Life Time Management of Mechanical Components

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ABSTRACT

Mechanical systems and components of nuclear power plants can be classified / ranked into three major groups, in principle:

(1): The quality status of the components in this group has to be guaranteed on a pre-defined (high) level.
(2): The quality status of the components in this group has to be maintained on its actual level.
(3): Other components with no specific demands on quality.

Life time management / ageing management is necessary for the first two of above groups; the quality status covers both integrity and function . Life time management of mechanical components consists of a bundle of technical and organization measures that enables a utility to control damage mechanisms of the selected systems and components during operation. The measures have to be applied within the frame of an overall procedure.

Regarding the first group, it is necessary to monitor the possible causes of damage in operation; thus the damage mechanisms can be assessed and controlled and the safety standard is maintained on the demanded high level without compromise. The monitoring of results of damage mechanisms is only a redundant measure.

The demand to maintain the quality status of the second group of components can be fulfilled by maintenance, tests, inspections and repair, using either a time dependant procedure or predictive maintenance methods, if there is enough experience.

A consequent life time management reduces resp. eliminates the negative effects of the ageing phenomena

- ageing of the basic concepts,
- ageing of technology and
- ageing of materials.

This paper summarizes the actual procedure for life time / ageing management of mechanical components in the German nuclear power plant GKN.

INTRODUCTION

Integrity and function of important systems and components of nuclear power plants have to be guaranteed or at least maintained for the entire period of operation. The demands on integrity and function determine the necessary quality status of a system or a component.

The basis of the necessary quality status is reached in the state of design using demands from standards and specifications, specified material characteristics, specified medium and loads and simplified boundary conditions. During the process of manufacturing this designed quality has to be established and proven.

The primary goal of the analysis in the state of design is to demonstrate that the results are within given limits. It is obvious that this formal and often very “conservative” procedure (in specification and in analysis) does not allow to draw conclusions regarding the state of integrity after a given period of operation. The integrity and function of a component in operation (safety, remaining life) is determined by the real operation history. In almost every system there are not specified load transients, e.g. stratification in the surge line, in the main coolant loop and in feedwater piping systems. Therefore a quantification of the state of quality of a component after a certain period of operation can only be made if there is an intensive monitoring of the operation parameters, so that those effects can be assessed realistically.

The quality status of a system or a component can be affected by changes in demands (e.g. standards) and by changes in knowledge, too. This has also to be considered during the period of operation.

A consequent procedure is necessary to consider all possible negative impacts on component safety resp. integrity and function. This procedure is called life time management or ageing management and it has to cover both technical and organisation tasks. Ageing management or the guarantee of the integrity of a component implements two tasks: first, it must be demonstrated, that the quality state of the component (i.e. the actual state of integrity) is high enough to match the demands; second, a qualified set of measures must be established to guarantee future operation, to limit possible damage mechanisms.

Using the procedure and the experience of the German nuclear power plant GKN – a utility with 900 MW-plant (over 20 years old) and a second 1200 MW-plant (over 10 years old) – as an example, the demands on an ageing management system are summarized in this paper.

AGEING PHENOMENA AND MEASURES TO REDUCE / ELIMINATE THEIR EFFECTS

Regarding components and systems in operation, three different ageing phenomena have to be considered generally, **Fig. 1**:

- ageing of the basic concepts,
- ageing of technology,
- ageing of materials.

The ageing of the basic concepts includes changes the demands on a system and changes in the overall safety philosophy which result from experience (incidents, faulted conditions etc.). The existing status of systems and components has to be analysed periodically (e.g. in the frame of a periodic safety analysis). If there are deficits, components must be replaced or even new systems have to be built in.

ageing of concept	**ageing of materials**
changes in demands	*damage mechanisms in operation like:*
changes in safety philosophy	material embrittlement
	material fatigue
ageing of technology	corrosion
new knowledge about:	wear
possible damage mechanisms	combination of above mechanisms
materials and design characteristics	*causes are in general:*
test procedures	material (degradation)
procedures for analysis	load history
calculation procedures	medium / environment history

Fig. 1: Ageing phenomena

The ageing of technology is caused by changes in knowledge, e.g. regarding possible damage mechanisms, material or component characteristics, test procedures, calculation procedures. These changes in knowledge result from research or product development projects or from analysis of operation experience. For a careful analysis detailed evaluation of the existing design (as built – not from specification) and realistic load histories are necessary. As consequence of the analysis the operation procedure may be changed, it may be necessary to optimise the component and its bearing constructions or even replace it.

Ageing of materials is a result of damage mechanisms in operation. Generally, changes of material characteristics, loads and medium cause material damage like material degradation, fatigue, corrosion, wear and combinations. Obvious results of these damage mechanisms can be changes in material behaviour, changes in surface structure, notches, crack initiation, crack growth, leakage, malfunction etc.. For systems and components where these damage mechanisms have to be under control, monitoring is the most appropriate measure. Monitoring of the *causes* for damage has significant advantages over monitoring of the *results* because there is the possibility to reduce the damage mechanism itself in time rather than to prevent follow-up failures.

BASIC DEMANDS REGARDING COMPONENT QUALITY IN OPERATION

One of the first actions in life time management / ageing management is the classification of the systems resp. the components. Three groups can be defined:

- group 1: The quality status of the components in this group has to be guaranteed on a pre-defined (high) level.
- group 2: The quality status of the components in this group has to be maintained on its actual level.
- group 3: Other components with no specific demands on quality.

For the first group (*guarantee of integrity*) the basic demands are given by the "*leak-before-break*"-concept, **Fig. 2**. The basis is a good quality after production (design and manufacture); this quality has to be guaranteed on this high level using independent redundancies to keep operation effects and other parameters of influence under control. This concept can be applied not only to new components (as initially intended) that are designed according to the latest standards recommendations but also to components after a certain time of operation. In this case, it is necessary to

- review the existing quality status on the base of actual standards´ demands and on the base of actual knowledge. Then this
- quality has to be guaranteed in future operation using appropriate redundant measures.

<table>
<tr><th colspan="5">component integrity</th></tr>
<tr><th>design and manufacture</th><th colspan="4">operation</th></tr>
<tr><td rowspan="3">quality through production</td><th colspan="2">monitoring of damage mechanisms</th><th colspan="2">consideration of changes in</th></tr>
<tr><td>causes</td><td>results</td><td>knowledge</td><td>safety analysis</td></tr>
<tr><td>loads
environment
change of material charcteristics</td><td>wall thickness
notches
cracks
crack growth
leakage
fracture</td><td>research
development
standards
experience</td><td>technology
fracture mechanics</td></tr>
<tr><th>basis safety</th><th colspan="4">independent redundancies</th></tr>
</table>

Fig. 2: Component integrity

This concept can also be applied to components that do not match the latest design demands of the standards (i.e. older design); in this case it has to be demonstrated that the stresses in the component are within strict limitations and there are no other damage mechanisms. The redundant measures can compensate for some deficits in design.

In this first group there are all the components that are important for the safety of a nuclear power plant, especially those that have no redundancy (e.g. nuclear pressure vessel). Additionally, analysis may show that follow-up effects (e.g. of a double ended failure of a piping system) cannot be treated in a technical and economical reliable manner; therefore economical reasons can be of influence while selecting the group of components, too. **Fig. 3** gives some more parameters affecting the selection of components and systems, **Fig. 4** shows the systems and components that are classified in this group at GKN.

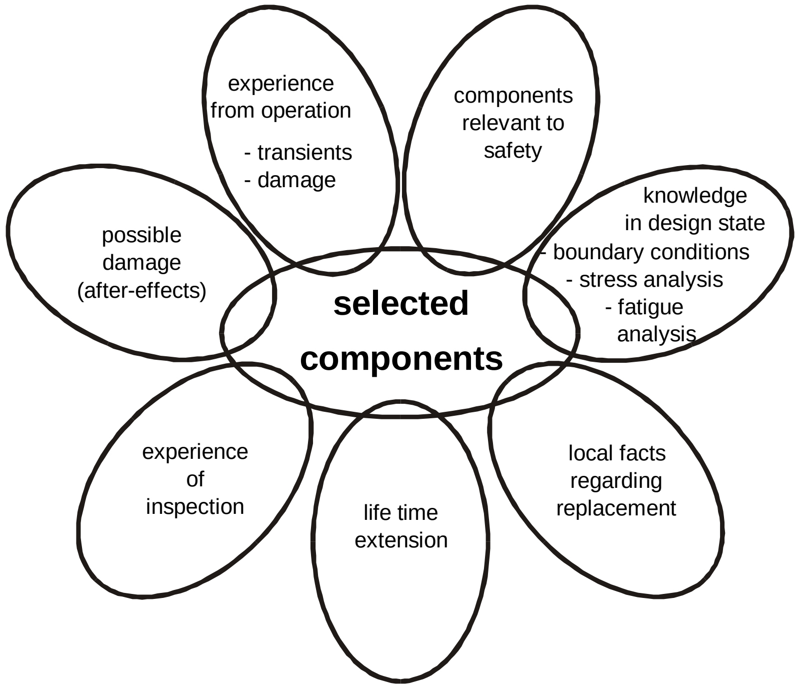

Fig. 3: Parameters for the selection of components and systems

In safety relevant systems that are built in with redundancy components may fail, at least theoretically, supposed that the follow-up failures can be managed. However, because they are safety relevant and their failure would raise too many problems, their quality status has to be maintained. This is the second group of components in above classification. Maintaining the quality in this case means that the components are tested and inspected regularly, so that maintenance, repair or exchange of parts can be managed in time, i.e. before failure. Again, as it is the case in the first group, economical aspects can be the reason to classify a component in this system, too.

All other components are classified in the third group. A failure of a system or a component in this group is not relevant to safety and to economical aspects of operation.

TECHNICAL MEASURES FOR AGEING MANAGEMENT

Guarantee of Integrity (Group 1 of Systems and Components)

As said above, the quality status of the systems and components of this group has to be reviewed first by

- determination of possible damage mechanisms,
- assessment of the component as-built, regarding design, materials, supports, testing etc.,
- determination of the relevant loads (operation from monitoring, faulted conditions from specifications),
- assessment of the safety status using stress analysis, fatigue analysis and fracture mechanics analysis.

The primary goal of this review is to demonstrate that the existing quality status is high enough to meet the demands, if necessary, supported by a set of additional redundant measures. In a subsequent step, this quality status has to be guaranteed by

- monitoring of causes and results of damage mechanisms,
- continuous assessment of the change in knowledge.

It is necessary to follow a consequent procedure to guarantee integrity of systems and components. e.g. the procedure of GKN in **Fig. 5**. This iterative procedure plays a key role in life time management in GKN. As shown, extensive monitoring of the loads (major cause for damage) is performed using global (plant instrumentation) and local (specially applied transducers) measurement points. The results of this monitoring and those of the monitoring

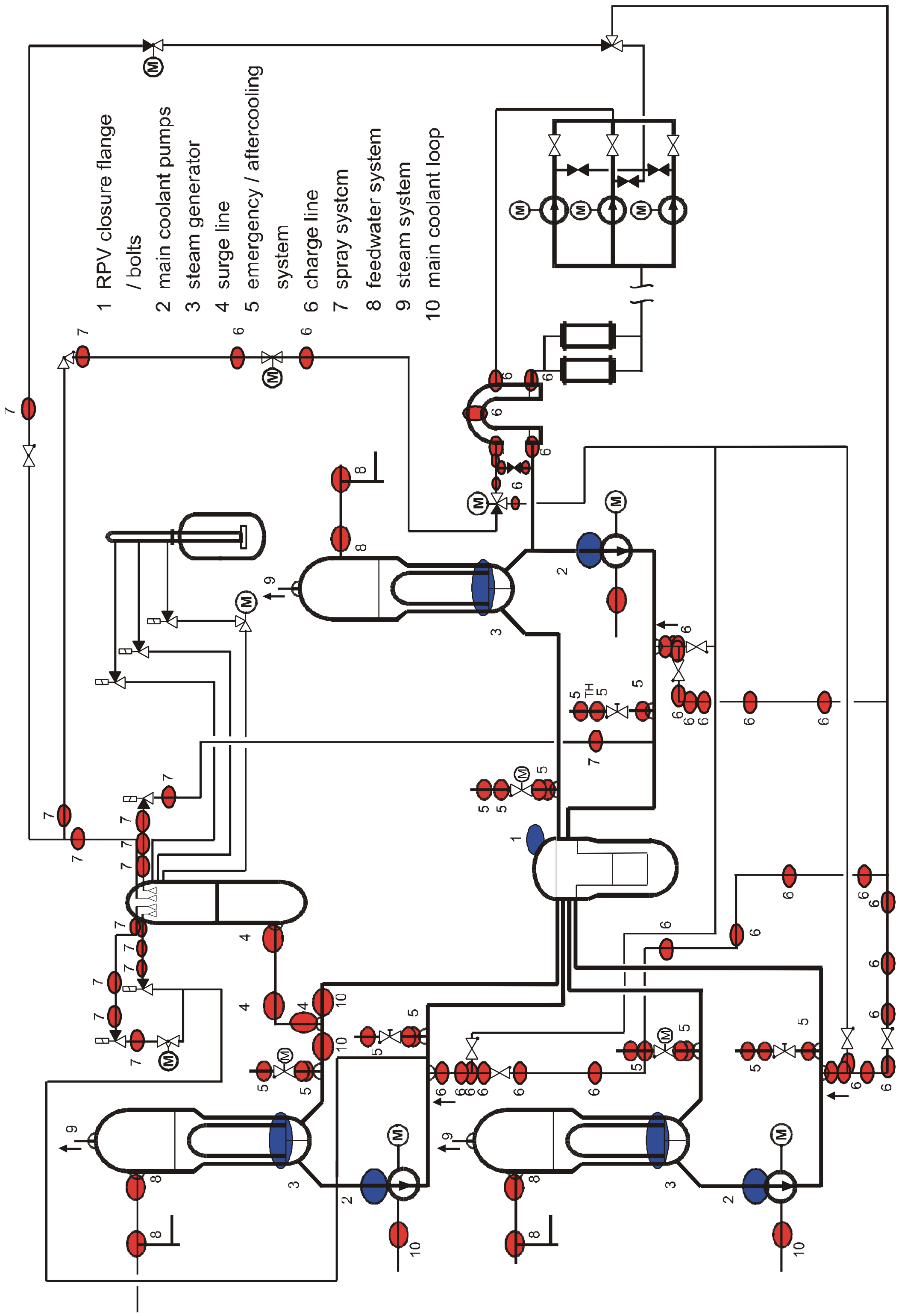

Fig. 4: Regions of systems and components with global and local monitoring

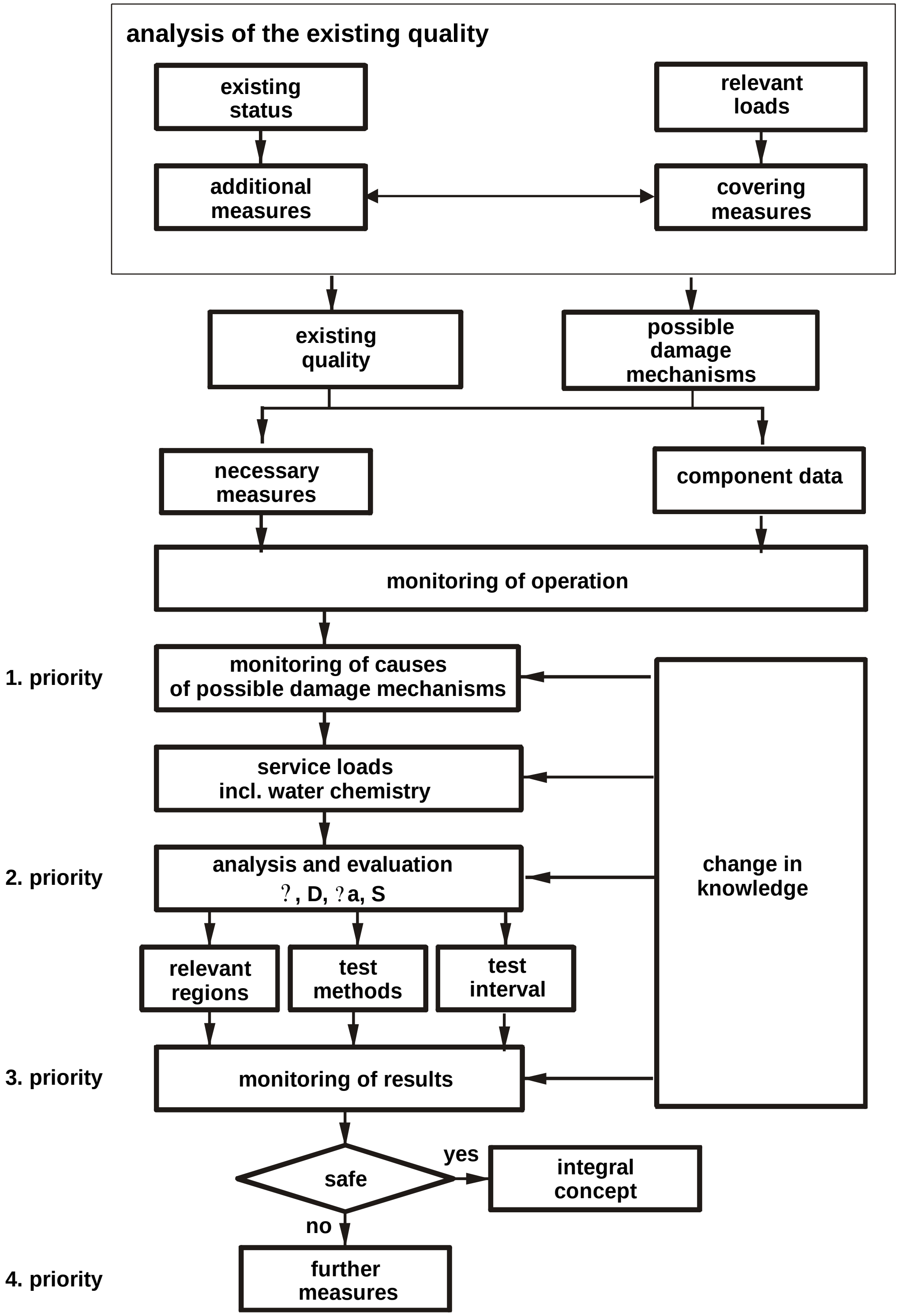

Fig. 5: Procedure to guarantee integrity of components

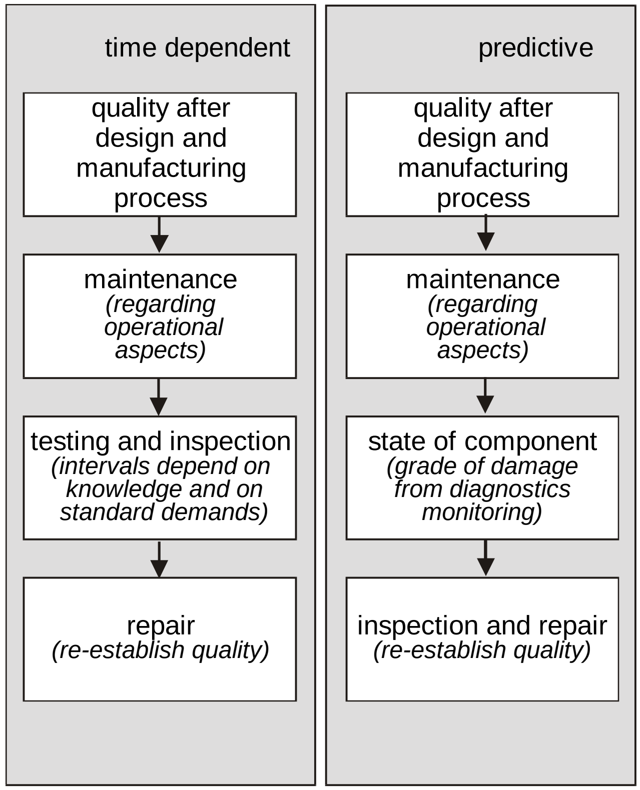

Fig. 6: Procedure to maintain integrity and function

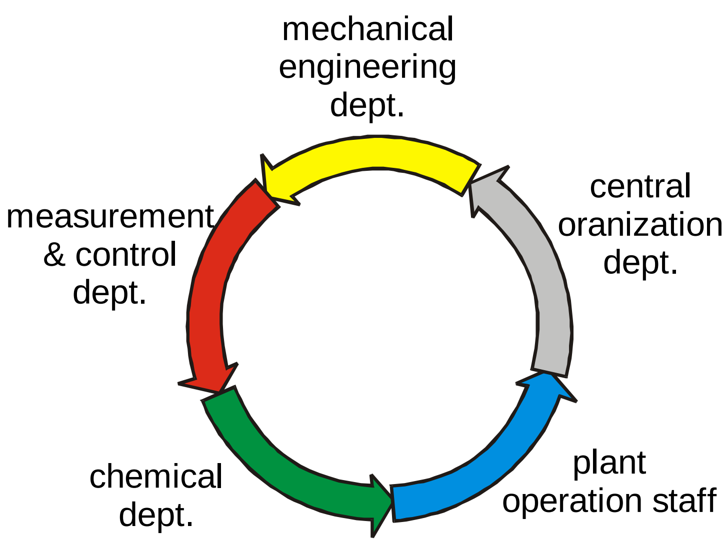

Fig. 7: Ageing management co-operation partners

of the water chemistry are evaluated and assessed regularly, thus used to optimise the locations and the test intervals of the monitoring of possible results of damage mechanisms (mainly performed using non destructive testing). Parallel to these actions, the change of knowledge is assessed.

At any time, this procedure provides an assessment of the existing quality /safety status of a component. There is a regular check if the bundle of redundant measures to guarantee integrity is complete.

Maintain Integrity (Group 2 of Systems and Components)

Regarding integrity and function of this group,

- tests and inspections have to be performed to monitor the actual status,
- maintenance action is necessary to maintain function and integrity, and (if necessary)
- measures to repair the component have to be performed.

The procedure can be time dependant or predictive, **Fig. 6**. To maintain integrity and function, maintenance, tests and inspections are performed regularly (time dependant) or based on monitoring of relevant parameters (predictive). The time dependant procedure is easier to establish but may be not cost-effective in some cases. The predictive method can only be used if there is enough experience with the component and the dominating damage mechanism. At the end of each cycle, the initial quality status (integrity and function) has to be re-established.

No Special Demands for Integrity (Group 3 of Systems and Components)

For this group of systems and components it is sufficient to perform maintenance on demand, i.e. if a failure is detected.

ORGANIZATION MEASURES FOR AGEING MANAGEMENT

There are a few departments of the utility involved in the actions regarding life time management of systems and components. Therefore besides the technical tasks it is a real management task to organize the necessary co-operation. In GKN e.g., the plant manager is responsible for safety in the end. On the technical side the mechanical engineering department (responsible for the system/component), the measurement and control department (responsible for the monitoring systems), the chemical department (responsible for water chemistry) and last but not least the plant operation department (optimisation of operation) have to work together, **Fig. 7**. The mechanical engineering dept. is the supervising dept. in ageing management.

The results of the different redundant measures in operation have to be collected and have to be documented in a database. These results have to be evaluated and assessed regularly as said above and – if necessary – corrective action has to be taken into account.

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