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Availability Improvement of German Nuclear Power Plants

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ABSTRACT

High availability is important for the safety and economical performance of Nuclear Power Plants (NPP). The strategy for availability improvement in a typical German PWR shall be discussed here. Key parameters for strategy development are plant design, availability of safety systems, component reliability, preventive maintenance and outage organization. Plant design, availability of safety systems and component reliability are to a greater extent given parameters that can hardly be influenced after the construction of the plant. But they set the frame for maintenance and outage organisation which have shown to have a large influence on the availability of the plant.

1 INTRODUCTION

Reliability of systems and components is extremely important in maintaining a high degree of safety. For Nuclear Power Plants, achieving high availability and reliability are essential factors for achieving good economics. The improvement of availability and reliability (and thereby safety) go hand in hand as it is as important to shorten the necessary outages for refuelling and maintenance as to omit the “unnecessary” outages by technical failure.

Nowadays high availability factors can be reached by a combination of measures including the application of various programs and organisation tools including personnel training, quality assurance, improved maintenance and outage planning. Further, ageing management is as well a tool to control the reliability of systems and components as a detailed analysis of component availability.

The influencing factors for plant availability are manifold. They can be divided in three groups:

Firstly there are the external influences:
- State policy and law
- Guidelines and specifications by the regulators

These influences are hardly controllable by the operators, so they shall be not discussed here.

Secondly, there are parameters that are (mostly) fixed with the construction of the plant - technical boundary conditions:
- Design of the plant and dimensioning of the system
- Quality of the components (repair frequency, life time)

Thirdly, there are the parameters that are directly in the responsibility of the plant operators – management options:
- Long-term and short-term organization of the outage
- Optimization of operational processes (e.g. start-up and shut-down of the plant).
- Management tools
- Systematic component and system analysis

There are two measures for the availability of a power plant that have to be distinguished: the equipment and the energy availability. The equipment availability is a measure for the number of days that a power plant is producing electricity per year. It is not distinguished if the load is 100% or less. The energy availability is a measure of how much electricity is produced compared to the amount that could have been produced at maximum load. Assuming a refuelling and maintenance outage of 14 days and an average load of 80 % for the rest of the year the equipment availability would be 96.1% and the energy availability would be 76.9 %.

The nuclear power plants in Germany are mainly responsible for the base load. This implies that equipement availability and energy availability are roughly the same. Otherwise this could be an evidence for technical problems. For example the breakdown of a main coolant pump does not mean that the plant has to be turned down but the maximum electricity output has to be lowered to 60 – 70 %.

According to data from WANO the world wide average equipment availability is around 85% (Figure 1). The availability of EnBW PWRs is well above 90%. The means and options to influence the availability shall be discussed in the proceeding chapters.

2 TECHNICAL BOUNDARY CONDITIONS

The basis for availability management is the given technical design of the plant. The basic design principles of the operating PWRs in Germany are similar. They were designed by KWU-Siemens. The main characteristics are

- 3- or 4-Loop primary systems (including Emergency Core Cooling System - ECCS)
- Accessible containment during operation
- Fuel element pool inside the containment

This design enables the operator to carry out periodic inspection and preventive maintenance during operation on redundant components. For example the ECCS is (mostly) designed as 4 x 50% system. Consequently only 2 loops are needed for the control of any possible incident. This allows the operator to inspect the ECCS systems outside the maintenance and refuelling outage.

Furthermore the maintenance and refuelling outage can be organized and prepared in advance as the containment is accessible. Two weeks before the outage starts the operating personal is preparing the tools and the locations for maintenance and repair works.

The fuel element pool inside the containment allows, firstly, an all year access to the fuel elements for repair and organisational activities, and secondly, a fast refuelling process as the fuel element pool is located right next to the reactor core which enables efficient transportation of the elements.

Consequently the mentioned design features provide the possibility to carry out a large part of the maintenance and organisational work in a preventive manner. This reduces the duration of planned outages and thereby increases equipment availability.

The quality of the components cannot be influenced significantly by the plant operator after the construction of the plant. Replacement is often not or hardly possible (or very expensive). For that reason an effective ageing management is an important tool to supervise the quality development of the components during operation. The ageing management shall provide all technical and organizational arrangements in order to limit the consequences of a physical ageing of the components. Effective ageing management will help avoiding technical failure and especially unplanned outages.

Thus the management of component quality increases as well equipment availability as well as the energy availability.

Guidelines and specifications of the regulators concerning technical issues are external boundary conditions that can have a significant impact on the plant availability but can only be influenced within certain limits by the operator. But in general the framework is given and is changed only very slowly over the years.

3 MANAGEMENT OPTIONS

There are a bundle of management tools that are used in a modern organization of a Nuclear Power Plant in order to control the availability and reliability of the components and the plant:

- Outage organisation
- Maintenance strategy
- Quality Management
- Ageing Management
- Availability analysis

Quality management shall not be discussed here for its existence and application according to the ISO-Norms is a natural fact in most companies, not only in nuclear power plants.

Also a separate description of the maintenance strategy is omitted as the essential parts of it are described as part of the outage organisation and the ageing management.

<u>Outage organization</u>

Depending on the given boundary conditions the operators focus mainly on the outage organisation for availability improvement. American units e.g. prefer 2-year cycles in order to reduce the number of outages and fuel exchanges. On the contrary strategies were developed for two outages per year in Germany. One outage is planned for refuelling in order to achieve a better utilization of the fuel and the other outage would be a combined one for refuelling and maintenance works. But the preferred strategy in the moment by almost all German utilities is one outage per year with combined maintenance and refuelling. This results in cycle lengths of 300 – 340 days of service per year.

Once an outage frequency is chosen (long-term organization) a detailed strategy for the outage has to be developed (short-term organization). The goal of the short-term organization is to reduce the duration of the outage but not at all costs. A reliable forecast of the duration has to be possible for the dispatcher that is purchasing the replacement electricity for the shut-down power plant. Comparing the current outage duration in different countries there are significant differences. There is Japan with 70 days or more, France with 50 – 60 days, 30 – 40 days in the USA and 10 – 20 days in Germany and Sweden. Figure 2 shows the development of the outage duration in unit GKN II (Neckarwestheim / Germany). In the 1980s outage durations of 30 days were standard in German units. By identifying the critical path of the maintenance workings it was possible to reduce the standard outage duration below 20 days. The optimization limit is reached when the maintenance workings are done in the slipstream of the reactor core refuelling. The performance optimization was achieved by permanent improvement of the working processes and working tools. Consequently an optimization of the refuelling process has to be examined as well.

The minimal-outage-length by design (MOD) is defined by the duration of an outage that is dominated only by the refuelling. Figure 3 shows the development of the MOD of unit GKN II since the 1990s. Improvement of the fuel element handling (e.g. an optimized replacement machine) was responsible for the reduction of the minimum outage length from 12 down to less than 10 days. Optimization of the replacement machine is an ongoing topic for discussion and action.

Today the improvement of equipment availability by optimization of the outage organisation has reached a limit. But the predictability of the outage duration is still an important factor as discussed already above.

<u>Ageing Management</u>

Ageing management in the power plants of the EnBW contains the implementation, organisation, technical execution and evaluation of a concept to protect against technological and physical ageing of safety relevant systems, structures and components (SSC). Ageing of technical components and systems can have two aspects:

1. Technological ageing by innovation and recent cognitions in the state-of-the-art of science and technology, concerning
    - Application of novel technical means and processes
    - Deterioration due to operation
    - Material, component and construction properties
    - Material testing and analysis
    - Computational Modelling
    - Verification methods

2. Physical (material) ageing
   Physical ageing contains the effects of time or operation dependent deterioration mechanisms, e.g. embrittlement, tiredness, corrosion, abrasion.

The ageing management concept divides the components into high, medium and low safety relevance. Following this classification different aspects and formalisms concerning quality management and maintenance are foreseen. For example concerning mechanical components a concept of integrity was developed for components with high safety relevance (e.g. reactor pressure vessel).This means that the relevant component quality has to be guaranteed and it is not allowed to fail. In contrast failure is allowed for components with medium or low safety relevance. They are treated with preventive or even fail-oriented maintenance.

<u>Availability analysis</u>

The goal of availability analysis is to reduce unplanned outages or production cutback. The strategy to achieve this goal is a systematic investigation of systems and components with respect to their relevance to the availability of plant operation. The analysis shall use existing tools of maintenance and ageing management. The analysis is concentrating mostly on non-safety but important operational systems like the electric generator.

The analysis of a specific system shall be done with the mathematical methods of a fault tree analysis. Thereby the relevant components of the system can be identified. After identification of the weak points in the system it can be improved by an adopted inspection program, replacement of the concerning components or even (if possible) a redesign of the system.

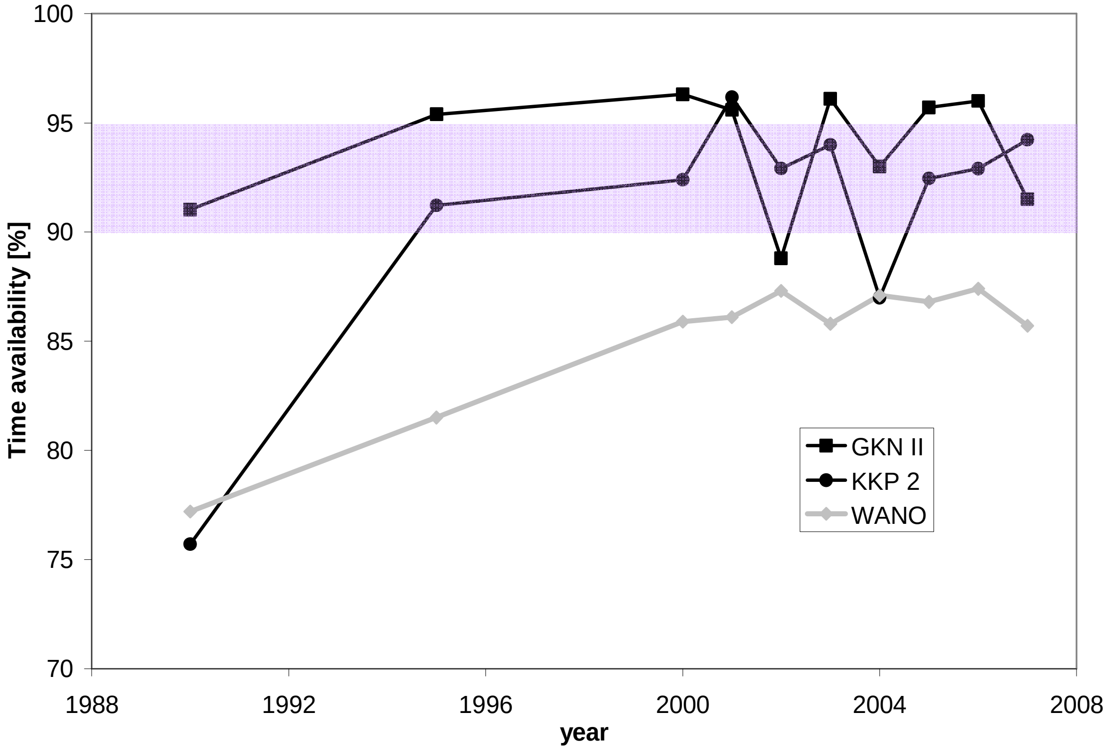

Figure 1: Time availability of the EnBW NPP GKN II and KKP 2 and the average value of NPP worldwide

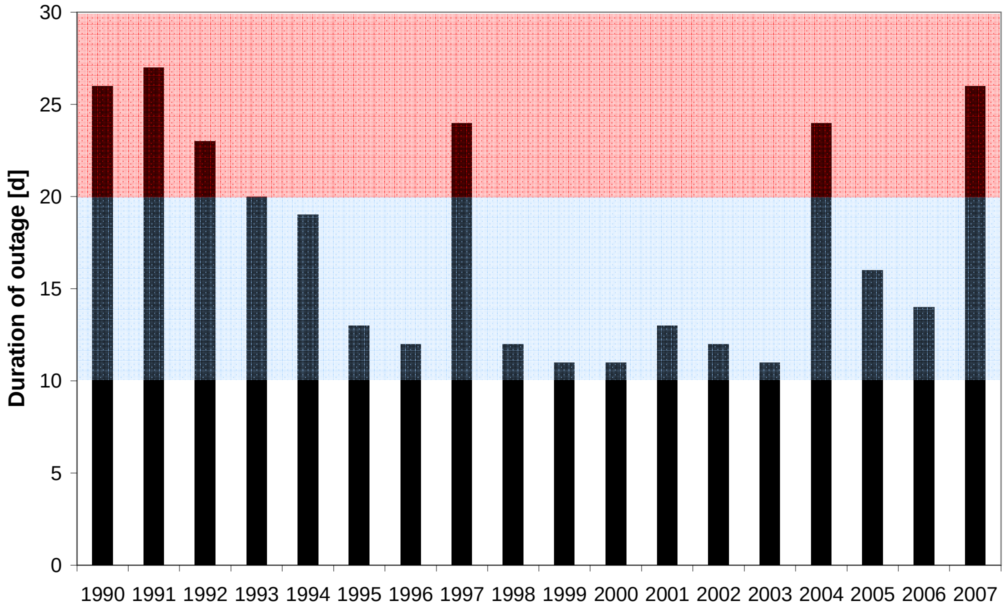

Figure 2: Development of outage duration in unit GKN II (Neckarwestheim / Germany)

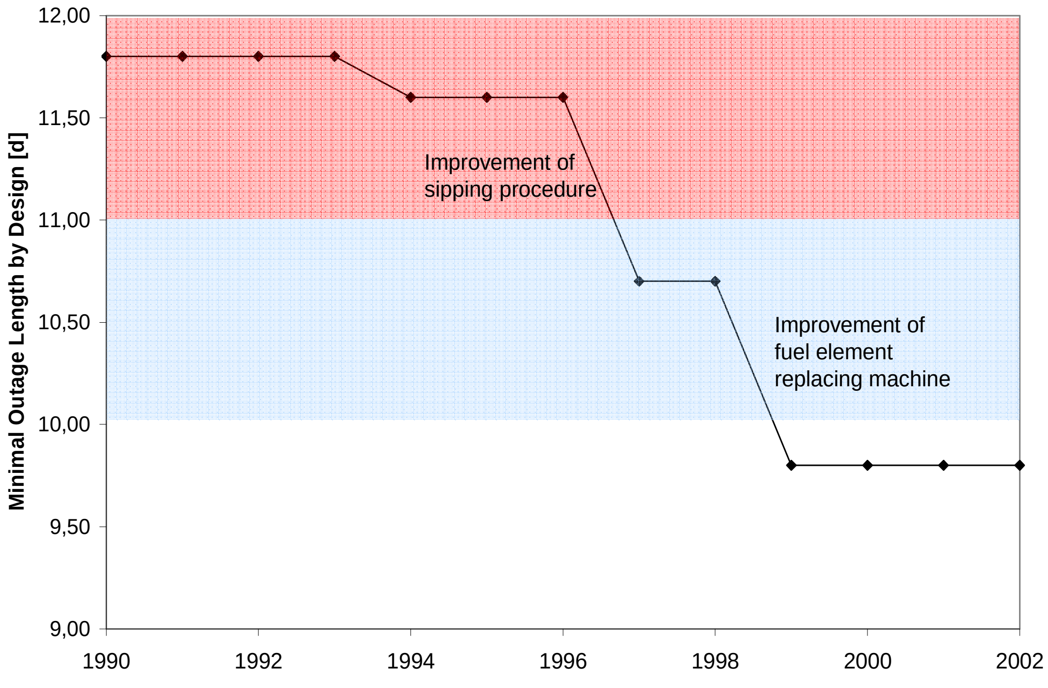

Figure 3: Development of the minimal-outage-length by design (MOD) of GKN II (Neckarwestheim / Germany)