 Number of outstanding backlogs (number of urgent orders) (lagging indicator)

A high number in this indicator indicates an inefficient maintenance programme and thus gives an alarm that equipment is not being adequately looked after. In some utilities this indicator is defined as the number of work orders that are pending for specified time period (one month, three months).

5.3.1.3 Planning compliance (lagging indicator)

There are different types of metrics to reflect the planning compliance. The *ratio of total labour hours planned divided by total labour hours in scheduled* is one of such metrics. The high number in this indicator indicates an effective maintenance programme and thus gives confidence that the equipment is adequately being looked after.

5.3.1.4 Schedule compliance (lagging indicator)

The scheduling is an important part of the maintenance management. It is assigning all required resources to perform the work at the optimum time to allow the most efficient execution of the job request.

The *schedule compliance* indicator is a measure of the effectiveness of the work scheduling process and indication of adherence to the maintenance schedule. It is usually calculated on either a daily or a weekly basis, and is based on hours. The indicator can be expressed as a percentage of the scheduled work accomplished (hours) to the total work time available to schedule.

The Schedule compliance metric can be useful to the maintenance management to look for the reserve for efficiency improvements.

The *schedule compliance* is the example when the same indicator can be leading and lagging. It is a lagging indicator of the efficiency of the scheduling process and a leading indicator for Wrench time (see pg.49). Despite that in the Report this indicator is attributed to the Planning and Scheduling this indicator can be equally placed under the Work management since schedule compliance in most part is dependent of the good work management and control.

5.3.1.5 Ratio of corrective work orders executed to work orders programmed

A high number of this indicator indicates an effective maintenance programme and gives confidence that the equipment is adequately being looked after.

5.3.1.6 Planner to craft worker ratio (lagging indicator)

This indicator represents the number of maintenance workers a single planner is preparing in the process of planning maintenance activities.

The ratio provides a measurement to management for determining planner work load. This ratio identifies the level of work planning activities necessary to maintain a backlog of planned work assignments. It is recommended to calculate this indicator on the long time (yearly) basis.

5.3.1.7 Other planning related indicators

Several nuclear utilities use in their maintenance monitoring practices the following indicators which can be useful to identify planning issues:

- Number of jobs planned but not performed;
- Number of jobs not started as planned;
- Actual versus planned man-hours (per job or totals).

5.3.2 Key performance indicator: Interface with operations

Good coordination should be established between the operations and the maintenance activities in order to avoid the potential interference with normal operation of a plant. Some examples of such interference are the overdue of maintenance activities on the safety related systems removed for the scheduled maintenance or functional testing, non authorized removal of the operational systems for maintenance, entering the conditions of the technical specification as a result of non authorized maintenance intervention. Significant number of such interferences is indicator of poor planning and coordination of maintenance activities. Some examples of specific indicators are proposed in support of this KPI.

5.3.2.1 Number of workarounds (leading indicator)

A workaround is a bypass of a recognized problem in a system or equipment. A workaround is typically a temporary fix that implies that a genuine solution to the problem is needed. Frequently workarounds are as creative as true solutions, involving high intellectual potential in their creation. A workaround is a temporary solution used to bypass, mask or otherwise avoid a problem in some system. Some power plants often find themselves living with workarounds for long periods of time rather than getting a problem solution as a result of the appropriate maintenance action. High number of workarounds is an indicator of poor maintenance practices, inadequate coordination between the operations and maintenance or inadequate engineering resources to properly resolve an existing problem.

5.3.2.2 Number of temporary modifications (leading indicator)

This indicator gives a measure of the number of problems that have been temporarily solved and indirectly assesses the effectiveness in providing a permanent or definitive solution.

Temporary modifications are the common practice in the nuclear power plant operations. Proper control of the temporary changes ensures the keeping power plant within the design envelope. However the trend in increase of number of temporary modifications is indicator that some problems may exist at a power plant. Those problems may be related to the lack of the resources to transfer the temporary modification in to the permanent establishment or lack of proper attitude from the plant management. Anyway the high level of temporary 'fixings' may be an early indicator of degradation of plant systems and equipment and the maintenance system as a whole.

5.3.2.3 Ratio of downtime to allowed outage time (leading indicator)

The purpose of this indicator is to measure the effectiveness of managerial processes and controls and coordination between the operations and maintenance. This indicator can also be interpreted as the percentage of the actual time the system is in TS limiting conditions for operation (LCO) to the prescribed LCO time.

5.3.2.4 Other operations related maintenance performance indicators

The indicator *Number of control room instruments out of service(lagging indicator)* is used at some nuclear power plants to identify the deficiencies in the I&C maintenance.

5.3.3 Key performance indicator: Work control

The adequate work control system facilitates implementation of maintenance activities. The comprehensive work control system includes authorizations, permits and certificates, supervision necessary to help ensure safety in the work area and to prevent maintenance activities from affecting other safety relevant areas. The work control system should ensure that the planned work is accomplished safely and with high quality, that the maintenance crew is qualified for the job assigned. The proper supervision should be provided in order to ensure that the work is performed in accordance with the work order conditions and approved maintenance procedures. Four specific indicators are proposed to reflect this KPI.

5.3.3.1 Duration of repair (lagging indicator)

This indicator is used at some power plants to directly measure the duration of the repair of the same type. The indicator may be used to reveal the deficiencies in the skills and the qualification of the maintenance personnel or the inadequacy of the maintenance management or the material management.

5.3.3.2 Repair time of components subject to the Technical Specifications (lagging indicator)

This indicator is the measure of the average repair time of failures causing unavailability of components defined in the Tech. Specs. (the indicator can be expressed as an average of the repair times of all failure repairs).

5.3.3.3 Response time to call (leading indicator)

Often a nuclear power plant requires immediate reactive services of call-to-repair support. Call-to-repair support provides coverage across the normal working hours as well as at any time such support is needed. A commitment to restore the system or equipment malfunctions within a specified time period requires adequate management level in several services, in particular good management of resources, both, manpower and material. This service should incorporate enhanced stocks inventory management to ensure spare parts are available when needed. The call-to-repair time indicator indicates the level of readiness of the maintenance organization to respond to the urgent operational needs. Low call-to-repair indicator witnesses the high level of the maintenance organization, including planning and coordination, resources management, material management, etc.

5.3.3.4 Wrench time (lagging indicator)

Wrench time represents the percentage of time an employee spends applying physical effort or attention to a tool, equipment, or materials in the accomplishment of assigned work. It is used to determine how efficient the plant is at planning, scheduling and executing work.

This metric allows one to identify the productivity of the maintenance processes in use, including planning and scheduling, supervision, and maintenance management, and is used to find opportunities for increasing productive work time.

The indicator can be expressed in the following way:

Wrench time (%) = [Productive work time / Total work time scheduled] * 100%;

Where Productive work time = (Total work time scheduled – breaks & personal time – meetings – traveling – planning and instructing - waiting – getting tools and materials - shop clean up).

5.3.3.5 Crew efficiency (leading indicator)

This indicator can be expressed as the percentage of the actual work hours completed on a scheduled work divided by the estimated time.

5.3.3.6 Overtime maintenance hours (OMH) (lagging indicator)

This metric assists in determining whether the permanent maintenance workforce is appropriately staffed and within guidelines for safety concerns and operational issues. A high overtime percentage could be also a result of poor wrench time and/or inadequate staffing.

The indicator is defined as a number of overtime maintenance labor hours used to maintain equipment, divided by the total maintenance labor hours to maintain equipment, expressed as a percentage.

5.3.3.7 Amount of maintenance rework (leading indicator)

This metric is useful to monitor the amount of work that is carried out repeatedly since the results of the previous work are inadequate. This indicator witnesses the quality of the maintenance performed. Knowing the level of rework and reasons of rework allows the maintenance management to identify what corrective actions are needed to minimize or eliminate rework. In addition it provides a measure to show if these corrective measures are effective. Rework can be calculated as a percentage of the corrective work identified as rework (in man-hours) to the total work (in man - hours).

5.3.3.8 Supervisor to Craft Worker Ratio (lagging indicator)

This indicator represents the number of maintenance workers a single supervisor is managing. As far as the supervisors are sometimes assigned with the other tasks it is important to control their supervising capacity. The indicator provides a measurement to management for determining supervisor work load.

5.3.4 Key performance indicator: Material management

Management of spare parts and materials is one of the key elements which support effective maintenance planning and scheduling and ensures the quality and efficiency of the maintenance process. If the right parts are not on hand when needed for routine maintenance or repairs, downtime is prolonged. If too many parts are on hand, the utility absorbs excessive costs and the overhead expenses of carrying the inventory.

Improved material and spare parts management will free up time for maintenance planners, maintenance supervisors, and hourly maintenance personnel. Good material management affects the wrench time increasing its value.

Capturing supplier service level data within the material management helps bring to light the most efficient, dependable, and cost-effective vendors. Preferred suppliers can be identified based on historical lead times, pricing, quality, number of short- or over-shipments, how often goods are received damaged, frequency of backorders, and other criteria. Preference can be given to these vendors in the procurement process.

Performance metrics for the material management are increasingly popular decision support tools. For this KPI the following specific indicators are proposed.

5.3.4.1 Number of work requests pending for spare (leading indicator)

This indicator is monitoring the ability of power plant to ensure the necessary material resources that are needed for the smooth maintenance process. The indicator can be expressed either as the total amount of work requests or as the percentage of pending work requests to the total amount of work requests.

5.3.4.2 Stores service level (lagging indicator)

This indicator can be calculated as how many times person comes to check out a part and receives a stock item divided by the number of times a person comes to the storeroom to check out a stocked item and item is not available. The indicator can be also expressed in percent of number of inventory requests with stock out to the total number of inventory requests.

This indicator can be used to minimize the waste associated with excess inventory. By reducing inventory value while maintaining an appropriate level of stock outs, an efficient work force with minimum inventory can be assured. By analysing the information provided by stock outs, management can identify planning problems, vendor supply issues, potential over stocking, and changes in equipment reliability.

5.3.4.3 Stock Inventory turns (lagging indicator)

The stock turnover rate is the rate at which the average inventory is replaced or turned over, throughout a pre-defined standard operating period, typically one year. Inventory turns identifies how quickly specific types of inventory are flowing through the inventory system. For the calculations of this indicator it is reasonable to divide the stocks inventory into two groups:

1) operating supplies that are supposed to turn frequently, and

2) spare parts which will usually have a lower turnover [14].

This indicator is a metrics that can be used to manage a facility's inventory to insure proper stock levels. This can be used in conjunction with the metrics Stock service level to verify that the inventory levels are adequate to the operational needs. A Stock service level and inventory turn ratio should be used to balance the inventory levels, and to manage risk to an acceptable level, on both operating supplies and spare parts. The optimum turn ratio will be different for different types of equipment, and is dependent of the amount of risk a facility can take. The reliability and availability requirements of the safety related equipment and systems should be taken into consideration when reducing the inventory levels. A high turn ratio on spare parts could indicate a reliability issue that needs to be addressed.

Inventory turns has no units and is calculated as follows:

Inventory turns = Value of Stock purchased /Value of Stock on hand

5.3.4.4 Stocked MRO Inventory Value as a Percent of Replacement Asset Value (RAV) (lagging indicator) [14]

The metric is the value of maintenance, repair and operating materials (MRO) and spare parts stocked on site to support maintenance, divided by the Replacement Asset Value (RAV) of the assets being maintained at the plant, expressed as a percentage. This metrics allows one to compare the value of stocked maintenance inventory on site with other plants of varying size and value, as well as to benchmarks. The RAV as the denominator is used to normalize the measurement given that different plants vary in size and value.

This indicator can be useful for the corporate managers to compare plants but also can be used by plant managers related to the maintenance activities.

The best plants with high asset utilization and high equipment reliability in most industries have less stocked inventory value because of a more predictable need for materials.

This indicator should be used cautiously because lower stocked inventory value does not necessarily equate to best in class. This indicator should be balanced with stock-outs (which should be low) and other indicators related to the stocked inventory.

5.3.4.5 Other indicators

There are other indicators used in the nuclear industry to monitor the material management aspects:

- *Average spares and tools waiting time;*
- *Stocks items available but not used;*
- *Inventory accuracy;*
- *Spare parts and material obsolescence;*
- *Vendor performance.*

The definitions of these indicators vary from utility to utility in accordance to the specific approaches and needs of the utilities.

5.4 Maintenance budget

The objective of the plant management of nuclear generating utility is to maximize production of electricity at the lowest cost, the highest quality and within the established safety standards. The maintenance budget is an increasingly important aspect in the new economical environment in the energy market. Reducing the production costs, including the maintenance costs in particular is the condition of survival in the competitive energy market. Collecting and analyzing necessary maintenance-cost information enables utilities to track engineering information. For example, by using life-cycle costing information, utility can purchase equipment with the lowest life-cycle cost rather than lowest initial costs. In this report we are not dealing much with the economical aspects of the maintenance. However we realize that the Cost effective maintenance should be the one of Key indicators for the maintenance budget. Figure 10 shows the proposed indicators structure for the maintenance budgeting.

5.4.1 Key performance indicator: Cost effective maintenance

Several specific indicators can be used to support the specific aspects of the maintenance budget.

5.4.1.1 Maintenance cost per kwh produced (lagging indicator)

Most of maintenance cost is a fixed amount per year for the regular service of the systems and components, but some utilities prefer to use a fixed amount per kWh of output in their calculations. The reasoning behind this method is that tear-and-wear of the equipment increases with the life time of the power plant. On the other hand this indicator is sensitive to the overall maintenance management and its strategy.

5.4.1.2 Overtime maintenance cost (lagging indicator)

This metric assists in determining whether the permanent maintenance workforce is performing and appropriately staffed for the maintenance workload. The indicator is expressed as a cost of overtime maintenance labor to maintain assets, divided by the total maintenance labor cost to maintain assets, expressed as a percentage.

5.4.1.3 Work orders complete within the determined costs (10%-20%) (lagging indicator)

This indicator is useful in monitoring the maintenance budget discipline. The indicator can be expressed as percentage of work orders that are accomplished beyond the planned costs. Increased value of this indicator may witness shortages in the maintenance planning and work control.

5.4.1.4 Unplanned costs as percentage of total maintenance costs (leading indicator)

The adequate maintenance planning at nuclear facility should take into account all the maintenance aspects that can affect the maintenance effectiveness including the maintenance costs within the planned budget. Departure from the budgeting forecast may indicate either poor planning, decreased reliability of the plant systems or the deficiencies in the work execution. All these aspects should be thoroughly analyzed when facing the increase in the unplanned maintenance costs.

5.4.1.5 Ratio of Replacement Asset Value (RAV) to Craft/Wage Head Count (leading indicator) [14]

This metric allows comparison the value of the Craft/Wage personnel on a site with other plants of varying size and value, as well as to benchmark data. The indicator may be useful for the plant maintenance managers to understand the effectiveness of the craft/wage workforce.

The RAV as a numerator is used to normalize the measurement given that different plants vary in size and value. The metric can be used to determine the standing of a plant relative to the best in industry plants, which have high asset utilization and high equipment reliability, and, in most industries, have a lower maintenance cost of employment.

The RAV is the value of the assets being maintained at the plant, divided by the craft/wage employee head count. The result is expressed as a ratio in euros per person.

5.4.1.6 Annual Maintenance Cost as a Percent of Replacement Asset Value (RAV) (lagging indicator) [14]

The metric is the amount of money spent annually maintaining assets, divided by the Replacement Asset Value (RAV) of the assets being maintained, expressed as a percentage.

This metric allows comparing the expenditures for maintenance with other plants of varying size and value, as well as to benchmarks. The RAV as the denominator is used to normalize the measurement given that different plants vary in size and value.

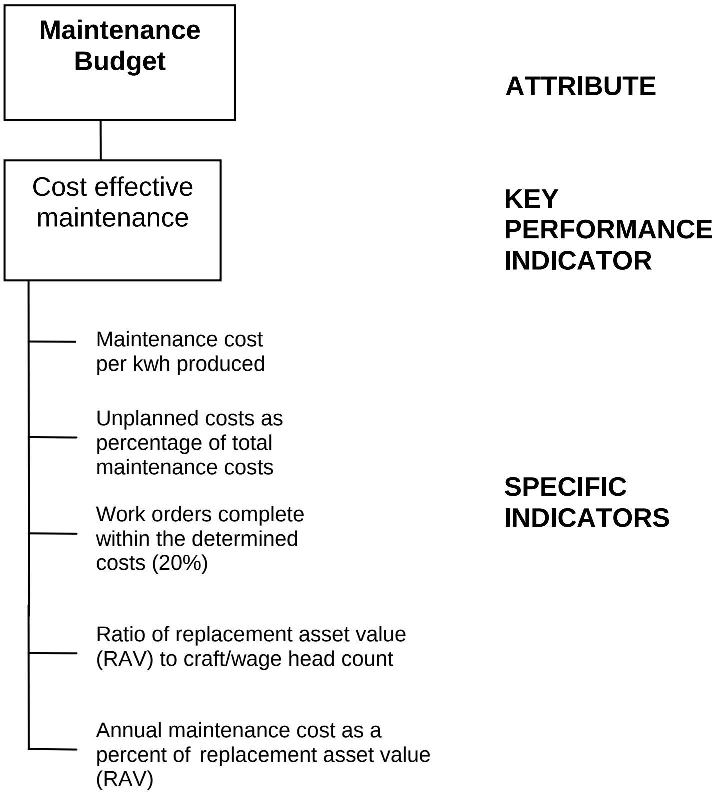

Figure 10 Indicators for the maintenance budget

6 Implementation of the maintenance performance indicators

6.1 Validation studies

The tentative system for the maintenance performance indicators described in Section 5 is the initial step in the development of the framework for the monitoring of the maintenance efficiency using measurable performance indicators. As a further step, the pilot study should be initiated in order to validate the applicability, usefulness and viability of the approach for implementation of proposed system of maintenance indicators at nuclear power plants.

The main objective of the pilot studies is to test applicability and usefulness of the proposed framework for the maintenance efficiency monitoring. It is expected that the pilot studies would provide feedback on whether this approach can be used to develop maintenance performance indicators that would meet the needs of operating nuclear power plants. Pilot studies are intended to determine the usefulness of the approach, identify the problems if experienced in implementing this framework, and developing recommendations for the framework improvement. The pilot studies are in no way directed to the evaluation of plant's maintenance performance. It is expected that there are volunteers to perform such testing studies, with various experiences in the current use of maintenance performance indicators at their power plants.

The findings, insights, lessons learned and recommendations from all the SENUF members would be welcome and extremely useful to implement this approach to maintenance performance monitoring.

The general objectives of the pilot studies are to gather feedback from the plant about:

- the feasibility of the proposed framework, and its usefulness;
- the usefulness of each individual indicator proposed;
- the validity of each indicator, i.e. whether the indicator provided meaningful information and the need for developing new indicators for monitoring the different specific areas;
- the definition of the selected indicators;
- processes used to collect the data for the indicators, additional efforts required for data collection;
- resources required to collect the data (human and other costs), and management feedback on the indicators and the framework.

It is expected that during the pilot studies period the participating plants will complete the following activities:

- selection of indicators;
- review of definitions of indicators;
- establishment of the necessary organizational support;
- data collection and analysis;
- development of support software; and
- preparation of reports.

6.2 Practical hints on the pilot implementation of the proposed maintenance performance indicators

6.2.1 Selection of indicators

The selection of the indicators to be studied is the initial stage of the studies. This task has different characteristics if there are maintenance performance indicators currently in use at the power plant or if such a programme is not yet established. In the latter case this pilot study marks the beginning of the establishment of such a programme. The primary basis for selection is the availability of data for the evaluation of indicators. To this end, each proposed indicator should be looked at to evaluate the data requirements. Once the data requirements are identified, then it is clear what indicators can be used. It could happen that some indicators can not be calculated as either the database is not sufficiently large or the available data are not in a form that is suitable for the evaluation of the concerned indicators. As an example of such indicator that requires quite extended database is the *Wrench time* (see pg. 49). This indicator can not be evaluated without detailed work control data base. If such data base is not available or it is not sufficient to provide reasonable statistics there is no basis for a meaningful evaluation. It could happen that some indicators can not be produced due to a lack of established system to record the data. Some other indicators may obviously be not meaningful for this plant and they also should be screened out.

It is not necessary to select all the indicators proposed in this Report. Initial screening may lead to about 50-60% of the total proposed indicators selected. At the latest stages may be some modifications will be made to enable the plant to start monitoring the indicators that were screened out due to data problems.

In the beginning it may also happen that some of the indicators do not seem to be meaningful for the plant; however in the process of system development it is reasonable to look for new indicators to cover the concerned maintenance aspect.

When selecting the indicators, the following should be taken into consideration:

- Indicators that already are in use in the plant;
- The usefulness of the indicators;
- The organizational and technical features of the plant.

In the implementation of a maintenance performance monitoring programme, consideration should also be given to the quality of the information that each indicator provides. Earlier activities performed under the auspices of the IAEA on development of operational safety indicators [6] identified a set of ideal characteristics of operational safety indicators. Some of these characteristics can be applicable for the maintenance:

- direct relationship between the indicator and maintenance;
- necessary data are available or capable of being generated; indicators can be expressed in quantitative terms;
- indicators are unambiguous;

- their significance is understood;
- they are not susceptible to manipulation;
- they are a manageable set;
- they are meaningful;
- they can be integrated into normal operational activities;
- they can be validated;
- they can be linked to the cause of a malfunction;
- the accuracy of the data at each level can be subjected to quality control and verification; and
- local actions can be taken on the basis of indicators.

The SMART test approach [4] may be also useful as a quick reference to determine the quality and applicability of particular performance indicator. The SMART test means:

S = Specific: proposed or developed performance indicator should be clear and focused to avoid misinterpretation and ambiguity;

M = Measurable: the developed indicator can be quantified and compared to other data;

A = Attainable: the measured indicator should be achievable, reasonable, and credible under conditions expected;

R = Realistic: fits into the organization's constraints and is cost Effective;

T = Timely: doable within the time frame given.

In addition the performance indicators should be trendable, observable, reliable, measurable, and specific.

6.2.2 Establishing indicator definitions

The establishing of clear and simple definition for each selected indicator is a key part of the programme implementation. In this report the definitions of the indicators are presented based on the common operational experience. When selecting the indicators for the validation studies at certain power plant it is recommended to review each indicator and to modify to plant specific definition if necessary. The elaboration of the best definition for the selected indicator is a very challenging task as it provides the evidence on how meaningful is that indicator for the power plant. The experience shows that the initial definitions may undergo changes during the indicator evaluation phase. The example of the modification of operational safety indicators in the process of their evaluation are presented below [6]:

a) Number of failures in a safety system and Number of times a safety system is unavailable.

By the nature of these indicators the significance would be negligible, as safety systems rarely fail. In order to increase their contribution and to make the indication more sensitive, these indicators can be combined into one and redefined as 'Number of times a safety system is unavailable or degraded'. Adding the words 'degraded' allows counting at the component level, thus increasing the weight significantly.

For this redefined indicator all the unsafe faults are counted, whereas safe faults/preventive maintenance occurrences are counted only if they cause unavailability or degradation when the system is required to be available for its intended function.

During the evaluation process it was found that this indicator gives a good overall picture of the ability of the system to respond to a challenge. However, to obtain a better understanding of pre-emptive actions that may be required before the indicator goes 'bad' it was seen appropriate to also trend the safe and unsafe failures separately. A decreasing trend for unsafe failures and an increasing trend for the safe failures may combine to give a satisfactory overall trend. However, an increasing trend for safe failures is clearly undesirable.

The indicator Number of times a system is unavailable/degraded may show a decreasing trend. At the same time the indicator 'unavailable hours' may show a zero slope. In such a way both indicators are accepted as satisfactory. However if to combine both indicators together it may happen that the combined result, down time per occurrence, is increasing, what is not satisfactory. So it is reasonable to implement the new indicator designated 'number of hours per occurrence of system unavailability or degradation'.

One more example of the modified indicator is taken from the experience of STUK in Finland [11].

Failures of components subject to the Technical Specifications:

Previously, the total number of failures of components defined in the Tech. Specs. during power operation was used as the indicator.

As the new version of the indicator, the failures are divided into two groups: failures causing an immediate operation restriction and failures causing an operation restriction in connection with repair work.

6.2.3 Identification of goals

After the selection of the performance indicators and review of definitions, the next step in the programme implementation is establishing the corresponding goals. The goals should represent the standards in maintenance the plant wants to follow, maintain or achieve. Although the process of establishing goals is a difficult task, goal development is considered to be an important step in the programme development. Some trends can be derived from the data collected. However the significance of the data and the benefit derived can be enhanced by establishing meaningful goals and targets against which performance will be evaluated. In the process of the goal development the industry benchmarks should be reviewed, the previous maintenance performance evaluated and management expectations for continuous improvement considered. The experience of the nuclear industry in the implementation of the performance monitoring programmers shows that the processes of establishing the indicators definitions and the goals are the most challenging and time and resources consuming tasks in the implementation of the programme. It is necessary to be very careful when formulating the goals for some indicators. For example, once an indicator is developed to track an item (e.g. '*overtime maintenance cost*'), the maintenance management may become much more aggressive in reducing this number. However, it should be noted that the development of certain indicators could produce unexpected results. An indicator to reduce the overtime maintenance cost may lead to an unintended outcome of increasing the *number of outstanding backlogs*. Additional measures would then be needed to ensure the proper planning of the maintenance.

6.2.4 Data collection and interpretation

It is an advantage if the maintenance performance indicators programme implementation can be based on the system of data collection which is available at the plant to support some other aspects of performance monitoring. This may help to avoid the additional burden of creating new data collection system. Nevertheless it is expected that the implementation of the comprehensive maintenance performance monitoring system impose the modification of computer programmes, some of plant procedures, training and communication to the staff.

Data collection system at some nuclear power plants includes the standardized computer input cards [6]. All the indicators selected are thoroughly studied by the group of experienced staff before they are included in the standardized computer input card. The computer input card is formatted to provide the necessary information, such as the names of the responsible personnel for data collection and verification, calculation formulas, etc. A responsible manager is assigned to ensure the quality of data collection, data processing and to co-ordinate data trending and follow-up of relevant corrective actions derived from the performance variances. The criteria for evaluating the performance variances are formulated on each input card and a color coding system is used to identify the variances.

For the purpose of evaluating the indicators the data covering considerable time period (four-five years) should be available. It should be also understood that the data analysis in this pilot study is not for the judgment of the maintenance performance of the plant but for the judgment of the validity and usefulness of selected indicators.

Different systems for collection and interpretation of the data and the trends on the basis of processing the data are used in the nuclear utilities. There is no strong recommendation on the preferences of one system against the other. At some power plants the graphic displays are used to show the operational safety performance indicators including definition, goal, graphic values, reference, comments and action, responsible coordinator/'owners', monthly numerical anticipated and actual values, etc. for specified time period.

In addition to providing a graphic display of information and trends, some power plants utilize a color rating system to assess indicator performance relative to established goals. Color ratings for each indicator are aggregated to produce ratings for higher level indicators or ‘windows’. If any specific indicator in a given area is rated ‘red’ or ‘unsatisfactory’, the higher level window is also assigned a ‘red’ rating to flag the area for management attention and action. These color ‘windows’ provide an effective management tool for review of performance in critical areas.

6.2.5 Organizational support and management involvement

The implementation of the maintenance performance monitoring programme may imply an additional effort by the plant. Depending on the starting point of each plant, this effort may be more or less significant. For the plants that already have in use the established performance indicator programme, implementation of new project does not require extensive resources. For such power plants the most resources (man-months) consuming tasks are the selection and the definition of the indicators and goals.

The plants that embark on performance monitoring programme should understand that the proposed model is the starting point in the implementation the programme at the plant. Implementation process should be followed by the review and evaluation. In fact the selection of proper MPI, their definition and the goal setting helps the power plant to focus on those maintenance aspects that are most critical in the organization.

Prior to starting the maintenance performance monitoring programme, it is reasonable to develop the programme implementation procedure and provide training to all concerned staff. The experience of similar exercises in the industry [6] shows that it is useful to establish special Project team for the implementation of the maintenance performance monitoring programme. Such a team may include the Project manager and the coordinators responsible for the collection, processing and trending the data in the specific maintenance area. While the computer format governs the method of data processing, each performance indicator coordinator is responsible for data verification. Any missing information can easily be seen and picked up by the responsible person. The most important step is the verification by the performance indicator coordinator of the effectiveness and validity of the data. The performance indicator coordinator also carries out calculation and trend analysis.

6.3 Challenges in the implementation of the maintenance performance monitoring programme

There is experience from the nuclear industry, in particular from the IAEA OSART (Operational Safety Review Team) findings [16] that very often performance measurement programmes were established with good intentions, but failed because they were short-sighted, ill conceived, and unfocused. Most of these shortcomings can be traced to one source: the lack of a viable approach to performance measurement from the start.

In developing quantitative performance measures, it is important to recognize potential pitfalls in their interpretation and use, in particular if these measures are used to monitor the outcome of the changes of the operational programmes:

- Improvement measures usually take a substantial time to be reflected in performance data, particularly when data are analysed on a rolling basis (e.g. monthly data analysed on a 12 month rolling average);
- Care needs to be taken in setting targets and analysing data when dealing with small numbers. Statistical fluctuations can easily mask trends;
- Whenever possible, quantitative measures should not relate solely to failures (e.g. number of events, number of accidents, etc.). Ideally, measures should also be designed to ensure progress on those activities which will improve maintenance programme. For example, the reporting of ‘near misses’, the number of safety inspections and the provision of training can all be used as input measures;

- Numerical measures must always be subject to careful interpretation and be used as part of an overall judgement about maintenance performance. They should not be regarded as an end in themselves.

It was also acknowledged that some problems may happen with the plant's staff acceptance of the implementation of comprehensive system of indicators [6]. In particular it could happen at power plants with established performance monitoring programmes. In these plants, there was a need to work with staff at the programme level and to solicit the support of management at lower levels within the organization in order to effectively implement the programme.

The experience collected in the IAEA documents shows that during the process of selecting the performance indicators, some concerns were raised that there were 'already too many indicators' and that 'some indicators identify problems that need fixing and activities that have positive impacts'. In some cases the implementation of new programme may be considered as additional burden and useless. For this reason, communication and additional explanation may be required with the elements of training to reach common understanding of the benefits of the programme.

Indicators should be periodically reviewed and their relative importance may change with time. So the implementation of maintenance performance indicators programme requires a long time commitment not only for the development but also for the continuous evaluation of the effectiveness and validity of the data. The use of a fixed set of maintenance performance indicators that do not reflect the evolution of the maintenance strategy and the programme at the plant should be avoided.

The implementation of the performance monitoring programme may require the modification of computer programs and plant procedures, training and communication to the staff. Already existing databases may need to be scrutinized to see if they will serve the purpose. Data collection and analysis systems may need changes. Some new databases may be required.

Not all indicators proposed in this Report will be found meaningful at the specific power plant, and not all the indicator definitions proposed in the Report are adequate for the plant. Some of them have to be adapted so that the most meaningful results could be obtained. New plant specific indicators may be found more meaningful to substitute the proposed ones in order to assess the same overall/strategic areas.

It should be noted that the low level indicators are often highly dependent upon site specific definitions and data collection systems, preventing viable comparisons on a plant-to-plant basis. Such comparison between the units of different design may also create difficulties in adapting this model for the common use.

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Monitoring the effectiveness of maintenance programs through the use of performance indicators

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Abstract

This Report summarizes the results of a research carried out in the year 2006 by the working group on Maintenance Optimisation of the SENUF (Safety of Eastern European type Nuclear Facilities) network. The research was focused on the development of performance indicators that can be used by SENUF Nuclear Power Plants for the evaluation of maintenance effectiveness. As an outcome of the research, some quantitative indicators have been selected and a maintenance performance monitoring framework has been proposed. A large amount of literature was analysed to establish the background on which the framework for the maintenance performance indicators was developed. The status of the application of maintenance performance indicators was analysed based on the information accumulated in the TSSTP Unit/EU-JRC/IE; in particular the response from the SENUF members to the questionnaire distributed among the SENUF partners on the maintenance practices at their nuclear power plants in the year 2005. Other sources of information from other Countries with advanced maintenance strategies and advanced systems for maintenance performance evaluation were also thoroughly examined. In particular, the experience of the IAEA in the development of operational safety performance indicators systems, proved very informative. As a result of these studies a set of maintenance related performance indicators was selected and a tentative maintenance performance monitoring system was developed. Recommendations for further steps in the development of a maintenance monitoring system are also provided, based on the experience accumulated in the nuclear and non-nuclear industry.

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