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COMSY Software Assists Lifetime Management Activities

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Abstract

The COMSY program has been developed to provide an effective software tool for the plant life management of systems and mechanical components. The program utilizes more than 20 years of experience resulting from research activities and operational experiences. It is designed to support a plant-wide strategy providing lifetime predictions for mechanical elements, which are validated by a small number of examinations at priority locations. The objective is to establish economically optimized inspection and maintenance programs, while maintaining high levels of plant safety and availability. This is accomplished by focusing inspection activities on the actually degradation relevant locations based on reliable service life predictions.

The capability to perform service life predictions is the key function of a software system for ageing and plant life management. The lifetime prediction capability requires

- an understanding of relevant ageing and damage mechanisms as well as
- the availability of data characterizing parameters required for lifetime calculations.

Parameters required cover the fields: system design and component geometry, material properties, the history of thermal-hydraulic and water chemical operation conditions, stress conditions and - if available - results from non-destructive testing. To manage these parameters the software utilizes a virtual power plant model. Based on the plant data, the program conducts a condition-oriented lifetime analysis for various damage mechanisms which may occur in power plants (e.g. strain-induced cracking, material fatigue, flow-accelerated corrosion, cavitation erosion, droplet impingement erosion, etc.). This capability was achieved by integrating advanced analysis tools with powerful databases.

The resulting service life prediction is validated and optimized through the performance of a small number of examinations at priority locations, which are indicated by the program. Trending functions support the comparison of the as-measured condition with the predicted progress of degradation while making allowance for measurement tolerances. The results of this comparison are used to improve the accuracy of future life expectancy predictions.

In combination with the deterministic degradation assessment a probabilistic approach is applied to consider risks and costs. The risks and costs are set in relation with the object to actuate the compound system reliability and efficiency.

This systematic closed loop process ensures the generation of a quantifiable database which is continually kept up to date with information related to the technical as-is status of the plant. On the basis of reliable and damage-relevant predictions, maintenance management and plant availability can be optimized. This capability is particularly useful for the service life extension of systems and components. Within the last years the program has been successfully applied to various nuclear power plants and the benefit of this software based strategy could be confirmed by field experience.

KEY WORDS: COMSY, software, lifetime, management, activities

KEY ntroduction

The COMSY software has been developed to provide a software tool for ageing and plant life management (PLIM) and plant life extension (PLEX) activities. It is designed to efficiently establish a virtual data model for power plant systems, focusing on piping and vessels. Analytical functions serve to scan the plant data for potentially degraded components and to perform a deterministic lifetime prediction for individual plant elements. Examination data is utilized to optimize the lifetime management process for a safe and economical operation of power plants over its entire lifetime.

The purpose of a systematic ageing and plant life management program is to allow the lifetime of plant components to be planned, and to indicate when a component has reached the end of its effective lifetime before it fails. Another important function of such a strategy is to increase the availability of power plants and to enable implementation of a targeted maintenance strategy in terms of its economic and technical effect.

Implementation of software tools for plant life management requires the existence of detailed information concerning the design and operating conditions as well as the components as-is state. Based on this information a prediction of the components remaining life can be performed, provided that the relevant degradation mechanism has been understood. Advanced software programs provide such predictions for a number of degradation mechanisms at reasonable cost across all systems.

The COMSY Concept

The **COMSY** software system (Condition Oriented ageing and plant life Monitoring System) was developed by Framatome ANP GmbH (formerly Siemens/KWU) as a tool for ageing and plant life management of mechanical components. This knowledge-based program system allows the overall lifetime of mechanical components to be tracked. The concept is based on a combination of deterministic and probabilistic approaches.

The application of the software system for the purpose of tracking the overall service life promises the following economic advantages to the plant operator:

- Concentration of examination and maintenance activities on system areas, where potentially degraded components are expected,
- comprehensive documentation continuously visualizing the current as-is condition of the plant,
- assessment of the effects of refitting work prior to its performance through the use of simulation calculations.

The COMSY software system acquires, manages and evaluates component and operating parameters relevant to service life. Plant data pertaining to individual vessel elements, piping elements and systems are stored in a "virtual power plant data model". Based on these plant data, the program conducts a condition-oriented lifetime analysis for various degradation mechanisms which may occur in power plants (strain-induced cracking, material fatigue, erosion corrosion, cavitation erosion, droplet impingement erosion). This process is supported via an intelligent user interface, powerful analysis functions (stress analysis, thermal-hydraulic and flow analysis functions, water chemistry cycle analysis), comprehensive material libraries (e.g. material data catalog, database of material acceptance values), a module for management and evaluation of examination results and a probabilistic tool which allows to prioritize and to optimize the inspection date by means of risks and costs criteria.

The concept is based on comprehensive experience gained in the use of the predecessor software tools WATHEC & DASY in conducting analyses of weak points for flow-induced forms of corrosion over a period of more than ten years.

In the following the ageing management strategy implemented in COMSY is described in more detail including the relevant sub-items:

- **Closed loop process**,
- **Plant wide diagnosis**,
- **Lifetime prediction for elements** and
- **Software tools** supporting the analysis.

Closed Loop Process

Service life prediction is the key function of a software system for ageing and plant life management. On this basis can maintenance management and plant availability be optimized and the service life of components be extended. An efficient service life management program builds on these degradation predictions, which are validated and optimized through the performance of a minimized number of examinations at critical points.

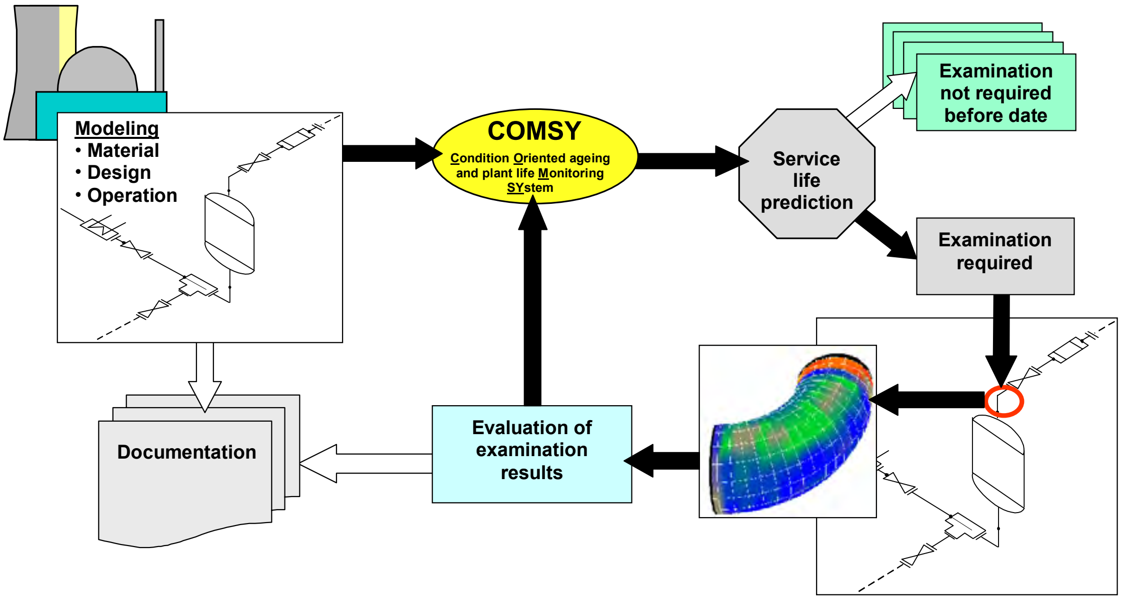

Fig. 1 The closed loop process for PLIM

Based on the predicted service life, components can then be prioritized for examination programs. Probabilistic tools are provided to set-up software guided inspection plans, as shown in Fig. 1. The results of component examinations are fed back into the program system, and are used for further optimization of service life predictions over the life cycle of the component. Overall, this systematic, closed-loop process enables up-to-date maintenance utilizing quantifiable data characterizing the technical as-is status of the plant.

Based on a known type of degradation and a validated rate of degradation progression, suitable remedies and preventive measures can be implemented in order to extend the service life of components. Experience over many years has shown that a maintenance management program based on reliable service life predictions enables costs to be minimized and plant availability to be increased.

Plant Wide Diagnosis

In order to efficiently scan a plant unit for systems potentially affected by the ageing and degradation mechanisms in question, a so-called **rough analysis** is performed (Fig. 2). During the rough analysis process the heat balance diagram of the water/steam cycle in the power plant is modeled using graphical tools. In a second step the system parameters are specified for each system area. The resulting model establishes the basic data structure of the virtual power plant, and allows for an analysis of the water chemistry cycle to be conducted based on the thermal-hydraulic parameters. Taking into consideration the representative materials used in each case, the system areas are then studied with respect to the potential risk posed by degradation mechanisms. The results indicate which power plant systems have a limited service life based on their design and operating parameters. The rough analysis process guarantees an economically and technically useful application strategy. Based on rough analysis priorities, the program provides information for staggered, condition-oriented generation of a data model in annual cycles.

Systems which are definitively not at risk as indicated by the rough analysis need not be examined in future analyses.

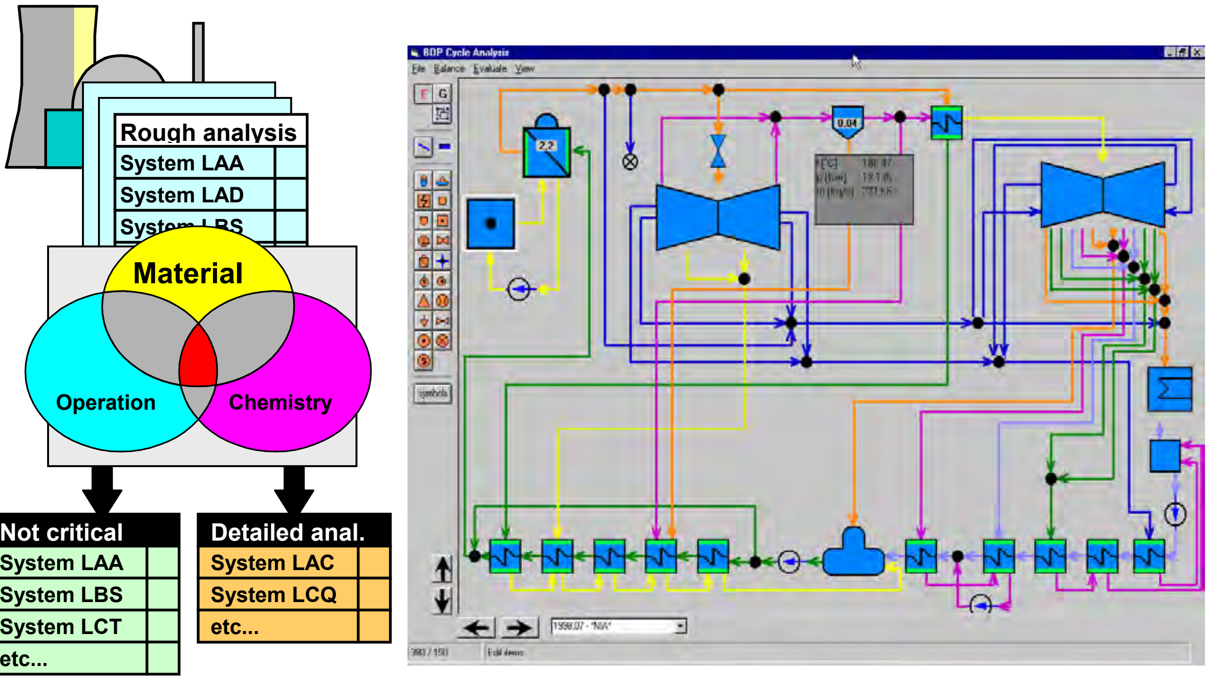

Fig. 2 Rough analysis using COMSY

In system areas in which the occurrence of a degradation mechanism is a possibility, the existing risk must be examined by means of a so-called **detailed analysis**, including a service life prediction for each component. This second step, which is based on the information used in the performance of the rough analysis, requires additional information about the relevant component or system parts in question and physical and chemical parameters for the implemented degradation models.

Lifetime Prediction for Elements

Ageing and wear mechanisms – in particular corrosion and fatigue – are the cause for a limited service life of mechanical components. In order to assess the service life of a component, the following questions have to be answered:

- Which degradation mechanisms are relevant to the material under its intended conditions of use?
- What rate of component degradation progression is to be expected under those conditions?
- Which limiting condition caused by the progression of the degradation places a restriction on the service life of the component?

The properties of the material, the ambient water chemistry and thermal-hydraulic conditions and the mechanical load on the component must be evaluated in order to assess the type of corrosion to be expected as well as the rate of degradation progression.

The limit on the service life of the component is reached, for example, when

- the maximum allowable stress in the pressure-retaining boundary is reached,
- the maximum allowable utilization factor is reached with respect to material fatigue,
- the toughness of the material drops below the required values.

Lifetime Prediction Models

The preparation of degradation models presumes a detailed understanding of the type of degradation concerned as well as the functional interactions of the relevant parameters which influence the rate of degradation progression. Studies and degradation analyses have been conducted in this area for some 25 years in the Framatome ANP laboratories in Erlangen, Germany. The experience gained from these activities has been compiled in analytical and semi-empirical corrosion models for each degradation mechanism. To date, degradation models have been elaborated for the following types of corrosion: strain-induced corrosion cracking, material fatigue, erosion corrosion (FAC), cavitation erosion, and droplet impingement corrosion. A degradation model for stress corrosion cracking is currently under development.

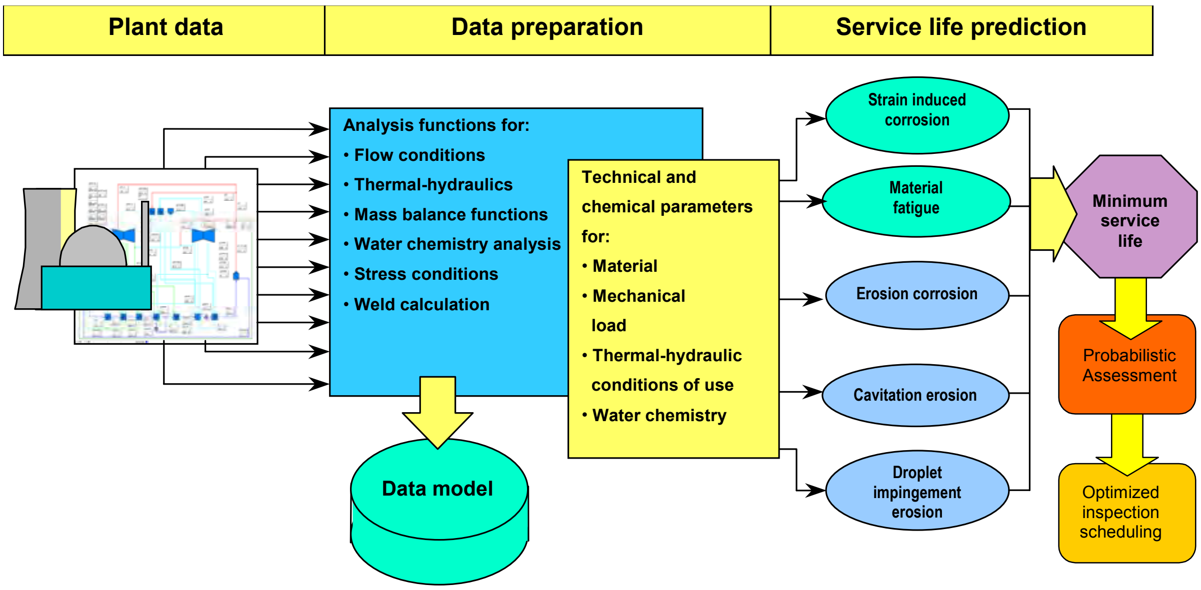

Fig. 3 Data conditioning for lifetime prediction

The corrosion models used to make deterministic service life predictions require the use of a number of physical and chemical parameters which cannot always be taken directly from the plant documentation. In order to enable economical application of service life predictions despite this limitation, COMSY includes appropriate analysis functions for pre-processing corrosion-relevant parameters based on the available documentation, see Fig. 3.

The rate of degradation progression is determined for the relevant degradation mechanism in each case using these degradation models, whereby a corresponding safety factor is used to allow for expected uncertainties. The calculated rate of degradation progression and the strength boundary conditions calculated for the component are used by COMSY to determine the minimum service life.

The probabilistic assessment provides information on the likelihood of failure for individual components based on analysis of existing component data. In combination with detailed analysis of existing examination data, this method allows to focus inspection and maintenance effort on those components with the highest failure probability. This process utilizes e.g. a crack growth model and considers the failure consequences.

”Calibration” of Lifetime Predictions

The COMSY software system acquires and assesses measurement results from non-destructive component examinations and visual inspections, see Fig. 4. The examination and inspection results are linked to the examined component for documentation of its as-is condition at that specific time in the operating history of the plant, and are integrated into the so called virtual power plant data model.

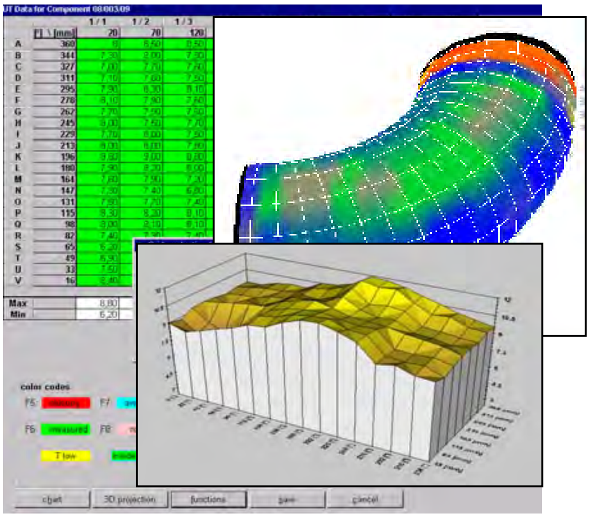

Fig. 4 Evaluation of component examinations

The evaluation of component examinations is supported by e.g. interactive analysis functions which greatly simplify the geometry-dependent evaluation of measurement results, among other things. A calibration function supports the comparison of the as-measured condition with the predicted progression of the degradation, while making allowance for measurement tolerances. The results of this comparison are used in order to improve the accuracy of future service life predictions.

This process ensures that experience gained from evaluation of examination data will be fed back into the performance of analytical service life predictions. Examination data resulting from in-service inspections are thus consistently used in the preparation of a reliable database which is kept continually up to date.

This process increases the informational value of the examination results, and makes it possible to prepare a transparent description of the as-is condition of components and systems, the quality of which will continue to increase with every year the process is in use.

Example for Lifetime Prediction

In the course of apply COMSY for a boiling water reactor, it was determined the performance of a rough analysis led to the result service life of the feedwater system is limited by three potential degradation mechanisms: erosion corrosion, strain-induced corrosion cracking and material fatigue. Using the service life predictions determined by the program, the subsequent revision of the program was used to perform examinations of specific welds, piping elements and vessel nozzles. The results of these examinations showed a high degree of correlation with the calculated degree of degradation, including conservative margins. In the next step, examination results and predictions were correlated to enable an even more precise determination of weak points in subsequent major inspections, and thus provide a long-term maintenance planning capability.

Software Tools

Power Plant Data Model

A systematic program for ageing and plant life management requires an overall view of the power plant, because individual components cannot be studied in isolation when attempting to predict the remaining service life.

The information used in making such a determination must on the one hand be stored in a component-specific manner (e.g. geometry, material, examination results, material acceptance data, etc.), but on the other hand must be valid across components (design criteria, thermal-hydraulic and water chemistry conditions of use) and across systems (flow rates, availability times). This is achieved by using a “virtual power plant data model” which enables the assignment of parameters to various plant element relations. A significant characteristic of the data model is the specification of environmental operation conditions as a function of time in service.

Component Model

The program processes components such as piping or vessel elements individually. If a piping element is to be generated in COMSY for a specific piping run, for example, the user selects the corresponding system area and selects the component type from a list of predefined component symbols. The operator selects the desired diameter, wall thickness and material from the integrated standard libraries. Subsequently, the program generates a component data sheet. Using integrated analysis tools, it calculates the conditions of use which apply to the component in question based on existing thermal-hydraulic and water chemistry data (flow condition, degree of turbulence, pH and oxygen concentration of the fluid). In a next step, the program calculates the strength conditions of the component for the given design criteria – in accordance with ASME, DIN, JIS, GOST – and displays this information on the component data sheet. A plausibility routine checks the design of the component for compliance with applicable standards, and indicates input errors. Subsequently, the automatic generation of service life predictions for each component is provided. The completed component data sheet is used as the basis for further evaluations. If required, additional information can be supplemented over the life cycle of the component.

In addition to material acceptance procedures, details concerning examination results such as examination records and pictures taken during visual inspections can be accessed for the component in question. The component data sheet also makes it possible to access static documents – drawings, parts lists, reports and acceptance certificates which exist as files – also in power-plant-specific documentation systems. Moreover, the software system enables the use and/or integration of information extracted from existing databases.

As-Built Material Data Library

The knowledge of specific material properties of components is indispensable in the detailed evaluation of specific degradation mechanisms (e.g. stress corrosion cracking). For this purpose COMSY can rely on an "as-built" material library which includes the material acceptance documentation prepared at the time the material or component was manufactured, for example. This database (see Fig. 5) contains the following information:

- material-relevant information on components about the manufacturing process (e.g. manufacturer, semi-finished product form dimensions, heat treatment steps),
- manufacturing and acceptance data regarding chemical analysis and mechanical characteristics (strength, toughness) for base material heats, welds, weld overlay cladding and buttering, as well as for production weld test coupons and welding material batches.

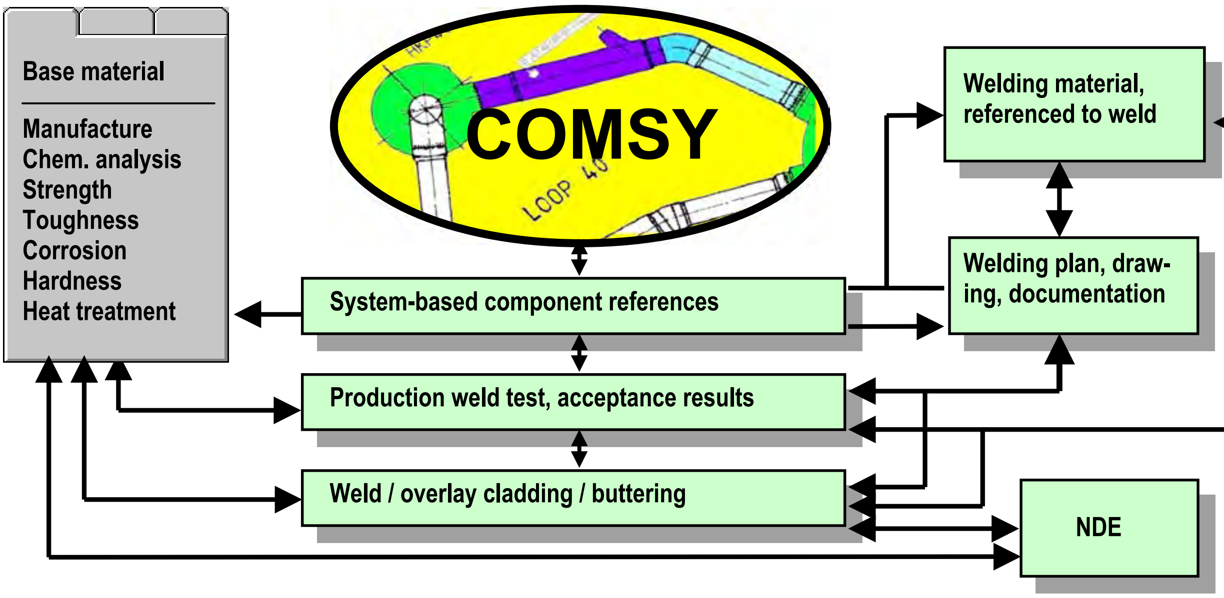

Fig. 5 Detailed material acceptance information

If a corresponding record exists, COMSY uses the "as-built" material properties of the component in assessing the degradation mechanisms. In this process, complex data associations allow the retrieval of material properties as well as the identification of other components made from the same heat.

Probabilistic assessment

The probabilistic assessment tool provides the option to utilize existing data from detailed analysis and previous inspection results to evaluate the damage probability within a given time period. The damage probability is associated with the expected damage consequence and cost for repair / replacement activities.
The damage frequency for individual components is based on an deterministic evaluation of operating and design conditions in combination with examination data which are administered in the database.
The damage consequence is evaluated taking into account the safety classes and the availability criteria.
Finally, the risk is determined by consideration of damage frequency and damage consequence. Only, if the risk does not represent a danger for environment, personnel and equipment financial effects are also assessed. In order to find the measure with the optimum risk/cost ratio the following options can be taken into account:

- repair or replacement associated with unplanned shutdown necessary
- redundant system available
- damage figure is difficult of access during normal operation
- arising expenses for repair or replacement
- increasing costs if repair or replacement is postponed

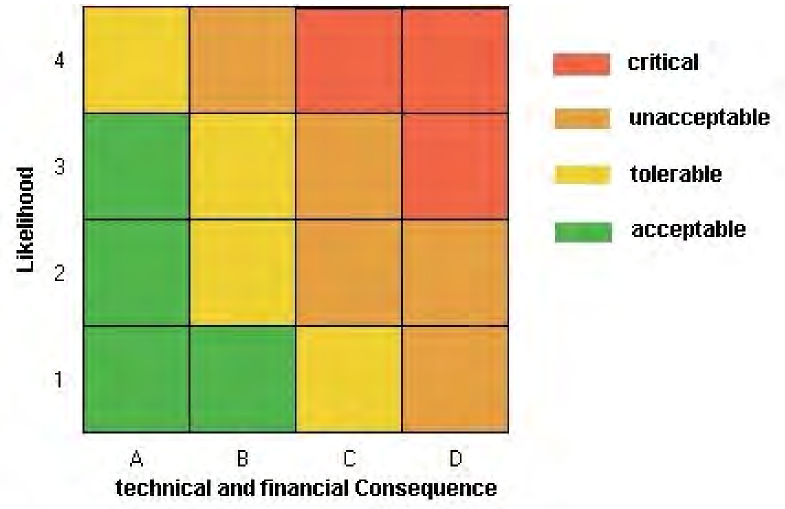

Fig. 6: Risk matrix

The result is illustrated by a four to four risk matrix (Fig. 6). It shows a classification for judging the necessity of arrangements to be taken.

This method allows to focus inspection and maintenance efforts on the components with highest failure probability. The results of component examinations are fed back into the program system and are used to update probabilistic assessment criteria for further optimization of service intervals.

Conclusions

For many utilities a systematic and efficient ageing and plant life management system is becoming more and more important to ensure an economical power plant operation in spite of continuous facility ageing.

In this regard the COMSY software system makes a knowledge-based program system available which integrates advanced analysis tools and comprehensive material libraries with a "virtual power plant data model." It enables the condition-oriented of evaluation service life of vessels, piping systems and entire plant units with respect to relevant degradation mechanisms. The results of component examinations are fed back into the program system, and are used for further status evaluation over the life cycle of power plant systems. Overall, this systematic, closed-loop process enables up-to-date maintenance utilizing quantifiable data characterizing the technical as-is status of the plant. On the basis of reliable predictions and of relevant degradation, maintenance management and plant availability can be optimized and the service life of costly systems and components extended.

The implementation of COMSY in various power plants within and outside Germany (e.g. Japan, Spain, Finland, Bulgaria and Hungary) has confirmed that systematic plant life management makes good economic sense, and that the process can be greatly streamlined through software support.