Qualified Maintenance - An Approach for Cutting Costs in Power Plants

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ABSTRACT

Maintenance work is defined as all activities in a power plant which serve to ensure safe and trouble-free production of electricity. These include activities relating to:

* Probabilistic and safety analyses and
* All analyses of the pressurised enclosure, for example component evaluations with regard to mechanical fractures,
* Overall plant maintenance, such as lubricating rotating components in accordance with operational requirements
* testing of equipment and
* Cleaning components and operating facilities.

The "scheduled maintenance" which was standard practice in the past has resulted both in a high level of plant availability and in good safety ratings in respect of operational malfunctions. The maintenance schedule was based on the component manufacturers' maintenance recommendations and on the requirements of the inspectorates in relation to power plant operation. The safety margins which came to be incorporated in the maintenance activities over time were either not quantified at all by the maintenance personnel or only to a very limited extent. This is understandable because the rigid framework of scheduled maintenance imposes severe restrictions on their responsibility for their own actions. The procedure is extremely labour-intensive, however, and necessitates a large number of spare parts. Although it helps to boost the sales of component suppliers, it is very costly for the electricity producers.

Market deregulation, along with decontrolled electricity prices, also means that a permanent 15 % increase in maintenance efficiency is demanded of the power plant operators. This work describes how this has been achieved at EnBW Germany, with reference both to its organisation and to its better qualified maintenance procedures, with the introduction of a condition-based maintenance concept. The efficiency improvements brought about by individual measures are quantified.

INTRODUCTION AND OBJECTIVES

Nuclear power plants with boiling and pressurised-water reactors (BWR and PWR) are in operation in Germany for more than 30 years. In terms of safety and availability their importance for safeguarding electricity supplies in the base-load sector is undisputed. The availability of German nuclear power plants has increased to more than 90 % over the commercial service period, Fig. 1 [1]. The key factors behind this development are as follows:

* High technical reliability of the systems and components,
* The frequent incorporation of plant modifications in line with the latest state of the art (Nuclear Power Act [2]),
* The reduction in time by burn elements exchange from 45 days/year originally to 17 days/year today [3].

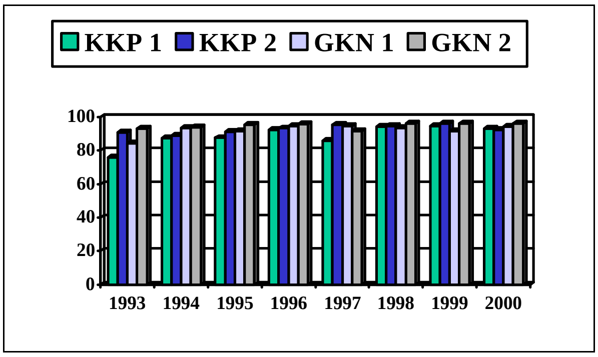


Fig. 1 Availability of KKP and GKN plants

The outcome of these measures is that German nuclear power plants regularly feature in the "top ten" list of the world's best [4]. Further efforts to improve the economic efficiency of nuclear power plants became necessary when the electricity markets were opened up - the German market has been completely deregulated since 1998 - though of course this had to be done without compromising the existing high safety standards in any way. One very effective measure for securing a lasting improvement in profitability is to optimise maintenance activities.

This strategy includes the following tasks

1. Measures for determining and assessing the condition of the technical equipment
2. Measures for preserving and restoring the specified condition of the technical equipment
3. Component maintenance adapted to operational needs
4. An organisational structure tailored to the maintenance process

EnBW has decided to conduct a detailed review of the content and costs of the above-mentioned tasks. The envisaged results will serve as a basis for a future realignment of maintenance schedules.

DATA COLLECTION

EnBW operates two light-water reactor (LWR) units at the Philippsburg site:

* One BWR unit with an output of 900 MW_{el} and
* One pre-convoy PWR unit with an output of 1,400 MW_{el}.

In order to ensure safe and reliable plant operation, a total of 16,329 maintenance activities need to be performed for the two units in the areas of mechanical/electrical components as well as instrumentation and control (8,620 activities for the BWR unit and 7,709 for the PWR unit). 40 % of there activities (6,660) are testing procedures. Fig. 2 specifies the number of activities in relation to different interval lengths.

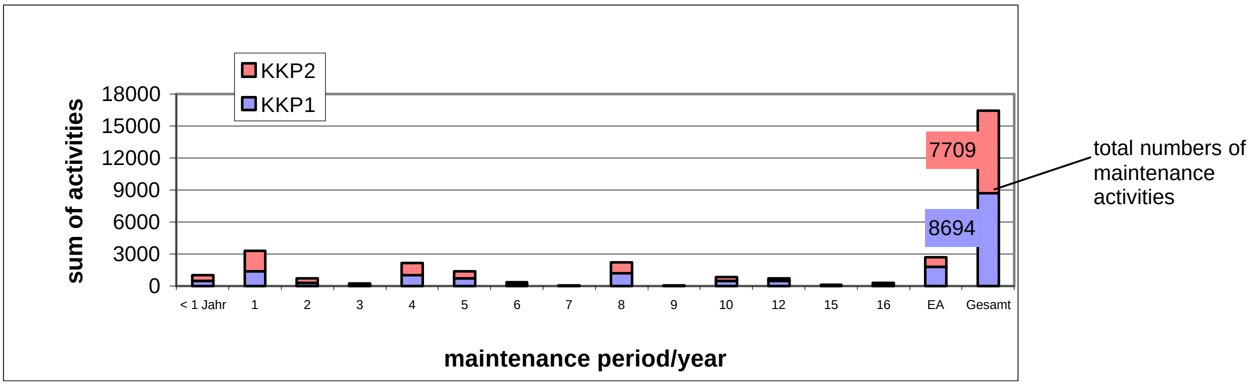


Fig. 2 Number of activities in different maintenance periods

Estimated costs based on previous work expenditure in the field were allocated to each of the 16,329 activities. These cost estimates were then converted to specific costs per year, Fig. 3. It can be seen from the diagram that the most expensive maintenance activities are those performed several times each year. The costs for activities with a periodicity of ≤ 1 are on average five times as high as the mean costs for all activities, see figure 3 (rightest column). It is moreover clear that no more than 40 % of the annually incurred maintenance costs are the result of work in the field. The remainder, in other words 60 % of the overall costs, is expended on work preparation and on coordinating/evaluating the results. This leads us to conclude that it would be worthwhile examining the steps that go to make up each activity again.

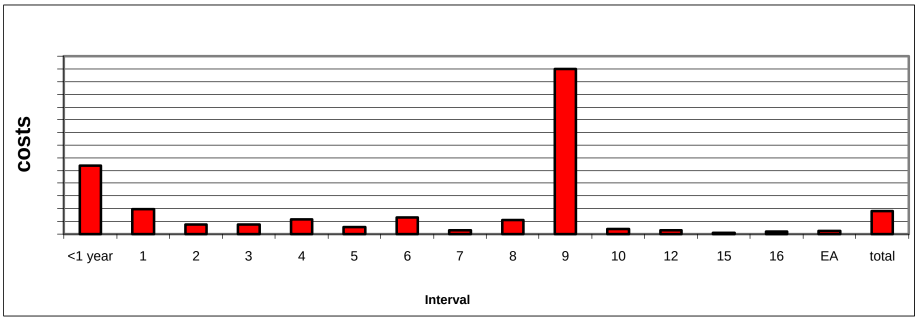


Fig. 3 Specific costs per year as a function of interval length

One of the most significant results of this study is that approximately 80 % of incurred maintenance costs are expended on components which are not safety-relevant. This means that any changes to the content and frequency of maintenance activities can be made autonomously without involving experts at the inspectorates.

15.5 % of costs can theoretically be eliminated by doubling the length of the activity intervals. This means that work expenditure can likewise be cut by 15.5 %.

CLASSIFICATION OF SYSTEMS AND OPTIMISATION MEASURES

With a view to optimising maintenance activities, a ranking list of the 48 most expensive systems for each of the two units (BWR: total 267 systems, PWR: total 550 systems) was drawn up on the basis of the costs measured for the individual activities, Fig. 4 and 5. The prices indicated here are the actual costs incurred for maintenance (full costs). As can be seen from the end total for the activities, these systems account for approximately 76 % of all annual maintenance expenditure (approxe metally 25 Mio. €/year, each block).

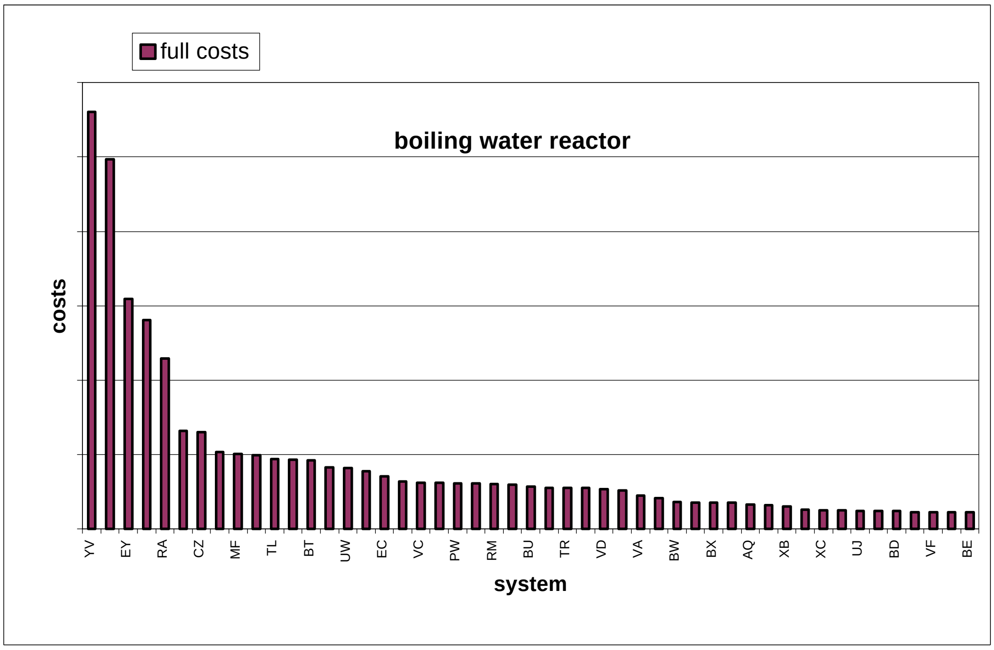


Fig. 4 Total cost for the fifty most expensive systems in boiling water reactor

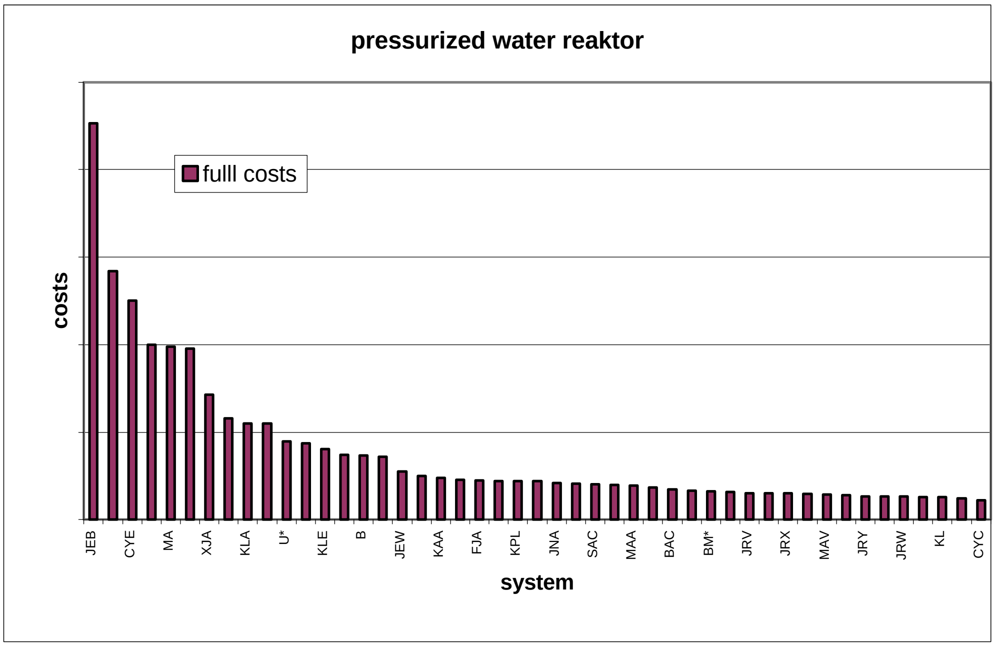


Fig. 5 Total cost for the fifty most expensive systems in pressurized water reactor

In the first phase, system engineers and maintenance managers collaborated in reviewing the content and frequency of individual maintenance activities on the basis of past experience (25 years), before implementing changes in the form of new maintenance schedules. The probabilistic method was employed for maintenance procedure changes to safety-relevant systems. The yardstick by which the reliability of each change is measured is the statutory failure probability limit, namely 10^{-5} to 10^{-6}/year.

This first phase enabled 12 % of the costs for ventilation systems to be decreased. The same procedure is also taking place for the remaining systems under the leadership of the system engineers. Optimising maintenance activities in safety-relevant systems with the help of probabilistic calculations entails additional work as well as discussions with the inspecting authorities. This work is being conducted in parallel; detailed results are not expected to be available for another two years.

USE OF DIAGNOSTIC METHODS

Diagnostic methods such as

- Evaluation of alarms, occurrences,
- Vibration measurements,
- Validation of operating data,
- Infrared measurements,
- Fatigue Monitoring System (FAMOS) etc.

are used, Fig. 6 [5]. If full use of all the diagnostic systems installed in the nuclear power plants, reliable information about the condition of the plants as a whole can be obtained.

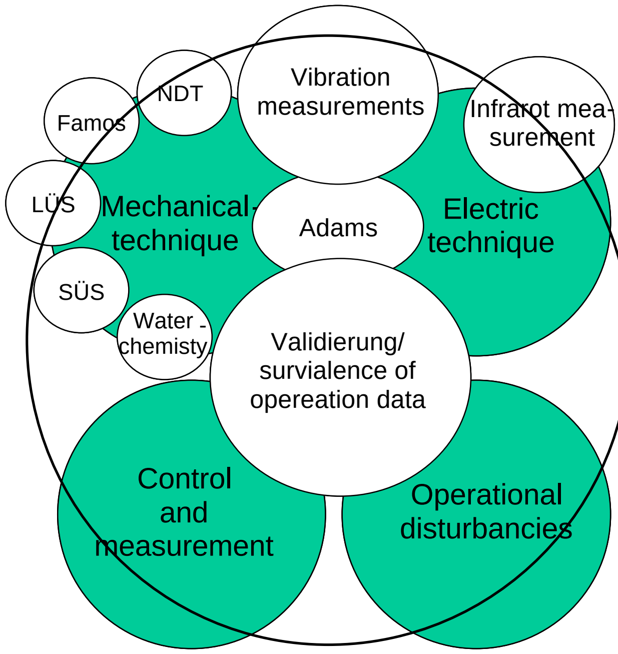


Fig. 6 Different diagnostic systems installed in NPP

Evaluation of alarm occurrences

A systematic evaluation of alarms provides basic information about the plant during the commercial service period. This information allows potential trouble spots to be eliminated, either by replacing the components concerned or by modifying their mode of operation. In all such cases it is also important to keep a continuous track on the information received from other (world wide) plants. The data supplied by older plants is extremely relevant to the choice of preventive measures for newer plants (for instance, the stratification problem in the feed water pipes of BWR and PWR plants) [6].

Vibration measurements

Vibration measurements are used to diagnose rotating assemblies. By evaluating the recorded signals using a Fourier analysis, it is possible to obtain information about the "running performance" of these assemblies. Economical implementation of vibration measurements for rotating equipment analysis in to the scale of plant maintenance procedure based on a combination of preventive and condition – based maintenance rules, Fig. 7.

Finger print measurement after start-up of rotating equipment build a data bases for the future. According experience the planed overhold is estimated in x-year. In the time (X – 1) year restarting of vibration diagnosis enable comparison of measured data with finger print data. In the case that new data are qualitative and quantitative comparable with original data about ability of the equipment be operate longer than previously planed can be assumed. Overhauled will be postponed about 1 year. During this time vibration diagnostic follow the operating conditions steadily. This procedure can be repeated so long till some findings will be registrated. After this the postponed preventive maintenance measure will proceed.

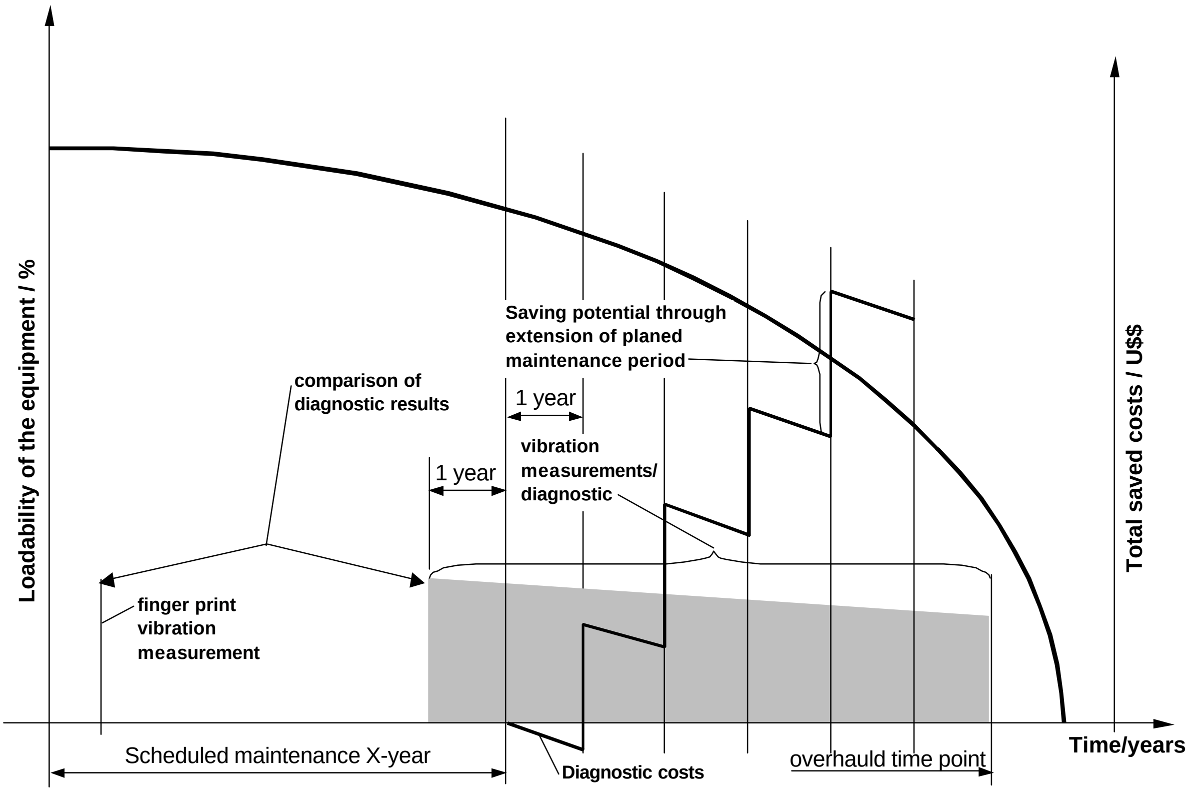


Fig. 7 Use of diagnostic in combination with preventive maintenance measures

Reconciliation of operation data

The thermal reactor output of all nuclear power plants is subject to statutory limits. Thermal reactor output is calculated mainly on the basis of the measured feed water flow. Like all measured values, these figures include certain tolerances. In order to ensure that the computed value is reliable, a "positive tolerance" is added to the values used for the calculation. In some plants the calculated reactor output is higher than the actual output. To reduce this tolerance margin (and increase the electrical output), the mass and energy balances of the complete power plant (primary and secondary) have to be determined by means of operational measurements, that is to say they must be validated. This is done by some plants in Germany online at 15-minute intervals. As confirmed by data validation systems that are already installed online [7, 8], the PWR output values can be as much as 40 MW_{th} (i.e. approximately 13 MW_{el}) less than those calculated on the basis of actual measured values. In the same amount the real power plant output (~ 13 MW_{el}) can be increased. Over the presently customary commercial service period for plants of this kind (cca. 25 years), this represents by not using the validation a financial loss equivalent to several million EURO/plant till today.

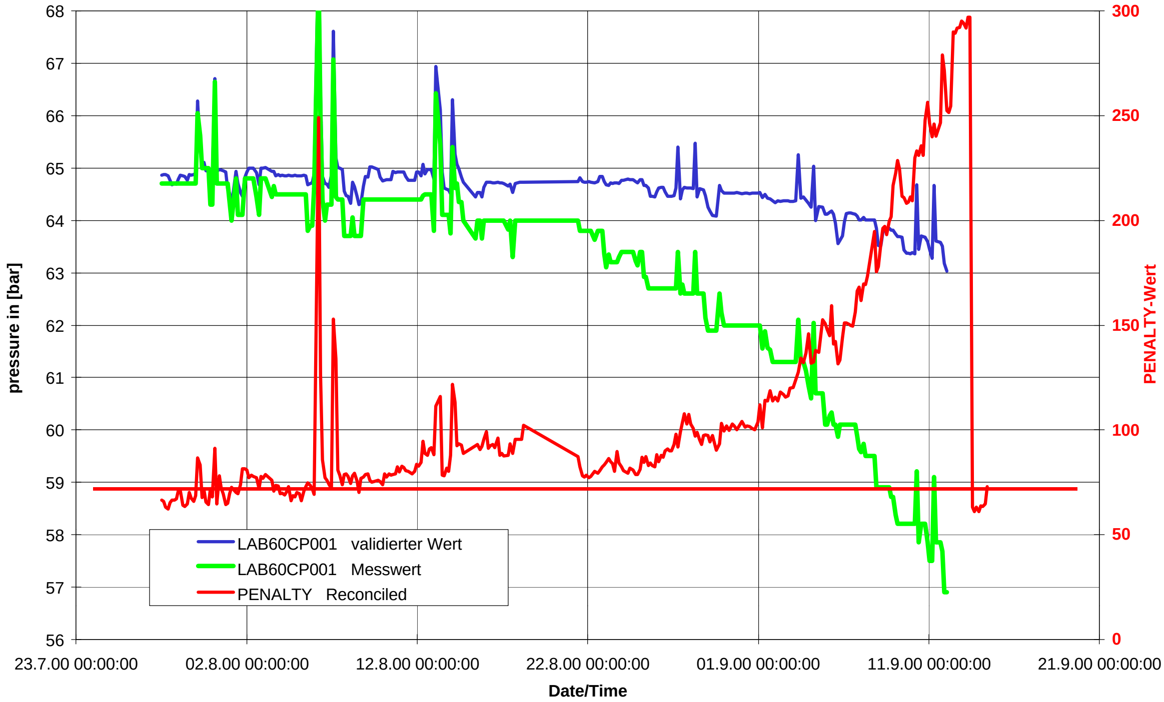


Fig. 8 Report for defect pressure transducer in feedwater pipe before the steam generator

Installing an online data validation system also facilitates savings when individual measuring systems are calibrated according validated results. How sensitive validations of individual measurements actually are can be seen from the example of the pressure indication upstream of the steam generator in Fig. 8. The data validation system predicted the slow drift of the measured value very early on in the form of a higher penalty. After this indication a failure in measuring device was discovered. The savings which can be achieved with data validation in connection with FAMOS (Fatigue Monitoring System) are shown in the tables in Fig. 9 and 10. The savings obtained simply from no longer having to calibrate additional instruments amount to EURO 0.21 million per year for the two plants was estimated.

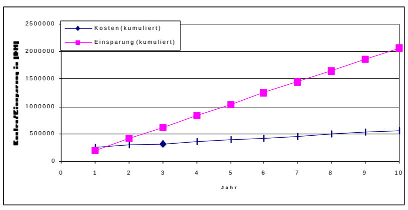
WPA-Nr	Beschreibung	Abschätzung KKP1		Intervall	Diagnose
		Mannstunden	in DM		
3-E3527-FP001	JP-Zusatzschränke für Messungen Famos-Meßwerterfassung 1 JP 32/33 RA-YV	260 Meßstellen je 3,5 h = 910 h	91000	3 Jahre	Datenvalidierung
1-E1427-FP001.90	Sicherheitstechn. wichtige Meßstelle	84 Meßstellen je 3,5 h = 294 h	29400	1 Jahr	Datenvalidierung
1-E-3851-*	Instrumentierung		44700	1 Jahr	Datenvalidierung

Gesamt	104433	1 Jahr
Gesamt Vollkosten	229753	1 Jahr

Kosten/Nutzen Analyse

Jährliche Einsparung durch Diagnose: 90 % von 229.753 DM = 206.777 DM
Kosten einmalig für Einführung der Diagnose: 220.000 DM
Jährliche Kosten durch Kalibrierarbeiten: 23.000 DM

Kosten (kumuliert)	Einsparung (kumuliert)	Gewinn/Verlust
1. Jahr: 220.000 DM + 11.250 DM (Wartung) + 23.000 DM (Kalibrierkosten) = 254.250 DM	206.777 DM	-47.473 DM
2. Jahr: 254.250 DM + 11.250 DM + 23.000 DM = 288.500 DM	413.554 DM	125.054 DM
10. Jahr: 562.500 DM	2.067.770 DM	1.505.270 DM



pay back time: 1 year 4 month

Fig. 9 Saving potential using data reconciliation instead of periodical calibration of measuring devices in KKP1

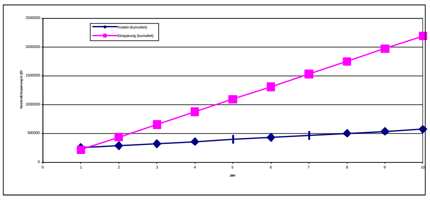
WPA-Nr	Beschreibung	Abschätzung KKP2 Mannstunden	in DM	Intervall	Diagnose
3-JYL 41.10	Ermüdungsüberwachungssystem FAMOS	378 Meßstellen je 3,5 h = 1323 h	132300	3 Jahre	Datenvalidierung
1-C..41.*	Sicherheitstechn. wichtige Meßstelle		15900	1 Jahr	Datenvalidierung
2-C..41.*	Wichtige Meßkreise		50600	1 Jahr	Datenvalidierung

Gesamt	110600	1 Jahr
Gesamt Vollkosten	243320	1 Jahr

Kosten/Nutzen Analyse

Jährliche Einsparung durch Diagnose: 90 % von 243.320 DM = 218.988 DM
Kosten einmalig für Einführung der Diagnose: 220.000 DM
Jährliche Kosten durch Kalibrierarbeiten: 24.300 DM

Kosten (kumuliert)	Einsparung (kumuliert)	Gewinn/Verlust
1. Jahr: 220.000 DM + 11.250 DM (Wartung) + 24.300 DM (Kalibrierkosten) = 255.550 DM	218.988 DM	-36.562 DM
2. Jahr: 255.550 DM + 11.250 DM + 24.300 DM = 291.100 DM	437.976 DM	146.876 DM
10. Jahr: 575.500 DM	2.067.770 DM	1.614.380 DM



pay back time: 1 year 2 month

Fig. 10 Saving potential using data reconciliation instead of periodical calibration of measuring devices in KKP2

Infrared measurements

Include both a digital photograph of the object and an infrared photograph, are vital here, Fig. 11. These two photographs should be taken from the same angle, to ensure that they are absolutely comparable. The next infrared measurement interval is fixed on the basis of the last measured actual condition. The feed water pump safety device shown in Figure 11 exhibits severe overheating in one phase. Providing this fault is detected at an early stage, the pump can be shut down before the fault causes it to fail completely. The infrared measurements of the electrical equipment are crucial to the safety and availability of the units.

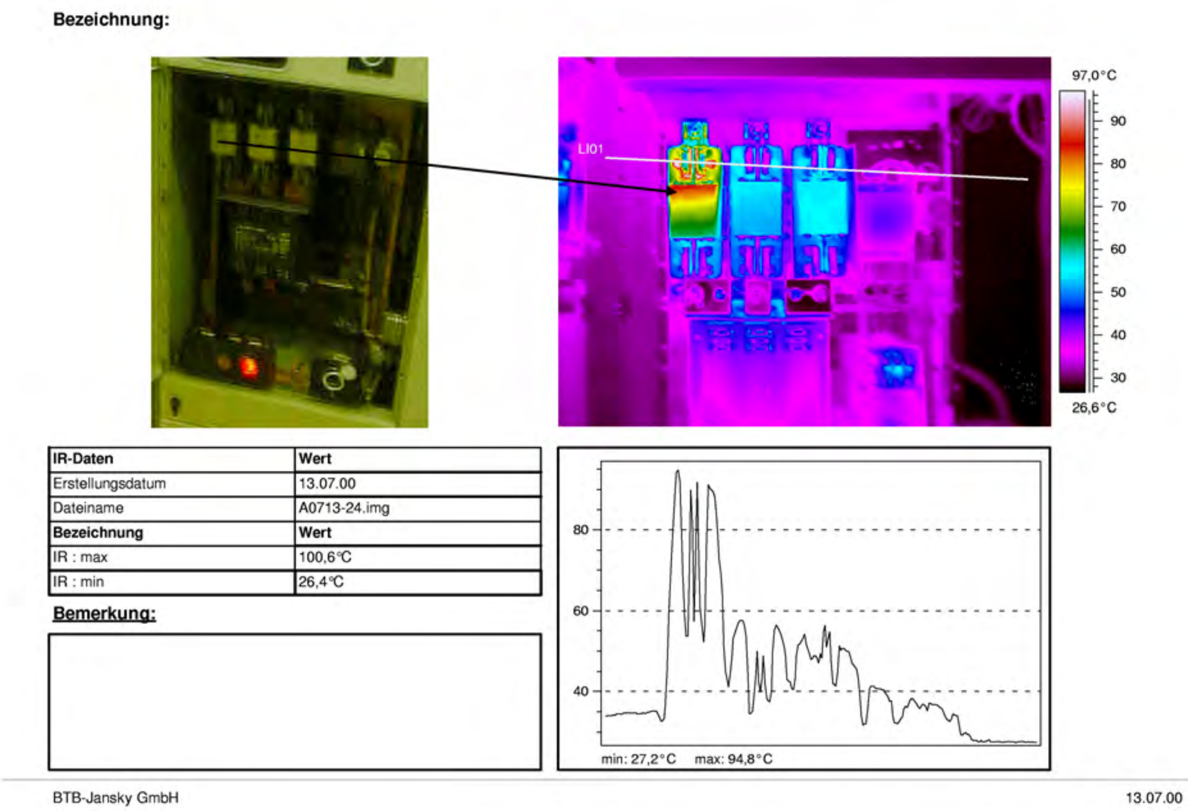


Fig. 11 Infrared diagnostic report for overheated pump safety protection device

Fatigue Monitoring System (FAMOS)

The pressure retaining component in horizontal piping sections is fitted with additional thermocouples applied on the pipe circumference (outside) [7]. Under certain operating conditions cold and hot pressurised water in the pipe cross section may be separated there (flow stratification). At these pipe areas through repeated temperature differences, cracks may develop on the inner surface and may subsequently propagate to the outside surface of the pipe (possibly leakages).

Non-destructive testing should concentrate on those areas in which ΔT are measured. If, on the other hand, no temperature differences have been measured in the past, it can be assumed that cracks cannot possibly develop in these areas. It may consequently be possible to dispense with prescribed non-destructive tests here.

SUMMARY OF THE RESULTS SO FAR

The survey of the costs for individual maintenance activities in two nuclear power plant units revealed the following information

- The most expensive activities are those with a periodicity ≤ 1 year,
- Maintenance of the 48 most expensive systems accounts for approximately 76 % of the total costs/year,
- Only around 40 % of all maintenance costs are incurred for activities actually in the field,
- Approximately 80 % of the total costs are incurred for plant components which are not safety-relevant (in other words not subject to inspections by the authorities).

These findings indicate that by

- Fixing longer intervals,
- Harmonising activities (performing electrical, I&C and mechanical maintenance simultaneously),

it is possible to reduce the costs for maintenance. This applies above all to the most expensive activities (those with the highest maintenance periodicity), which account for approximately 50 % of the total costs. Specific results were cited as an example: in one system section it has been possible to reduce the costs "instantly" by around 12 %, simply as a result of discussing experiences within the framework of a working party.

Concentrating the optimisation measures on the 30 most expensive systems enables work on optimisation to progress rapidly. Introducing diagnostic maintenance methods (in other words, changing over from preventive maintenance to condition-based maintenance) permits costs to be cut, while at the same time providing additional information about the condition of the plant and its components. It is, however, always essential to weigh up whether introducing a system of this kind is ultimately cheaper than traditional, preventive maintenance (cost-benefit analysis). Without cost benefit analysis, based on detailed cost knowledge, no decision for or against condition based maintenance can be done.

CONCLUSIONS

The approach for optimising maintenance work in the Philippsburg nuclear power plant by influencing the prices of individual systems is proving successful. Initially, activities in the most expensive system areas are being selectively reviewed and optimised.

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