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Benchmarking study of maintenance performance monitoring practices

Summary Report

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Executive Sumary

This Report summarizes the results of the studies performed at the IE/JRC in 2007 on the utilization of maintenance performance indicators in the European nuclear industry. These studies are the follow-up activities of the research that took place in the IE/JRC in 2006. The objective of the research in 2006 was to analyze the maintenance performance monitoring practices in nuclear and non-nuclear industries in order to propose comprehensive list of indicators that can be used by nuclear power plants for the evaluation of their own maintenance programmes as well as for benchmarking purposes. As an outcome of these studies maintenance performance monitoring framework was proposed, which consist of three hierarchical levels and include 43 specific indicators in total. The results of the research, including detailed description of the proposed maintenance performance monitoring framework were published in the EU Report 22602 [3]. The follow-up research activities in 2007 were focused on checking the applicability, usefulness, and viability of the proposed framework on the basis of the experience of selected European nuclear utilities. In particular the task for 2007 was to check to what degree the maintenance performance monitoring system presented in [3] is in compliance with the maintenance monitoring practices in the European nuclear utilities. A questionnaire was developed and circulated to the European nuclear power plants to collect the accumulated experience in the utilization of quantitative indicators for the monitoring of the maintenance performance. It was expected that this survey would provide feedback on whether the approach proposed by IE/JRC is valid and the proposed maintenance monitoring framework can be implemented in the SENUF nuclear utilities and later in the other EU nuclear power plants.

Responses to the survey of the maintenance performance monitoring practices have been received from ten European nuclear power plants and utilities. Analysis of the responses received allows drawing preliminary comments concerning the validity of maintenance performance monitoring framework proposed by IE/JRC and described in [3]. It was found that European utilities accumulated wide experience (more than 10 years) in monitoring the maintenance performance through the use of performance metrics. It was learned from the survey results that the maintenance performance monitoring is integral part of the overall maintenance management system at all the utilities that responded to the survey. The scope and completeness of the maintenance monitoring systems vary from those that use single maintenance performance indicators to more sophisticated systems that are part of the plant's asset management system and include several groups and categories of maintenance performance metrics.

Maintenance monitoring results are periodically reported to the utility or plant management and are used by plant managers as a tool to measure progress in

achieving goals and objectives and monitoring current performance problems and identifying areas requiring management attention. Dedicated Data Bases and specific software for data processing are implemented at some European utilities for maintenance monitoring purposes.

The maintenance monitoring system in many nuclear utilities is in the process of further enhancement, which includes increase of the number of performance indicators, installation of specific software and establishing or upgrading the Data Base of operational data.

Statistical analysis was applied to the survey results to evaluate the weight of utilisation of the proposed indicators at the European nuclear utilities. It was found that the majority of European respondents prefer the indicators that are directly related with equipment reliability and availability. The weight of utilisation of proposed indicators characterizing the preventive character of maintenance is more then 60%. This is a clear recognition by the European utilities of the role of preventive maintenance. 55% of the respondents to the questionnaire use the numerical indicators to monitor quality of the planning and scheduling of their maintenance activities.

Not all maintenance management aspects are presented so successfully. Only 30% of respondents use the complete set of proposed numerical indicators for the work control. The weight of implementation of the material management indicators proposed in our framework is only 38%, despite of the fact that the management of spare parts and materials is one of the key elements to support effective maintenance planning and scheduling. The maintenance budget is presented in the survey results only by 24%. Cost effective maintenance is one of the key indicators of the performance of nuclear power plant in the new economical environment in the energy market.

In addition to statistical information, the respondents delivered comments and proposals related to the proposed maintenance monitoring framework and specific aspects of the maintenance process. The comments and proposals received from the respondents provided a basis for the improvements to the original framework. As a result of these improvements some modifications have been made to the structure of the system, some indicators have been removed from the system. It was evident from the comments of several respondents that additional explanations are needed for clarifications of some definitions used for the maintenance performance metrics proposed in [3]. Such explanations have been included in this Report. The Report also includes considerations concerning the coverage of the specific areas of maintenance process in the proposed maintenance monitoring framework. These areas are the definitions of selected indicators, the coverage of maintenance management aspects, preventive and predictive maintenance, monitoring contractor performance.

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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 research 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. After 4 years of successful operation, the SENUF network was integrated into the new Direct Action of the European Commission, SONIS (Safe Operation of Nuclear Installations), where research on maintenance monitoring and optimisation plays a major role. Primarily the SENUF activities were 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 to be an important contributor to the safety of ageing nuclear power plants. The maintenance performance monitoring was one of the research tasks of the SENUF (Safety of European Nuclear Facilities) network. SONIS is the natural follow-up of the SENUF activity that was carried out in the last cycle, but in the much more enlarged framework of addressing the research needs in relation to the whole operational safety in the Member Countries of the EU 27. Maintenance related issues, built on the SENUF experience and currently taken over by SONIS framework are focused on the maintenance performance monitoring, reliability centered methods, and operational plant life management

The studies in the maintenance performance monitoring were dedicated to the application of quantitative indicators. The purpose of this research was to select quantitative indicators that can be used by nuclear power plants for the evaluation of their own maintenance programmes as well as for benchmarking purposes. As a first stage of this research in 2006 a list of indicators was selected and their definitions were developed [3]. The selected indicators were put into the hierarchical structure, in such a way establishing the framework for the maintenance performance monitoring. The SENUF Steering committee in Madrid [4] approved the results of research performed in 2006 and proposed the work plan for the follow-up of this task for 2007-2008 (within the SONIS framework). As a next step the validation of the proposed framework and selected indicators was intended to evaluate their adequacy and viability. After these phases, a modified framework with an updated list of maintenance performance indicators is 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 2007 in the framework of the SONIS program (Task 1.1.1, Maintenance effectiveness indicators and risk monitors). The first task of this Report is to introduce the results of the survey of maintenance monitoring practices in the European nuclear utilities on the basis of the questionnaire prepared for this purpose. The main objective of the survey was to check the validity of the proposed specific maintenance indicators analyzing the practices in the utilization of the maintenance performance metrics at the European utilities. The second objective of this Report is to analyse the applicability of the proposed system to the needs of the operating power plants.

1.3 Document structure

The report consists of six Sections. Section 1 presents the background information and establishes the link between the previous SENUF activities and the SONIS framework. Section 2 introduces the maintenance performance indicators proposed by IE/JRC in 2006 and described in [3]. Section 3 presents examples of European experience in the use of maintenance performance indicators. Section 4 is dedicated to the analysis of survey results on the use of maintenance monitoring systems at European nuclear utilities. Section 5 presents the improvements to the proposed maintenance performance monitoring framework. Finally Section 6 provides main conclusions of the analysis performed and proposals for the further activities.

2 Introduction of maintenance performance indicators (MPI) framework

In the IE/JRC studies a business process approach was applied to the analysis of the maintenance function as described in [3]. This concept of process management is based on the assumption that the process itself produces the desired results and 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.

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 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.

As a first step in the development of the maintenance performance monitoring framework, we considered the definition of the maintenance monitoring concept. It was 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. The proposed approach to monitoring of maintenance performance is presented in Fig. 1.

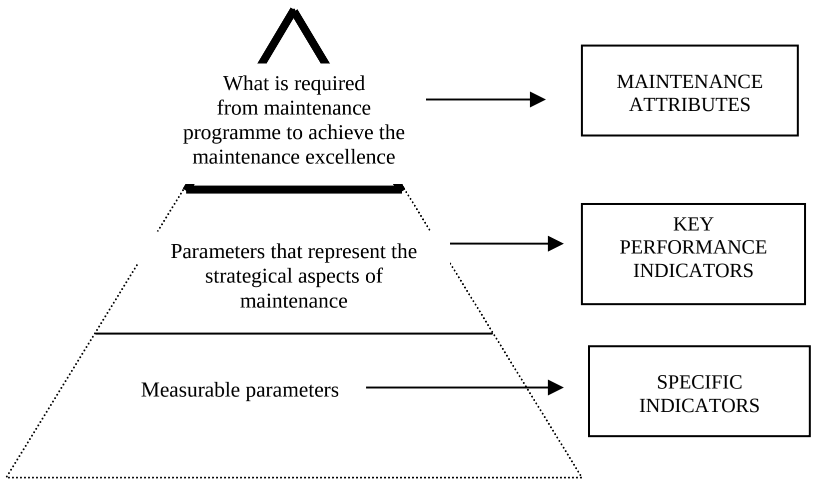

Figure 1 An approach to the monitoring of maintenance performance

On the top of the maintenance performance hierarchical structure we proposed the Maintenance Excellence, from which we developed three attributes that are associated with the excellence of the maintenance programme:

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

Using the excellence attributes as a starting point, a set of maintenance performance indicators is proposed. Below each attribute, key performance indicators are established. The key performance indicators are envisioned to provide overall coverage of relevant aspects of maintenance performance. Each key performance indicator is supported by a set of specific indicators, majority of which are already in use in the industry. A range of specific leading and lagging indicators were selected in order to represent the overall performance of a maintenance programme and its trend over time. 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.

The proposed maintenance monitoring system contains a mix of lagging and leading indicators. For the maintenance application, the leading indicators measure the effectiveness of the maintenance process, while lagging indicators measure results. 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). On the other hand the outcome 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.
It is very important to understand that performance indicators are not just a measure/demonstration of success but should be used as a tool to manage successfully the maintenance process. The utilities should utilize performance indicators to identify opportunities for improvement rather than measures of success or failure.

3 Analysis of European experience in the use of maintenance performance indicators

3.1 General experience of EU countries in using maintenance performance indicators

The preliminary analysis of the status of the maintenance performance monitoring in the utilities of SENUF Group memebers was made in 2006, based on the survey of the maintenance practices in the SENUF Group utilities [5]. The appropriate questionnaire on ‘Advanced Strategies to optimize maintenance’ developed to explore the advanced maintenance methods and approaches provides limited information on the use of performance indicators for the maintenance monitoring. It was 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 results on the application of maintenance performance indicators in the SENUF Group utilities.

The survey results show that almost all power plants (seven out of eight respondents) monitor the rework which is characteristic of the maintenance quality. In the majority of SENUF NPPs monitoring of maintenance effectiveness is focused on the equipment reliability and availability. Despite of the fact 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 maintenance performance indicators 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 [6]. This system reflects 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 [7]. 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.

Table 1 Maintenance performance indicators in SENUF utilities*

№	MPI	Spain	Cerna voda	Bohu Nice**	EMO	Krsko	REA	Igna lina
1	Number of outstanding Backlogs	X		X	X			
2	Number of urgent and first priority orders					X		
3	Reliability of equipment	X		X			X	
4	Number of equipment failures	X	X	X***				
5	Component and system availability	X		X				X
6	Amount of maintenance rework	X	X	X	X	X	X	X
7	Availability of spare parts	X						
10	Overdue of PM activities		X	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	X***				
13	Ratio of planned and unplanned maintenance				X			
14	Ratio of PM & CM activities					X		
15	Duration of repair			X			X	
16	Cost of repair			X			X	X
17	System health		X					
18	Specific work orders indicators					X		

* the data as of 2004-2005
** updated in 2007
*** planned for implementation

3.2 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 [8]. 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 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.2).

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. 2).

A specific Regulatory Guide [9] 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. 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.

The definition of the indicator Failures of components subject to the Technical Specifications is an example of the specific approach to the selected indicator. 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 [8].

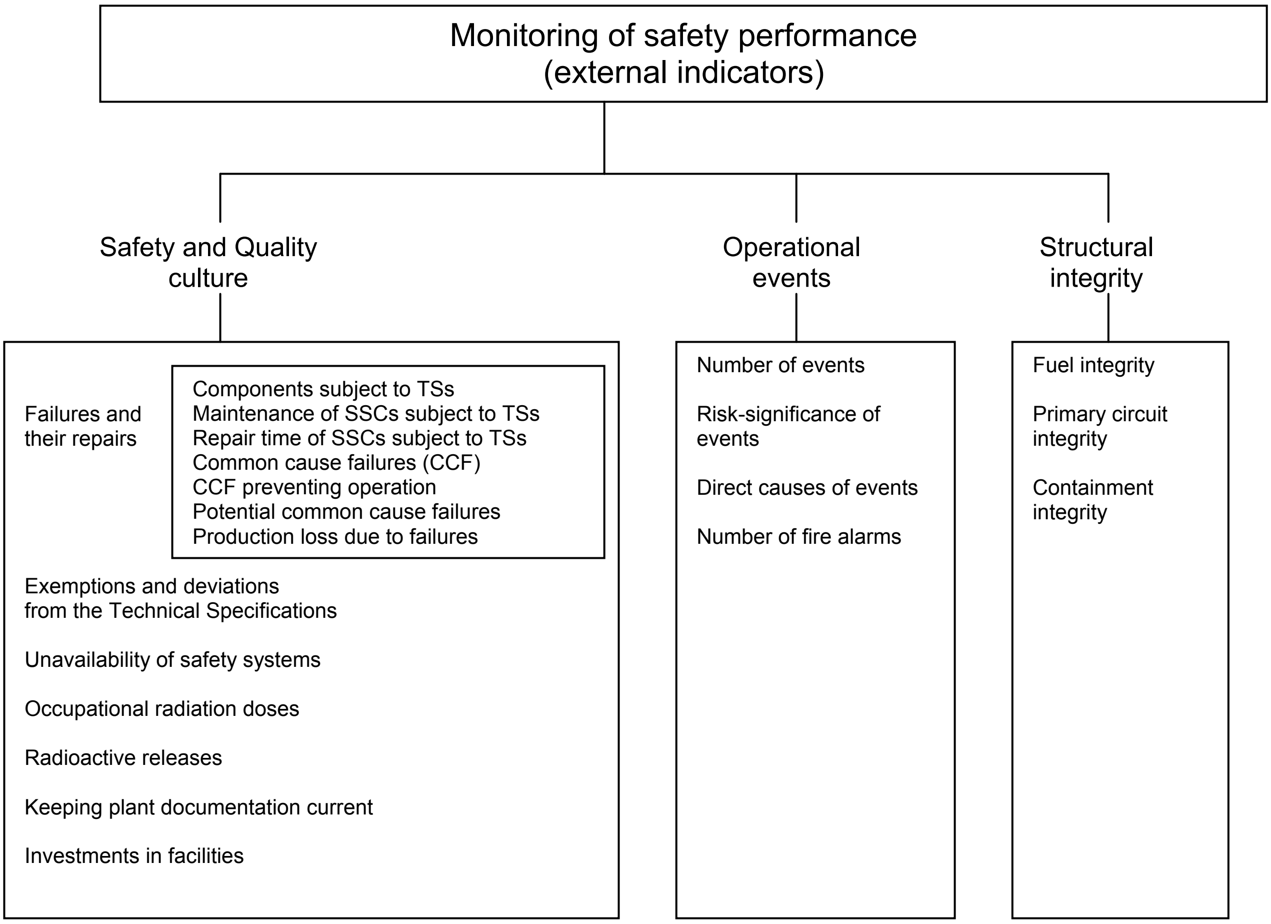

Figure 2 Structure of STUK safety performance indicators for the nuclear power plants in Finland

The STUK safety performance monitoring system comprises the various processes of power plant operation (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.

3.3 Survey of the European maintenance monitoring practises

The European nuclear industry accumulated a great experience in the development and use of performance indicators in different fields of operation of nuclear power plants. 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 understanding its importance for enhancement of 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 (WANO).

Therefore in 2007 a dedicated questionnaire on ‘Maintenance performance monitoring through the use of performance indicators’ (see Annex) was developed at the IE/JRC, and circulated to all SENUF partners and to European nuclear power plants. The list of selected indicators that are in use in different industrial sectors worldwide (Attachment to the Annex) is an integral part of the questionnaire. These indicators were used as a basis for the development of maintenance monitoring framework described in the Ref [3].

The objective of the questionnaire was to explore the methods in use in the plant operating community to monitor the maintenance performance, focusing on the utilisation of the quantitative metrics. The intention of the survey was not to rate the different maintenance performance systems, but rather to search for the best operational practises in order to make them acceptable for the broad nuclear plants community. To cover main aspects of the maintenance monitoring the questionnaire included the following items:

1. Availability of the maintenance performance indicators system;
2. Specific characteristics of the system;
3. The list of specific performance indicators in use at the power plant ;
4. The duration, the monitoring system is in use ;
5. Maintenance performance reporting ;
6. Dedicated Data Base;

7. Use of specific software;
8. Assignments of responsible personnel;
9. Update and modification of the monitoring system.

The additional objective of the questionnaire was to get response to the proposed MPI system from the operating utilities. Based on the received responses from several SENUF members some modifications to the maintenance performance monitoring system have been already implemented, as it is reflected in the Technical Report EU 22602 [3]. Some others, received after the publication of the Report, have been taken into consideration in the course of Research activities performed in 2007 and presented in this Report.

3.4 Synthesis of the survey of the European maintenance monitoring practices

The responses to the survey of the maintenance performance monitoring practices have been received from ten European nuclear power plants and utilities and one technical support organisation. They represent the following European countries:

Belgium, Germany, Czech Republic, Hungary, Lithuania, Nederland, Slovakia, Sweden, UK, Ukraine. Romania in the survey was presented by CITON, Center of Technology and Engineering for Nuclear Projects.

The survey results show that the maintenance performance indicators are in use at all European utilities and nuclear power plants who responded to the questionnaire. All respondents report that the maintenance performance indicators are part of the overall performance indicator system. Seven respondents explained that they have in use the monitoring system specifically dedicated to the maintenance programme. Another group of respondents explained that the maintenance monitoring is carried out within the overall asset management system.

There is variation in the complexity of maintenance monitoring systems. Some of them utilise single performance indicators, more advanced systems include several groups or categories of maintenance performance metrics.

80% of respondents have been using the maintenance monitoring indicators for more then 5 years, four respondents report that they use such a system for more then 10 years. In three cases the maintenance monitoring experience is between 1 and 3 years.

Maintenance monitoring results are periodically reported to the utility or plant management. Annual reporting is the usual practice among the responded plants. Only in one case the reports are being produced quarterly.

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. Six respondents report that they use specific Data Base for the maintenance monitoring purposes. These data bases include definitions of maintenance performance indicators, goals, graphic values, references, comments and actions, responsible coordinators/'owners', anticipated and actual indicator values, etc. Five respondents report that the data bases are supported by specific software for the processing of collected information for the trending results and demonstration and reporting. 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 for specified time period.

Majority of respondents (80%) reports that they are planning further improvements of their maintenance monitoring system. In three cases new maintenance monitoring system is planned. Almost 50% of respondents are planning to increase the number of performance indicators in their monitoring systems. The other modifications include installation of specific software and establishing or upgrading the Data Base.

4 Validation of the proposed key performance indicators (KPI)

4.1 General considerations

The maintenance monitoring survey results were analysed to clarify:

1. The list of specific performance indicators that are in use at the European nuclear utilities;
2. To what degree the maintenance performance monitoring system, developed in IE/JRC is in compliance with the maintenance efficiency monitoring practices in the European nuclear utilities; and
3. Viability of specific indicators to support certain KPI.

Despite the available statistics were not sufficient to draw the sound conclusions, some preliminary trends and conclusions can be identified. Based on the responses from the European utilities we analysed how frequently the key performance indicators and specific indicators are used in the nuclear industry. The task was to evaluate the weight of utilisation of proposed indicators at the European nuclear utilities. To apply this weighting approach to the key performance indicators we established specific coefficient, weight of utilisation of key performance indicator (W).

The weight of utilization of key performance indicator is defined as:

$$W= \sum^{n_{smi}} N_{smi} \,/\, N \times n_{smi} \times 100\% \qquad (1)$$

W – weight of utilization of key performance indicator;

N – number of responses received (in our case N is 10);

n_{smi} – number of specific indicators within the group of certain KPI (n_{smi} is 9 for KPI, PM effectiveness, 6- for KPI, System and equipment availability, etc.);

N_{smi} – number of respondents who use the specific maintenance performance indicator (e.g component and system unavailability, scheduled downtime, MTBF, schedule compliance, etc.).

Table 2 presents the survey results for the evaluation of the weight of maintenance performance indicators. The table comprises specific maintenance performance indicators grouped under the certain key performance indicator in accordance with the system developed by IE/JRC [3].

It is evident that the majority of European respondents prefer the indicators that are directly related with the equipment reliability and availability (>60%)[1]. The adherence of nuclear utilities to this type of indicators is quite clear. The final product of maintenance activities is reliability and availability of system and equipment and the indicator of the quality of this final product is logical and binding part of the system which is measuring the maintenance performance (see also 4.3 in Ref. [3]).

There is a clear recognition by the European utilities of the role of preventive maintenance. The weight of utilisation of proposed indicators representing preventive character of maintenance is more then 60%. Preventive maintenance programs are established at the majority of nuclear facilities to maintain equipment within design operating conditions and/or to extend equipment life. 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

[1] percentage provided in this section is indicator of how completely the responded power plants use the set of specific performance indicators grouped under the certain key performance indicator (KPI) in the proposed MPI framework (system and equipment availability, reliability of systems and components, PM effectiveness, planning and scheduling, etc.) Low percentage does not mean that this category of key performance indicators is completely missing at specific power plant. It may also mean inadequate grouping of the specific indicators or the fact that validity of some specific indicators are not proven by the operational practice. More detailed discussion on this subject is presented in the Section 5 of the Report.

at times that do not interfere with production schedules, thereby removing one of the largest factors from downtime cost, increasing profitability.

50% of the respondents to the questionnaire use the numerical indicators to monitor quality of the planning and scheduling of their maintenance activities. The work planning system provides for maintaining high availability and reliability of important plant structures, systems and components. 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.

Good coordination of maintenance activities in order to avoid the potential interference with normal operation of a plant is one of the attributes of good maintenance management. Significant number of such interferences is indicator of poor planning and coordination of maintenance activities. Significance of this attribute recognizes about 50% of the responded nuclear power plants.

Not all maintenance management aspects are presented so successfully. Only 30% of respondents use the complete set of proposed numerical indicators for the work control. It is supposed that the adequate work control system facilitates implementation of maintenance activities and ensures safety in the work area and prevents maintenance activities from affecting other safety relevant areas. The material management aspects are monitored only by 35% of respondents, despite that management of spare parts and materials is one of the key elements to support effective maintenance planning and scheduling and ensure the quality and efficiency of the maintenance process. Improved material and spare parts management may free up time for maintenance planners, maintenance supervisors, and hourly maintenance personnel.

The maintenance budget is covered in the survey results only by 24%. 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. Cost effective maintenance should be the one of the key indicators of the performance of nuclear power plant.

Table 2 Survey results for the evaluation of the weight of utilization of maintenance performance indicators

№	*Performance indicators*	N_{smi}	W (%)	Comments
System and equipment availability				
1	Component and system unavailability	9	85	
2	Total downtime	9		
3	Scheduled downtime	9		
4	Unscheduled Downtime	10		
5	Number of forced power reductions or outages due to maintenance causes	9		
6	Mean time between maintenance (MTBM)	5		
Reliability of systems and components				
7	Number of corrective work orders issued	8	65	
8	Number of failures in safety related systems	10		
9	Mean time between failures	4		
10	Mean time to repair (MTTR)	4		
PM effectiveness				
11	Preventive maintenance compliance	6	65	
12	Ratio of corrective work resulted from PM activities	6		
13	PM work order backlog trend	7		
14	Percentage of deficiencies discovered by surveillance, testing & inspections	5		
15	Ratio of PM activities to all maintenance activities	6		
16	Overdue of PM activities	7		
17	Number of jobs planned but not performed	10		
18	Number of jobs not started as planned	7		
19	Actual versus planned man-hours (per job or totals)	5		
Planning & scheduling				
20	Ratio of unplanned to planned working orders	5	55	
21	Planning compliance	8		
22	Schedule compliance	9		
23	Ratio of corrective work orders executed to work orders programmed	3		
24	Number of outstanding backlogs (urgent orders)	8		

№	*Performance indicators*	N_{smi}	W (%)	Comments
25	Planner to craft work ratio	0		
Interface with operations				
26	Workarounds	4	50	
27	Temporary modifications	9		
28	Ratio of downtime to allowed outage time	6		
29	Number of MCR instruments out of service	1		
Work control				
30	Duration of repair	4	30	
31	Repair time of components subject to the Technical Specifications	4		
32	Wrench time	1		
33	Crew efficiency	0		
34	Amount of maintenance rework	7		
35	Supervisor to Craft Worker Ratio	1		
36	Response time to call	1		
37	Overtime maintenance hours	6		
Material management				
38	Stores service level	5	38	
39	No of works pending for spare parts	2		
40	Stocks inventory turns	6		
41	Stocked MRO Inventory Value as a Percent of Replacement Asset Value (RAV)	3		
42	Average spares and tools waiting time.	1		
43	Stocks items available but not used	3		
44	Inventory accuracy	5		
45	Spare parts and material obsolescence	4		
46	Vendor performance	6		
Cost effective maintenance				
47	Maintenance cost per kwh produced	6	24	
48	Unplanned costs as percentage of total maintenance costs	4		
49	Work orders complete within the determined costs (20%)	1		
50	Ratio of replacement asset value (RAV) to craft/wage head count	0		
51	Annual maintenance cost as a percent of replacement asset value (RAV)	1		

3.2 Analysis of performance indicators for the effectiveness of preventive maintenance

For the preventive attributes of maintenance the following three key indicators were 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. 2.

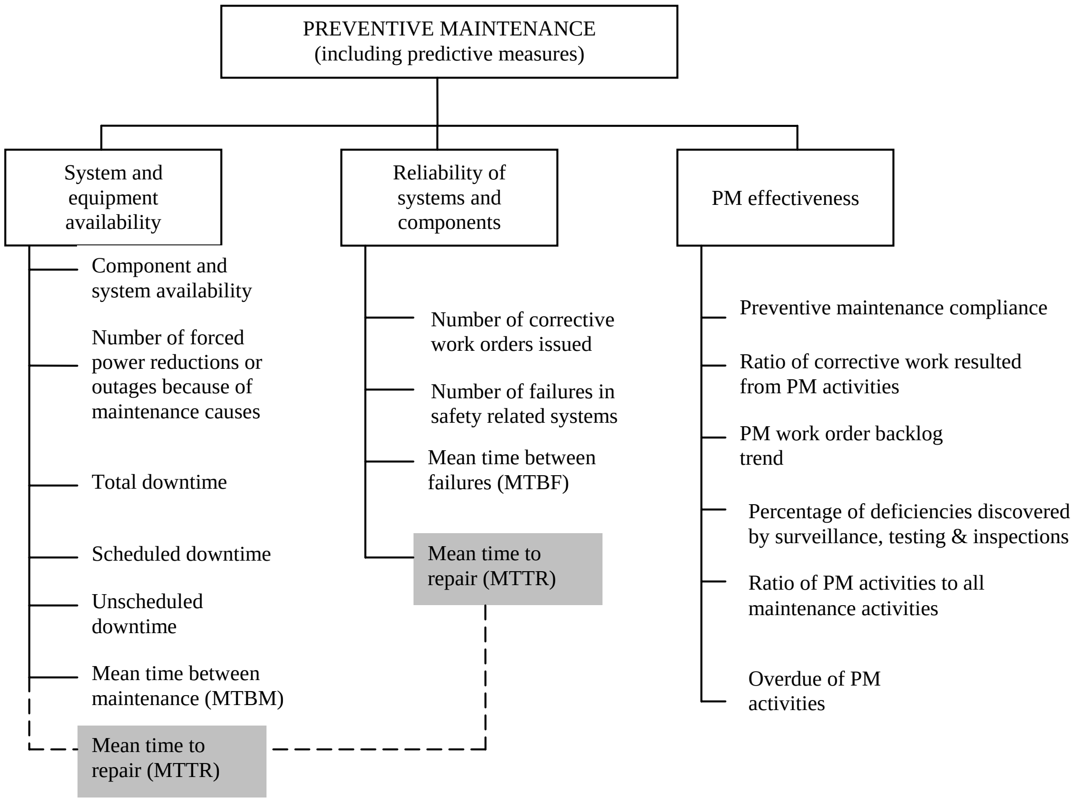

Figure 2 Performance indicators for the preventive maintenance

The cursory acquaintance with the survey results (Table 2) shows that almost all respondents use the proposed indicators for the system and equipment availability and reliability. However from the survey results and comments received it seems that there is confusion with the perception of the indicators:

Mean time between maintenance (MTBM),
Mean time between failures (MTBF),
Mean time to repair (MTTR).

Despite that the definitions for the above indicators have been presented in the Ref [3], additional explanations are needed for the clarification of the role of each of the above indicators and the differences between them. So far as all three indicators are related to the equipment reliability and availability, additional arguments are needed for the definition of the reliability and availability and the interrelation between these two terms.

The term *availability* for a system or equipment denotes the probability that the system or equipment can be used when needed. Alternatively, the term describes the fraction of the time that the service is available. The term *unavailability* is defined as the probability that a system or equipment is not available when needed, or as the fraction of the time service is not available.

The term *reliability* of a system or equipment is defined as the probability that the system or equipment will perform its intended function without failure over a given period of time. A commonly used measure of reliability is known as *Mean time between failures* (MTBF), which is the average expected time between failures [3]. A maintenance service outage caused by a failure is defined as the *Mean time to repair* (MTTR). MTTR includes time required for failure detection, fault diagnosis, and actual repair. 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 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.

Availability (A) is related to MTBF and MTTR as follows:

$$A = MTBF/(MTBF + MTTR) \qquad (2)$$

This relationship shows that increasing MTBF and decreasing MTTR improves availability. This means that the availability of a system or equipment can be improved by increasing the reliability of its components. Similarly, improving the reliability of its constituent elements can enhance the availability of a system or component.

Another indicator which is directly related with the equipment or system availability is *Mean time between maintenance* (MTBM). In [3] MTBM is defined as the average length of time between one maintenance action and another for a piece of equipment or component. The metric is applied only for maintenance actions which require or result in function interruption. The mean time between maintenance (MTBM) includes all corrective and preventive actions (compared to MTBF which only accounts for failures). The MTBM is calculated as the total operation time divided by number of maintenance actions during the same period. This metric is useful in assessment of maintenance effectiveness. MTBM measures how many times a maintenance task is being performed on the equipment or system 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.

Following the reasoning above and comments received from some of survey respondents we slightly modified the grouping of the maintenance performance indicators. We agree with those respondents that consider that the indicator *Mean time to repair* (MTTR) is more related to the availability then to reliability and moved this indicator under the KPI System and equipment availability (see Fig. 2).

Survey results identified additional indicators that are in use at some nuclear power plants and which are characterizing maintenance effectiveness. They are:

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

We found appropriate to include these indicators in the updated IE/JRC list of maintenance performance indicators (Table 3, pgs. 37-38).

4.3 Analysis of performance indicators for maintenance management

To reflect the maintenance management aspects we proposed the following key indicators [3]:

- 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. 3.

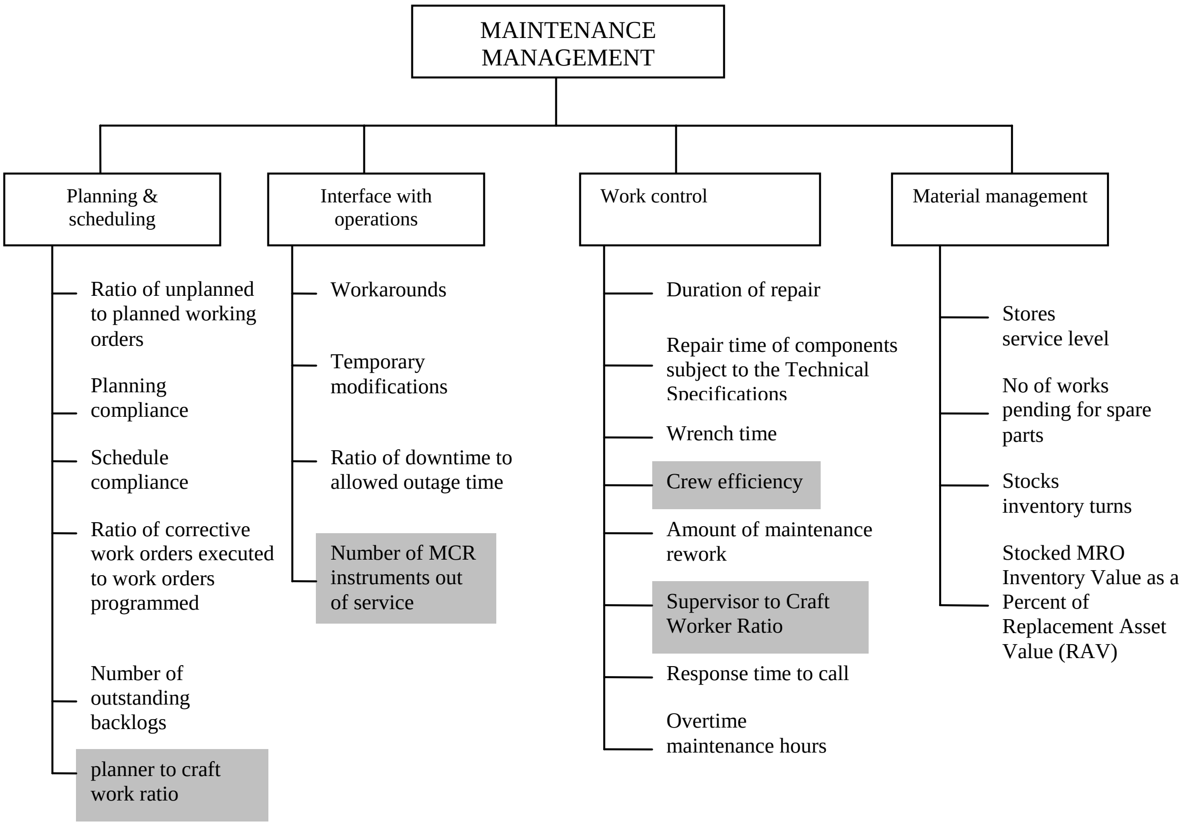

Figure 3 Indicators structure for the maintenance management

Planning and scheduling of maintenance activities in our system [3] are supported by 5 specific indicators (Fig.3). The survey results show (Table 2) that the most popular in this group are indicators *planning compliance, schedule compliance* and *number of outstanding backlogs.* Still three utilities report that they use indicator *Ratio of corrective work orders executed to work orders programmed.* We also found that the indicator *Planner to craft work ratio* was not used in any of responded utilities, so we removed this indicator from our system.

The weight of the KPI *Interface with operations* is 50%. In this group only one respondent reported on the use of the indicator *Number of MCR instruments out of service*. We found appropriate to remove this indicator from the system.

The work control indicators are also poorly represented in the survey results. The weight of the indicators in this group is 30%. Most popular indicators in this group are *Amount of maintenance rework* and *Overtime maintenance hours.* These two indicators are related to each other and the relatively high rating of these indicators witnesses that utilities acknowledge the necessity to maintain high quality of maintenance services. Based on the survey results we found appropriate to remove *Crew efficiency* and *Supervisor to Craft Worker Ratio* from the maintenance performance indicators system.

Despite the poor representation of indicators *Response time to call* and *Wrench time* we still preserved these indicators in our scheme. We suppose that the indicator *Response time to call* can be useful in connection to suggestion of some respondents to reflect in the maintenance performance monitoring system the quality of the contractor's services. A commitment to restore the system or equipment malfunctions within a specified time period requires adequate management level and good cooperation between operation and contractors. This indicator also incorporates 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 contracted 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**.**

The *Wrench time* indicator is frequently used in the other industries to demonstrate high efficiency of maintenance services. 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. 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. We found useful to encourage nuclear utilities to incorporate this indicator into their maintenance monitoring practice.

Material management aspects in the maintenance performance monitoring are presented by nine specific performance indictors (Fig. 3). The weight of material management indicators was found 38%. To our understanding the material management deserves more attention then that shown in the survey results. The material management aspects become significant contributors into plant economic health in new competitive circumstances [10]. In the past nuclear plant managers and operators were primarily focused on optimizing plant operating parameters, such as minimizing the duration of major maintenance and refuel outages and achieving high availability factors, and, to a lesser extent, were concerned about efficient inventory management. Generally, materials and supplies were expected to be available whenever required and in plentiful supply. Prior to the onset of electricity deregulation and the renewed emphasis on efficient electricity production, it was not unusual to have large nuclear power plants' inventory levels exceeding $40–50 million per unit. With deregulation and electricity price competition, the requirement for the careful management and tracking of nuclear plant materials and supplies inventories, as well as the maintenance of high inventory turnover rates, will be essential for efficient and competitive nuclear electricity production. Despite the majority of respondents acknowledge the role of stores service level, stocks inventory turns and the vendor performance, additional efforts should be made to encourage nuclear power plants to use the material management indicators at broader scale. In the updated list we included some new indicators that are in the practice of European nuclear utilities (see Table 3 on pgs.37-38). They are:

- Stocks items available but not used;
- Inventory accuracy;
- Spare parts and material obsolescence;
- Vendor performance.

4.4 Analysis of key performance indicators for maintenance budget

Despite that the maintenance budget is an increasingly important aspect in the new economical environment in the energy market, the budgetary indicators were poorly presented in the survey results. 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. Reducing the production costs, including the maintenance costs in particular is the condition of survival in the competitive energy market. Figure 4 shows the proposed indicators structure for the maintenance budgeting.

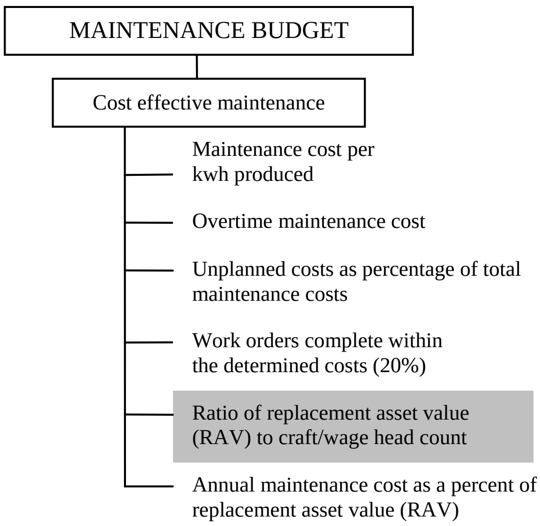

Figure 4 Indicators for the maintenance budget

Majority of the respondents recognize the *maintenance cost per kwh produced* and *unplanned maintenance costs* as the most important budgetary indicators. The other indicators are not frequently used in the maintenance monitoring practices. Based on the survey results we found reasonable to remove the indicator *Ratio of replacement asset value (RAV) to craft/wage head count from* the proposed framework.

5 Improvements to the proposed maintenance performance monitoring framework

5.1 General considerations

The main purpose of the questionnaire on the maintenance performance indicators was to obtain information on the maintenance performance monitoring practices, in particular, on the monitoring of maintenance performance through the use of numerical indicators. However the respondents did not limit themselves solely with the maintenance performance metrics, but provided also comments on the maintenance monitoring system developed by IE/JRC. The responses received reveal some critical topics of the maintenance programme. The received comments and suggestions were carefully analysed for the identification of further research areas in the maintenance domain and improvements of the proposed maintenance monitoring framework.

The following areas for further research were identified from the analysis of the questionnaire:

- Definitions of the selected indicators. The definitions of the specific indicators should be tailored in accordance with the plant specific needs. The experience shows that the initial definitions may undergo changes during the indicator evaluation phase at the specific plant.

- Predictive character of preventive maintenance. More emphasis should be put on the results derived from the condition based monitoring and the predictive character of maintenance actions.

- Efficiency of the contractors' services. Increased used of contractor services in maintenance necessitates rigid control and monitoring of contractor's performance.

We found that some maintenance monitoring aspects need additional clarification. This concerns such matters as definitions of specific maintenance indicators, interrelation between preventive and predictive maintenance, the coverage of maintenance management aspects in the maintenance monitoring framework, monitoring of contractor's performance. The following sections are dealing with these specific items.

5.2 Definition of selected indicators

Several comments have been received from nuclear power plants related to the definition of selected indicators. Some respondents proposed to modify the definitions for certain performance indicators to make them suitable for specific plant conditions or practices, some others proposed new indicators in addition to those presented in the IE system. For example there was a proposal to include in the system the indicator addressing the failure to transfer the equipment into operation after the completion of maintenance service. In the MPI system proposed by IE/JRC the similar indicator was identified as *Amount of maintenance rework* (see 5.3.3.7 in [3]). This leading indicator is useful to monitor the amount of work that is carried out repeatedly. However the further analysis showed that at some power plants the failure to return to service the plant systems and components following maintenance activities is associated not only with the quality of the maintenance performed and consequently, a need for maintenance rework. In many cases the reason for rejection by operations to accept the equipment after maintenance activities is incomplete documentation, violation of maintenance procedures, including post-maintenance testing. So the indicator *Amount of maintenance rework* defined as the metric to monitor the amount of rework is unable to reveal the real causes of the deviation from the maintenance schedule. Another indicator *Schedule compliance* defined as a percentage of the scheduled work accomplished to the total work time available to schedule is also improper metrics to address the matters of maintenance diligence or negligence. The solution may be found in the modification of the definition of the indicator *Schedule compliance* binding the schedule of maintenance activity to the deadline to return the equipment into the service.

It was pointed out in the previous Report that the clear and simple definition for each selected indicator is a key part of the implementation of the monitoring programme. When selecting indicators for specific 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.

In the EU Report 22602 [3] it was noted that not all proposed indicators will be found meaningful at the specific power plant, and not all the indicator definitions introduced in the Report are adequate for the specific plant. The definitions of some indicators vary from utility to utility in accordance to the specific approaches and needs of the utilities. In particular 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. Some of them have to be adapted so that the most meaningful results could be obtained.

The sensitivity of the performance indicators has been demonstrated by the STUK (Finland) experience [8]. 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.

Another example of the changeableness of definitions of maintenance performance indicators is the definitions of the mean time between failures (MTBF). 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.

Several respondents commented that not all management aspects critical for the maintenance performance are adequately presented in the proposed maintenance monitoring system. The following aspects were proposed for inclusion in the maintenance monitoring system:

- Failure to return the equipment into service, following maintenance activities, at the first presentation;
- Non compliance with the maintenance procedures;
- Control of contractors efficiency.

It was already mentioned that not all indicators proposed in Ref [3] will be found meaningful at the specific power plant and new plant specific indicators may be found more meaningful to substitute the proposed ones in order to assess the same overall/strategic areas. The proposals to consider new maintenance performance metrics and to modify the definitions of proposed indicators to make them more suitable to the needs of specific plant will be taken into consideration for the further improvements of the proposed system.

5.3 Preventive versus predictive maintenance

Preventive maintenance (PM) can be defined as a series of systematically planned and scheduled actions performed for the purpose of preventing equipment, system, or facility failure. We selected the **preventive** as one of the attributes of the maintenance excellence. Some respondents of the survey commented that the attribute **Preventive** should be supplemented with the **predictive** (Pd) to make this attribute more comprehensive. 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.

As far as the discussion arises very often on what is *preventive* and what is *predictive* maintenance and what is interrelation between these two maintenance modes we found reasonable to explore a little bit in this subject in order to introduce, if necessary, improvements to the proposed maintenance monitoring system.

Despite the preventive character of maintenance assumes the alternative to the corrective maintenance it does not mean too much. It was found that in many cases the preventive maintenance is not a proper remedy to increase the equipment reliability and availability and to avoid the recurring equipment breakdowns. If preventive maintenance programme is time based and follows only the manufacturers suggestions and recommendations, such a preventive approach in maintenance does not work as expected. Research on equipment failures during the past years has proven that more than 70% of failures aren't related to equipment age or use. As a consequence, that means that only less than 30% of our proactive maintenance tasks should be driven by time, equipment age or usage. The major part of maintenance actions should be predictive and detective.

There are different views on the interrelation between the preventive and predictive maintenance. One of them is that the predictive maintenance (Pdm) is a subset of preventive maintenance. Such approach is described in 'The Complete Guide to Preventive and Predictive maintenance' by J. Levitt [11]. In accordance with this approach the comprehensive PM programme should be also predictive in nature. It should include the predictive activities to view or examine the equipment, component or system to "predict" if the condition will cause a failure before the next inspection cycle. In this interpretation of preventive maintenance the fundamental part of the definition of the PM programme is "Detect that an equipment has had critical wear and is about to fail".

Another approach is that the predictive maintenance is a separate, independent category of maintenance. Some maintenance experts consider the predictive maintenance in the historical perspective as the more advanced maintenance strategy. Tracking back the maintenance history and forecasting the further development tendency the road map for the maintenance excellence can be illustrated as in Fig. 5 [12]. In this approach the predictive maintenance (PdM) is defined as a right-on-time maintenance strategy. Predictive maintenance may be described as a process which requires technologies and people skills, while combining and using all available diagnostic and performance data, maintenance histories, operator logs and design data to make timely decisions about maintenance requirements of major/critical equipment. It is the integration of various data, information and processes that leads to the success of a Pdm program [12]. It analyzes the trend of measured physical parameters against known engineering limits for the purpose of detecting, analyzing and correcting a problem before a failure occurs. A maintenance plan is made based on the prediction results derived from condition based monitoring. This can cost more up front than PM because of the additional monitoring hardware and software investing, manning, tooling, and education required to establish a predictive maintenance program. However, it offers increased equipment reliability and a sufficient advance in information to improve planning, thereby reducing unexpected downtime and operating costs, which is very important for the nuclear industry.

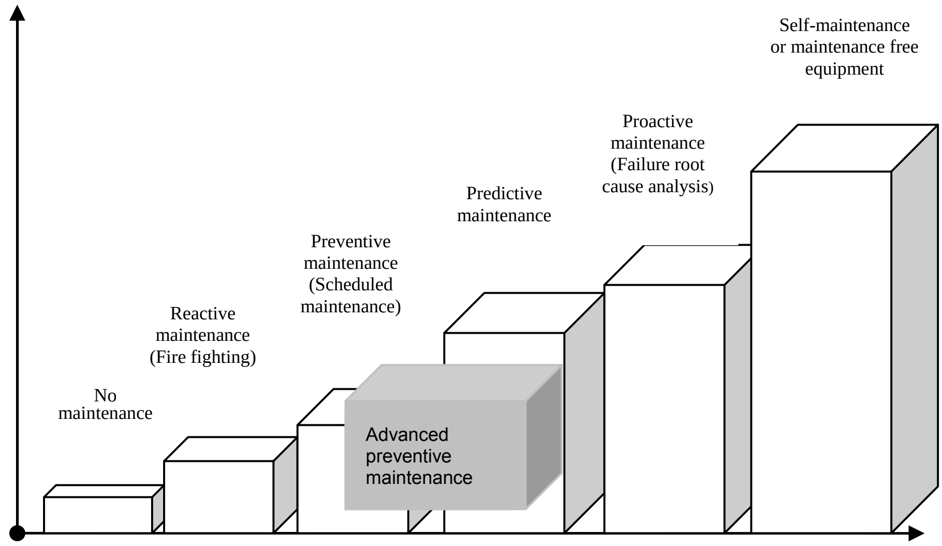

Figure 5 The development of maintenance technologies

In the maintenance monitoring framework proposed by IE/JRC we hold with those who consider the predictive maintenance as a part of preventive maintenance. In our interpretation the attribute of maintenance excellence *Preventive maintenance (including predictive measures)* can be treated as the Advanced Preventive maintenance (see Fig. 5). The appropriate corrections have been introduced into proposed MPI system. We consider that this subject is rather the matter of terminology then of essence.

5.4 Monitoring contractor performance

Several respondents proposed to include in the MPI system the indicators to monitor the contractor efficiency. In particular, these proposals came from the countries where in the recent past the complete in-house maintenance staffing was the traditional approach. This approach was typical at all nuclear power plants in the former Soviet Union and East European countries operating Russian design NPPs.

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. Downsizing and cutting down on staff numbers is the common feature when companies try to rationalize in new economic environment. Outsourcing or increased use of contractor services is one way to achieve downsizing. Use of contractors for periodic, occasional, or one-time tasks can provide for enhanced efficiency, since the required staffing levels and/or expertise need not be maintained within the plant organization when they are not needed. Majority of nuclear utilities in new economic environment are using downsizing as one aspect of their strategy for dealing with deregulation. However, use of contractors may be more appropriate for some tasks than others. Typical examples of outsourcing in nuclear industry include maintenance, engineering services, computer services, training of operating staff and archive functions. Downsizing and outsourcing of services, in particular maintenance services lead to increased use of contractors for safety related work and arose challenges in oversight of the contractor's activities.

The use of contractors has, in some cases, increased the risk of incidents at nuclear utilities. This may be due to the fact that the contractors do not have sufficient knowledge or training in the safety policy and procedures, or there is not sufficient co-ordination with regular staff. A basic principle should be that the contracted workforce receives the proper training for the installation, and should work under the same conditions as would employees, applying the normal utility's safety policy and procedures.

Generic safety aspects associated with contract maintenance is the operator's ability to keep and develop enough competence within its organization to be able to maintain full control over safety related maintenance activities in the short and long perspective. To ensure that contractors comply with the same safety requirements, policies, and procedures, as employees the appropriate contractor performance management system should be applied.

In order to control the quality of contractors and consultants a system of authorization is sometimes used. If this is done the assessment of the contractors should include a demonstration of the financial, technical, material and organizational preconditions, including a quality system. Proof of specialist qualifications should also be included in the assessment. In some countries an authorization for outsourced work is a subject to regulatory control on the same basis as the licensee.

Contractor Performance Management (CPM) is the process that enables both parties to a contract to meet their obligations in order to deliver the objectives required from the contract. It also involves building a good working relationship between the utility and its Contractors. It is expected that the contracted maintenance services are performed safely, efficiently, effectively and economically. Effectiveness is the measure of the extent to which the objectives have been achieved, efficiency is the comparison of output with the input required to produce it and finally the economy is concerned with obtaining the same results more cheaply.

Following the respondents' comments and proposals we analyzed the available experience in energy sector and other industries on monitoring the contractor performance. We found that the following examples of the contractor performance measures can be selected for consideration:

- Availability of equipment the contractor has performed maintenance on;
- Quality assurance audit;
- Maintenance rework activities;
- Number of outstanding defects;
- Injuries;
- Schedule adherence;
- Improvement of opportunities identified;
- Number of late deliveries of equipment;
- Response time to call (see Section 4.2).

6 Conclusions and proposals

The survey presented in the Report should be regarded as a sample of ten European nuclear power plants which have been selected from 62 nuclear power plants where the questionnaire was distributed to. Sampling is the process of selecting units (in our case nuclear power plants) from a population of interest (European utilities) so that by studying the sample we may fairly generalize our results back to the population from which they were chosen. We have processed the information received from a sample of ten nuclear power plants and the results obtained can be treated as a preliminary view on the subject under discussion.

Analysis of the responses received from European nuclear utilities on the maintenance performance monitoring practices allows drawing preliminary comments concerning the validity of maintenance performance monitoring framework proposed by IE/JRC and described in [3]. It was learned from the survey results that the maintenance performance monitoring is the integral part of the overall maintenance management system at all utilities responded to the survey. The scope and completeness of the maintenance monitoring systems vary from those that use single maintenance performance indicators to more sophisticated systems that are part of the plant's asset management system and include several groups and categories of maintenance performance metrics.

The concept of process management, based on the assumption that the process itself produces the desired results, was used in the development of maintenance monitoring system described in Ref. [3]. This approach ensures that we successfully manage the maintenance process in order to achieve optimal levels of equipment reliability, availability and cost effectiveness. This approach is well understood by the nuclear industry and is demonstrated by the survey results.

Despite of the fact that majority of maintenance monitoring practices are focused on those indicators that are direct measure of equipment reliability and availability, there is a clear recognition by the European utilities of the role of preventive maintenance. Preventive maintenance programs are established at the majority of nuclear facilities to maintain equipment within design operating conditions and/or to extend equipment life. Following the proposals from some respondents we modified the title of the key performance indicator ‘preventive maintenance’, including the ‘predictive’ component. We found useful to give additional explanations of our understanding of the relationship between the preventive and predictive character of maintenance activities in the overall maintenance concept (see Section 5.3). We also agree with the comments from some respondents that the predictive character of maintenance is not adequately presented in the proposed maintenance monitoring framework and additional efforts are needed on this matter.

Maintenance monitoring results are periodically reported to the utility or plant management. This information is useful management tool to measure progress in achieving goals and objectives and monitoring current performance problems and identifying areas requiring management attention. Annual reporting is the usual practice among the responded plants.

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. Dedicated Data Bases and the specific software for the data processing are implemented at some European utilities for the maintenance monitoring purposes. At some power plants the graphic displays are used to show the maintenance 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.

The survey results were also used for checking the validity of selected specific indicators. We found that the majority of those put in our framework are in use at European nuclear power plants, despite that the weight of their use is different. For some of them we did not find sufficient evidence of their value and they have been excluded from the system. On the other hand there were some indicators identified that were not included in the original scheme [3].Taking into account survey results and the proposals of the European nuclear utilities, the modified list of the maintenance performance indicators is presented in the Table 3.

Further progress in the research on the maintenance performance monitoring is assumed as a response to the comments and proposals received in the course of the survey in 2007. These comments and proposals provide a good basis for planning further SONIS activities for 2008, in particular for the Task 1.2, Maintenance effectiveness indicators. The responses received were analyzed for identification of areas that are of most interest or concern of European nuclear community and where further research might be useful. To this point the following topics and items should be a subject for the further research activities in this area:

- Representation of the predictive character of maintenance in the maintenance monitoring system;
- Monitoring of contractor performance;
- Material management monitoring (inventory, spare parts, vendors);
- Maintenance budget.

These maintenance aspects need additional analysis for their role in the overall maintenance process taking into account current status of the nuclear industry and the role of the maintenance programme in the strengthening the position of nuclear industry in the competitive energy market.

In addition, the survey results show that further actions in this field should be focused also on the implementation practices. The following practical items are of the most interest of the survey respondents:

- Data collection for the indicators;
- Establishing indicator definitions (plant specific);
- Identification of goals;
- Indicators trending;
- Data display and interpretation;
- Data Base and software.

Table 3 Modified list of maintenance performance indicators

Performance indicators		Comments
System and equipment availability		
1	Component and system unavailability	
2	Total downtime	
3	Scheduled downtime	
4	Unscheduled Downtime	
5	Number of forced power reductions or outages due to maintenance causes	
6	Mean time between maintenance (MTBM)	
7	Mean time to repair (MTTR)	
Reliability of systems and components		
8	Number of corrective work orders issued	
9	Number of failures in safety related systems	
10	Mean time between failures (MTBF)	
PM effectiveness		
11	Preventive maintenance compliance	
12	Ratio of corrective work resulted from PM activities	
13	PM work order backlog trend	
14	Percentage of deficiencies discovered by surveillance, testing & inspections	
15	Ratio of PM activities to all maintenance activities	
16	Overdue of PM activities	
17	Number of jobs planned but not performed*	
18	Number of jobs not started as planned*	
19	Actual versus planned man-hours (per job or totals)*	
Planning & scheduling		
20	Ratio of unplanned to planned working orders	
21	Planning compliance	
22	Schedule compliance	
23	Ratio of corrective work orders executed to work orders programmed	
24	Number of outstanding backlogs (urgent orders)	

Performance indicators		Comments
Interface with operations		
25	Workarounds	
26	Temporary modifications	
27	Ratio of downtime to allowed outage time	
Work control		
28	Duration of repair	
29	Repair time of components subject to the Technical Specifications	
30	Wrench time	
31	Amount of maintenance rework	
32	Response time to call	
33	Overtime maintenance hours	
Material management		
34	Stores service level	
35	No of works pending for spare parts	
36	Stocks inventory turns	
37	Stocked MRO Inventory Value as a Percent of Replacement Asset Value (RAV)	
38	Stocks items available but not used*	
39	Inventory accuracy*	
40	Spare parts and material obsolescence*	
41	Vendor performance*	
Cost effective maintenance		
42	Maintenance cost per kwh produced	
43	Unplanned costs as percentage of total maintenance costs	
44	Overtime maintenance cost	
45	Work orders complete within the determined costs (20%)	
46	Annual maintenance cost as a percent of replacement asset value (RAV)	

* The maintenance performance indicators included in the system based on the survey results (see Table 2 on the pgs. 19-20)

References

[1] SENUF Agreement – Working Group on NPP maintenance, 01 September 2003, Petten.

[2] SENUF-Minutes of meeting, 26-27 January 2006, Petten.

[3] P. Vaisnys, P. Contri, M. Bieth, Monitoring the effectiveness of maintenance programs through the use of performance indicators, Summary Report, DG-JRC- Institute of Energy, EUR 22602, 2006.

[4] SENUF – Minutes of the Steering Committee meeting, April 19-20, 2007, Madrid.

[5] P. Contri, G. Manna, V. Ranguelova, C. Rieg and M. Bieth, Benchmarking study on implemented organizational Schemes, Advanced Methods and Strategies for Maintenance Optimization, Summary Report, DG-JRC-Institute of Energy, 2006.

[6] Safety evaluation of the Paks Nuclear Power Plant in 2002, Annual Report. www.npp.hu/biztonsag/biztert2002ang.htm.

[7] IAEA, Convention on Nuclear Safety, Questions posted to Hungary in 2005, www.haea.gov.hu.

[8] Regulatory control of nuclear safety in Finland, STUK-B-YTO 241, Annual Report, STUK, Helsinki, 2005.

[9] Calculation, assessment and utilization of the NRR indicators, YTV 1.4, STUK, Finland.

[10] IAEA, Economic Performance Indicators for Nuclear Power plants, Technical report Series No. 437, Vienna, (2006).

[11] Levitt. J, Complete Guide To Preventive and Predictive Maintenance, Industrial Press, New York, (2003).

[12] Hai Qiu and Jay Lee, Near-zero downtime: Overview and trends, the University of Cincinnati, USA , (2007).

[13] James C. Fitch, P.E., Proactive Maintenance can Yield More than a 10-Fold Savings Over Conventional Predictive/Preventive Maintenance Programs, http://www.maintenanceresources.com/ReferenceLibrary/OilAnalysis/oa-pm.htm

[14] Ray Beebe, predictive maintenance by performance monitoring of plant, http://www.goldson.free-online.co.uk/techart/MFPT52.htm

[15] Owen Ambur, Monitoring Contractor Performance, University of Maryland, USA, April, (1998).

[16] Partnering with Contractors and vendors to Perform Maintenance Activities, EPRI, Palo Alto, (2003).

[17] IAEA, Integrated approach to optimize operation and maintenance costs, IAEA-TECDOC 1509, Vienna, 2006.

[18] Donel Nyman, Don Levitt, Joel Levitt, Maintenance Planning, Scheduling, and Coordination, Industrial Press Inc., 2001.

[19] IAEA, Surveillance of Items Important to Safety in Nuclear Power Plants, Safety Series No. 50-SG-O8 (Rev. 1), IAEA, Vienna, 1990.

[20] IAEA, Good practices for cost effective maintenance of nuclear power plants, IAEA-TECDOC-928, VIENNA, 1997.

[21] IAEA, Developing an Economic Performance System to Enhance Nuclear Power Plant Competitiveness, Technical Reports Series No. 406, Vienna ,2002.

[22] Spicer, L., PSEG Nuclear, LLC Business Planning process, EUCG Fall conference, New York, USA, 2004.

[23] Demella, J., Spiegelberg-Planer, R., Condu, M., Improving Economic Performance of Nuclear Power Plants, Nuclear Plant Journal, No.1 (2005).

[24] IAEA, Guidance for Optimizing Nuclear Power Plant Maintenance Programmes, IAEA-TECDOC-1383, IAEA, Vienna ,2004.

[25] IAEA, Strategies for Competitive Nuclear Power Plants, IAEA-TECDOC-1123, IAEA, Vienna (1999).

Annex

Maintenance performance monitoring through the use of performance indicators (Survey of maintenance experience)

№	Subject	Yes	No	Comments*
1	Do you use the maintenance performance indicators at your organization (plant, utility)?			
2	Do you have the separate maintenance monitoring system at your organization,			
	or the maintenance performance indicators are the part of overall performance indicator system?			
3	Does your maintenance performance indicators system consist of: • Single performance indicators?			
	• More advanced system with several groups or categories?			
	• Part of the asset management system?			
4	What performance indicators are in use at your organization from the list attached? (see Attachment)			
5	How long do you utilize the maintenance performance indicators system at your organization:			
	• Less then 1 year?			
	• Between 1 and 3 years?			
	• Between 3 and 5 years?			
	• Between 5 and 10 years?			
	• More then 10 years?			

№	Subject	Yes	No	Comments*
6	Do you issue the maintenance performance monitoring reports (based on the analysis of maintenance performance indicators)? What periodicity:			
	• Once per year?			
	• Once per quarter?			
	• Other periodicity?			
7	Do you use the specific Data Base for the maintenance performance indicators?			
8	Do you use the specific software to process the maintenance performance indicators?			
9	Did you assign the specific person (group) at your organization to coordinate (maintain) the maintenance performance indicators system?			
10	Are you planning to implement (update, modify) the maintenance performance monitoring system at you organization within 1-2 years period. What are the main aspects of the implementation (update):			
	• To implement new system?			
	• To increase the number of performance indicators?			
	• To install the specific software ?			
	• To establish the data base (upgrade data base)?			
	• Other modifications			

Note: We kindly appreciate if your comments will exceed the physical bounds of the cells of the table. Your extended information on the matters concerning any aspect of the application of the maintenance monitoring system is the invaluable contribution into overall exchange of the best maintenance practices.

Attachment

List of maintenance performance indicators*that are in use in different industrial sectors worldwide

Performance indicators		Yes	No	Comments
System and equipment availability				
1	Component and system unavailability			
2	Total downtime			
3	Scheduled downtime			
4	Unscheduled Downtime			
5	Number of forced power reductions or outages due to maintenance causes			
6	Mean time between maintenance (MTBM)			
Reliability of systems and components				
7	Number of corrective work orders issued			
8	Number of failures in safety related systems			
9	Mean time between failures			
10	Mean time to repair (MTTR)			
PM effectiveness				
11	Preventive maintenance compliance			
12	Ratio of corrective work resulted from PM activities			
13	PM work order backlog trend			
14	Percentage of deficiencies discovered by surveillance, testing & inspections			
15	Ratio of PM activities to all maintenance activities			
16	Overdue of PM activities			
17	Number of jobs planned but not performed			
18	Number of jobs not started as planned			
19	Actual versus planned man-hours (per job or totals)			
Planning & scheduling				
20	Ratio of unplanned to planned working orders			
21	Planning compliance			
22	Schedule compliance			

Performance indicators		Yes	No	Comments
23	Ratio of corrective work orders executed to work orders programmed			
24	Number of outstanding backlogs (urgent orders)			
25	Planner to craft work ratio			
Interface with operations				
26	Workarounds			
27	Temporary modifications			
28	Ratio of downtime to allowed outage time			
29	Number of MCR instruments out of service			
Work control				
30	Duration of repair			
31	Repair time of components subject to the Technical Specifications			
32	Wrench time			
33	Crew efficiency			
34	Amount of maintenance rework			
35	Supervisor to Craft Worker Ratio			
36	Response time to call			
37	Overtime maintenance hours			
Material management				
38	Stores service level			
39	No of works pending for spare parts			
40	Stocks inventory turns			
41	Stocked MRO Inventory Value as a Percent of Replacement Asset Value (RAV)			
42	Average spares and tools waiting time.			
43	Stocks items available but not used			
44	Inventory accuracy			
45	Spare parts and material obsolescence;			
46	Vendor performance			
Cost effective maintenance				
47	Maintenance cost per kwh produced			
48	Unplanned costs as percentage of total maintenance costs			
49	Work orders complete within the determined costs (20%)			

Performance indicators		**Yes**	**No**	**Comments**
50	Ratio of replacement asset value (RAV) to craft/wage head count			
51	Annual maintenance cost as a percent of replacement asset value (RAV)			

***Please indicate by 'Yes' or 'No' in the appropriate cell what indicators are used in your organization. If definition of the indicator in the table differs from that used in your organization please make a note in the column 'comments'. Definitions for the majority of the maintenance performance indicators in the list can be found in the EU Report 22602 EN 'Monitoring the effectiveness of maintenance programs through the use of performance indicators'.**

European Commission

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Benchmarking study of maintenance performance monitoring practices

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Abstract:

This Report summarizes the results of a research carried out in the year 2007 under the SONIS (Safety of Nuclear Installations) programme for 2007, Task 1.1.1, Maintenance effectiveness indicators and risk monitors. The research was based on the survey of the experience of European nuclear utilities in the use of maintenance performance indicators at selected European nuclear utilities. The survey results proved the validity of the specific maintenance performance indicators selected for the maintenance performance monitoring framework proposed by IE/JRC and published in the EU Report 22602. The results obtained provide good basis for the further development and implementation of the proposed maintenance monitoring system. The analysis of the survey results revealed additional maintenance aspects critical to the effectiveness of maintenance programme. All these topics will be carefully analysed in the next steps of the research in connection to their coverage in the maintenance monitoring system and identification of critical items that could be subject for the further activities in the SONIS Research program.

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