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Ageing Management in German Nuclear Power Plants

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ABSTRACT

The report deals with questions of ageing and backfitting in connection with quality management in German nuclear power plants from the point of view of the Federal Office for Radiation Protection. In particular, the ageing aspects of mechanical as well as instrumentation and control components and structural engineering are discussed. Within the scope of the comprehensive reflection, conceptional, technical and staff ageing phenomena are mentioned and examples are given of the practice-oriented implementation of ageing management.

1. INTRODUCTION

Measures to maintain quality over a long period of time (ageing management) have been an integral part of the quality requirements specified in German nuclear safety regulations from the very beginning. Different ageing aspects are monitored during operation as well as periodically in regular intervals. In the case of irregularities this results in repair works or an exchange of components and vessels. Information on events in a plant is given to other plants and may possibly lead to a preventive repair. Due to the use of data bases, operational experiences are efficiently evaluated with regard to technical processes and human behaviour. In the following different ageing aspects are discussed.

2. MANAGEMENT OF MATERIAL AGEING

2.1 Operation monitoring

On behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU) and the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS), the fatigue monitoring of pipes and vessels by monitoring systems which is usual in German nuclear power plants (NPP) was shown and evaluated [1]. The fatigue-relevant areas in German nuclear power plants are known and have been evaluated in numerous detailed analyses with the help of measured transients. Monitoring systems serve to discover cracks in time and facilitate a finding and an exchange of affected components.

The best-known concept for fatigue monitoring mostly used in German nuclear power plants is the FAMOS system of Siemens. This concept consists of four stages: elaboration of a fatigue manual, registration of measured values, evaluation of measured values and fatigue calculation. Existing operational signals and temperatures are measured at the outer wall of pipelines. Different measurement levels of 2 or 7 thermo-elements exist which are distributed over the surface.

The concept of the TÜV Rheinland [2] consists of 5 phases (figure 1), experiences gained with the commissioning measurements, basic monitoring with most simple measurement technology, special measurements to investigate special events, permanent monitoring of temperatures, dilations, etc. as well as fatigue calculation. In addition to the measurement of operational signals, a multitude of transducers to measure special values is adapted to the respective measurement task.

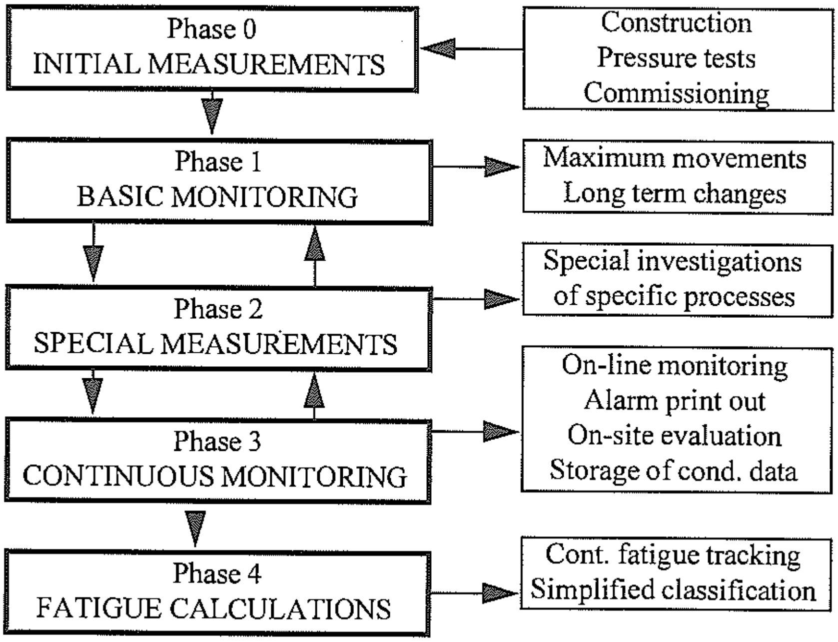

Figure I: Pipework and pressure vessel monitoring concept

There is a multitude of mechanical and thermal loads (figure 2) requiring - depending on each case - a registration of operational signals, temperature monitoring, basic monitoring and special measurements. By measuring the surface temperatures, temperature loads, like thermal shock, stratifications etc. are registered (FAMOS) but not other processes, like e. g. pipeline vibrations. Therefore, it is reasonable to determine such processes by basic monitoring and to investigate them by special measurements and to evaluate them.

Type of load	Operational signals	Temperature monitoring	Basic monitoring	Special measurements[1)]
Operational pressure	XX	0	0	XX
Operational temperature	XX	XX	0	XX
Temperature transient	XX	XX	0	XX
Temperature stratification	0	XX	0	XX
Temperature shock	X	XX	0	XX
Vagabond streams	0	XX	0	XX
Line shock	X	0	XX	XX
Obstructed thermal expansion	0	0	XX	XX
Failure of shock arrestor	0	0	XX	XX
Downward expansion of pipeline	0	0	XX	XX
Pipeline vibration	0	0	XX	XX

XX Registration
X Hint (Indication)
0 No reaction
1) If arranged for

Figure 2: Operational monitoring of pipelines

2.2 Further development of testing engineering

For several years, testing engineering has permanently been developed to increase the safety of components. To guarantee the monitoring of ageing-caused damaging mechanisms the following issues were, for instance, dealt with: Under the supervision and on behalf of BMU/BfS the low-frequency-eddy-current test was developed further to test the austenitic plating of the reactor pressure vessel. First tests of this system in a NPP shows the functionality. With the help of a special eddy-current sensor it is possible to detect failures in and under the plating by using low-frequency excitation. First experiences could be gained by investigating test bodies and by testing at components. The measured data is evaluated by applying special evaluating algorithms so that the background noise of the surface structure can be filtered. This improves the evaluation of the indication and increases the certainty of analysis. These investigations are carried out as prophylactics against the occurrence of fatigue damages which can be caused by loads over longer periods of operation.

The permanently developing testing engineering in the non-destructive material testing of reactor components is accompanied by an essential improvement of signal processing and data recording. Two main directions of development become apparent: on the one hand, the further improvement of test statements and failure descriptions and, on the other hand, the increase of effectiveness of the testing (reduction of test time). Today testing devices are used for the testing of reactor components which enable a concentration of several testing stages and testing methods in one testing operation. For example, testing techniques used up to now in ultrasonic testing (ALOK, phased array technique) are unified in a device system. This provides the possibility to make use of the advantages of the different testing techniques for indication evaluation and description of failures. These developments are accompanied by an improvement of testing efficiency and precision which guarantees the increasing safety requirements. A new approach has been developed for the modelling of testing situations: considering the real component geometry (CAD-model) and the determined failure data, a virtual reproduction of the testing situation is created which allows the evaluation of complex testing problems.

By using a further developed potential drop measurement method, the early detection of failures in critical pipe systems can be improved and the radiation exposure of the test staff can be reduced [3]. The potential drop method can be applied as an additional alternative in places and under conditions where it is difficult for currently applied methods to detect and monitor defects in materials. With the help of a new developed belt it is possible to install the potential drop measuring field now much faster than before. This is of particular advantage in areas of increased radiation levels.

2.3 Repair works

The observation of ageing-caused changes by plant monitoring and the evaluation of the results measured led to repair works. During the last years, austenitic pipes of older boiling-water reactor plants were exchanged for pipes of the material with a reduced carbon content using Nb-stabilized (X 6 CrNiNb 19 10 S) instead of Ti-stabilized steel (X 10 CrNiTi 18 9).

Nearly all observed cracks in pipelines of Ti-stabilized steels were in the heat-affected zone. Corrosion-supported cracking (intercrystalline stress corrosion cracking) was determined as cause for this. This was due to a local sensitisation of the material together with cold work and wrinkling having occurred when the welded joints were made. The new material was processed with modified welding technique with low thermal input and reduced residual stresses and avoiding notches and wrinkling.

3. AGEING OF ELECTRIC ENGINEERING AND INSTRUMENTATION AND CONTROL INSTALLATIONS

Experimental investigations concerning the long-term constancy of electric installations have been performed. During operation, these components are periodically tested and their reliability data is controlled with the help of failure statistics. Parts with a tendency to age are exchanged preventively.

The conceptional renewal is performed through the exchange of electrical parts, the production of which expires. In instrumentation and control, technology has been changed to digital systems.

The german nuclear safety organisation „Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)" analysed comprehensively ageing phenomena in German nuclear power plants on the basis of reported events in different periods of time [4]. From 1974 to 1996 the relative share of causes due to ageing in the case of reported events at pressurized components of primary cooling systems was 25%. The corresponding share of active mechanical installations from 1974 to 1995 was 7% and of electric engineering and instrumentation and control installations from 1993 to 1997 14%.

A special investigation project [5] dealt with the long-term constancy of operationally aged electric actuators as process-oriented electric key components as well as with cables from the containment of German pressurized water reactors and boiling water reactors. The influence of the following parameters having synergistic effects on ageing during operation (temperature and γ-radiation as well as load cycle and incident conditions) were examined:

- ambient temperature in compressed air from 35°C to 68°C,
- maximum accumulated dose of appr. 15kGy,
- mechanical load through load application.

The electric actuators used in the safety system of German nuclear power plants never reached their designed load applications within the course of their useful life since, as a rule, they were only handled in the case of periodical inspections.

Following this, to provoke failures, the test samples are exposed to a saturated steam atmosphere at 120°C for a maximum of 2 days. Prior to the examination, the actuators and cables examined had been used in NPP operation over a period of time of at least ten years at exposed positions with regard to load through temperature and radiation. The result of the component tests at electric actuators is that to a wide extent the designed function was proved over the whole course of the test. The evaluation of the results of the single test stages, in particular under incident conditions, did not show significant, i. e. function-relevant peculiarities.

Parallel to the tests of actuators, the related energy-supply and instrumentation and control cables were also investigated in single samples (dismantled in cable sheathing and cable core insulation) and cable sections in containers under the following test conditions according to the tests of Seguchi et al. [6]:

- load in compressed air appr. 5.5 bar or, respectively, pressureless in air,
- thermal ageing in air and compressed air atmosphere in the containment at 105°C, 208 days,
- radiological ageing at room temperature in air and compressed air atmosphere in the containment, 250kGy, dose rate appr. 200Gy/h,
- reference measurements with regard to elongation-at-break and tensile strength.

As an example of extensive test results the elongation-at-break of cables in the case of thermal/radiological and, vice-versa, radiological/thermal ageing in air is chosen. Independent of the load order the elongation-at-break of the insulation covering of the cable cores is reduced as a result of thermal ageing. In the case of the cable sheathing, in addition to each load, the load order is decisive for the reduction of the relative elongation-at-break and with this for the level of damage. According to [5], this effect is founded in the thermal decomposition of peroxydes following a previous irradiation. It is suggested by the authors [5] to include in the test programme also the determination of the elongation-at-break as reference quantity for qualification measures to be performed in future in order to gain reference data for the tests accompanying operation. Solely the control of electrical parameters is no more considered sufficient. Through weather influences (frost, heat, humidity, impact of UV radiation and oxygen) the ageing of cables can considerably be influenced. It is, therefore, recommendable to comply with the instructions of the cable producers with regard to cable storage. In the case of a use in safety-related areas it should be checked if it is justified to store cables in the open.

4. PREVENTION STRATEGIES FOR AGEING OF BUILDING STRUCTURES

Ageing prevention strategies are primarily related to those building structures which carry the operational and potential accidental loads to guarantee the integrity of the buildings and structures relevant to safety. These are mostly reinforced concrete parts, steel constructions and links like anchorings, passages or hermetic sealings. Important parts or structures are the steel containment, the biological shield, the concrete basement and the reactor building outer shell.

The requirements related to structures in German nuclear power plants are laid down in a number of rules and guidelines as well as in DIN standards. As an example, the KTA Standard 2201 "Design of Nuclear Power Plants against Seismic Loads" shall be mentioned, especially part 3 of this standard, "Design of Structural Components". Prevention of ageing is achieved by an appropriate combination of adequate production including quality assurance and a monitoring/inspection programme.

The components are, in addition to the crack initiating process occurring at practically all buildings, monitored with regard to the known ageing mechanisms specific to the materials concerned.

There are a number of stressors that influence the characteristics of the components of the containment. Causes for concrete degradation are external and internal environments as well as weather influences (leaching, freeze and thaw cycles), thermal exposure, chemical attack by groundwater and the internal chemical reactions in the concrete, carbonization, effects of radiation, vibration and structural loads.

Causes for damage to steel components (liners or reinforcement) are corrosion, fatigue and embrittlement due to radiation. Any cracking and spalling of the concrete of the containment may expose the steel to an external aggressive environment and enhance the corrosion process. Fatigue of reinforcing steel in concrete containments is not a major concern.

Causes for damage to synthetic material like coatings and gap material are heat, light, chemicals and mechanical wear.

Monitoring of buildings is mainly performed by visual inspections of concrete surfaces to determine the general structural condition. Surface areas that are identified as being suspect should be further examined to characterize the degradation. The protective coatings provide a barrier to the external stressors. In addition, instrumentational methods are used, for example setting measurements or measurements of potentials to detect corroded reinforcement.

The important potential failure mode is loss of some of the structural integrity of the containment. Radioactive fluids might be released from inside the containment to the outside environment. Leak tests are performed regularly.

Operational experiences confirm the adequacy of the existing approach to prevent ageing degradation of building structures.

5. MAN-MACHINE-INTERACTION

5.1 Ageing management of staff actions

In addition to the technical installations, reliable and safety-oriented action of the staff is decisive for the safe operation of nuclear power plants. Essential factors influencing staff actions are, in addition to the staff's quality which is required to be kept permanently, the automatization level of the plant and the design of the control room. This also includes questions of operational organization and operational documentation.

The staff is regularly trained in simulators. This guarantees long-term capability of dealing with disturbances and incidents rarely occurring during operation. There are special simulators for each plant type. Because of the high automatization level in German NPP, the staff is released from numerous handlings. There is sufficient time for the diagnosis and initiation of measures in the case of disturbances and incidents. Incidents are controlled automatically for at least 30 minutes. Emergency systems are installed in the plants for the case of impacts from outside. They are designed for a save operation until 10 hours.

From the control room, German nuclear power plants are practically controlled and monitored completely. Ergonomical aspects are taken into account by the structuring of the displays and actuators on the desks and boards of the control room. The overall view and work routines are facilitated through the order of displays and actuators in flow diagrams. The construction of the systems and the interactions between the systems are represented schematically. Supply of information of the conventional user surface is increasingly supplemented by computer-aided information systems. Defective conventional components which can no more be supplied are replaced by computer systems.

Simultaneously, operational organization is of great importance for the staff's acting as failure-free as possible. Operation, maintenance/technical support and monitoring are separated in different areas. Through the clear determination of the tasks and responsibilities, clear competences are achieved and conflicts of interests are avoided.

A complete operational documentation is required for the reliable and safety-oriented action of the operating staff. The permissible actions of the staff are determined in detail in the operational manual (Betriebshandbuch, BHB). It includes the instructions concerning normal operation as well as the control of disturbances (abnormal operation) and incidents. Within the BHB, the operational order regulates the tasks, authorization and responsibilities of the staff. The operational manual must be observed.

Emergency manuals include the procedure and measures for in-plant emergency management with regard to events exceeding design-basis accidents.

5.2 Ageing management through evaluation of operational experience

In addition to technical analyses, operational experience is systematically evaluated with regard to human failures and possible improving measures. All reported events above the reporting threshold are documented in the BEVOR database of the Federal Office for Radiation Protection. Failures are analyzed and causes as well as remedial measures are - if required - made accessible to other operators (with forwarding messages). Below the reporting threshold, the German operators developed an own reporting and evaluating system which was established in some plants. "Almost"-events and the reporting of weak points which may lead to human failures are registered as far as this is possible. These results are systematically used for improvements in the plants. The reflux of experience from reportable events led, in addition to technical improvements, to an optimization of the mode of plant operation and human action. Federal investigation programmes supported this development.

6. SUMMARY AND CONCLUSIONS

Comprehensive measures are employed in German nuclear power plants to counter the unacceptable effects from ageing. Ageing aspects are considered during design, manufacturing and inspection of technical equipment. Material ageing is managed by monitoring of equipment and operating conditions with respect to detecting any deteriorations of normal operation. Parts are replaced by preventive maintenance or repaired. Testing engineering is permanently developed. Ageing of electric engineering and instrumentation and control installations is under special research. The qualification of staff is maintained at a sufficiently high level. Operational experiences confirm the effectiveness of measures taken.

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