An Approach to Nuclear-Power-Plant Life Management

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ABSTRACT

The plant life of a nuclear power plant (NPP) depends on degradation processes and ageing. Degradation is a deterioration phenomenon that can lead to component failure or limit the life of a component or the NPP itself. Ageing describes a continuous time or operational degradation of materials due to operational conditions, which include both normal and operating conditions. As a result of ageing degradation the state of the NPP or component can vary throughout the operating life. The degradation mechanisms for metallic components are general and local corrosion, erosion/corrosion, fatigue, corrosion fatigue, material changes due to irradiation and temperature, creep and wear. All the components of an NPP are subject to ageing, which may lead to the degradation of the physical barriers and redundant components, resulting in an increased probability of common-cause failures. The aims of NPP ageing management are to ensure that the necessary safety margins, adequate reliability and unforeseen and uncontrolled ageing of critical components do not shorten the NPP’s lifetime.

For the reasons stated above, plans are necessary to maintain the NPP in a state of high reliability. These are plans for an assessment of the life of the components that cannot be readily replaced, plans for operating life assessment or the planned replacement of major components where economic considerations will largely condition whether replacement or decommissioning should be pursued and plans for maintenance and replacements so that outages and delays can be minimised. In this paper some aspects of the process of NPP life management will be presented.

1 INTRODUCTION

There are numerous reasons to keep existing nuclear power plants in service as long as they can continue to provide safe and economical power generation. One of the reasons is the high cost of a new NPP in comparison to a gas-turbine power plant. Figure 1 shows the
relationship between specific investment costs for different types of power generation and the plant’s output power [1].

![Figure 1: Relationship between specific investment costs for different types of power generation and the output power](image)

The markings in Figure 1 are as follows:
A internal combustion Otto engines
B small Diesel engines
C gas-turbine power plants
Č large Diesel engine plants
D gas-turbine combined-cycle power plants
E classic coal-fired power plants
F nuclear power plants

Furthermore, in some countries there are difficulties with finding new locations for NPPs. Plant-life extension is, therefore, a very desirable option. The lifetime of the plant can be affected by:

- the normal wear of its components and systems, which depends particularly on the age, operating conditions and maintenance,
- the safety level must comply with the safety requirements applicable to power stations at all times and which could change with new sets of regulations,
- economics, the costs of nuclear power generation must always be compared with the costs of other methods of power production.

The term “plant life extension” refers to the operational or service life. The life management of an NPP is a broader term than life extension and has been defined as the integration of ageing management and economic planning to [2]:

- optimise the operation, maintenance, and service life of the system and the components,
- maintain an acceptable level of performance and safety,
- maximise the return on investment over the service life of the plant.

There are many different types of NPP and each plant has its own characteristics. Because of that, it is difficult to determine generic common rules for plant-life management. Some of the possible approaches are as follows:
1. determination of the nuclear power plant’s key components and classification,
2. degradation processes and degradation monitoring,
3. an acceptance criterion,
4. data collection and analysis,
5. decision on a component’s residual life.

2 DETERMINATION OF THE NPP’S COMPONENTS

An NPP has many components, which are made from a variety of materials. Each of these components is subjected to different ageing degradation processes [3]. The first step is to identify those components which are key when it comes to NPP safety and, considering the economic assessment, whose repair or replacement would cause a substantial rise in maintenance costs or prolong outage times. There are some other categorisation factors to be taken into consideration, such as the impact on plant availability, the radiation dose, the modifications required, the seismic loads, the degradation processes, the regulatory issues and the influence of the modification on the NPP’s safety. These are common categorisation factors, which in some cases can be disregarded or in other cases be important.

For most of the nuclear power plants with pressurised-water reactors (PWRs) the key components are the reactor pressure-vessel (RPV), the RPV internals, the reactor-coolant pressure boundary piping, the RPV safe ends, the control-rod drive housings and guide tubes, the vent system, the reactor vessel support, concrete structures (RPV pedestal, drywell foundation, biological shield, fuel pool slabs and walls, the reactor building basement sacrificial shield wall, the reactor building floor slabs and walls and turbine pedestal), the plant control centre and the emergency diesel generators [4]. Some of the possible categorisations of key components are as follows:

- category 1 components, which are generally considered to be irreplaceable, such as the reactor pressure vessel and the steel containment,
- category 2 components, which are replaceable, but are costly and require a long outage, an example of which is the steam generator and the reactor vessel head, which have been replaced many times,
- category 3 components, all other components important to safety, but not in category 1 and 2.

There are three categories mentioned in this approach, whereas in some other approaches critical and non-critical components are determined using appropriate screening criteria.

3 DEGRADATION AND DEGRADATION MONITORING

All the components of an NPP are subjected to degradation processes. For metallic components the main degradation mechanisms are general and local corrosion, erosion/corrosion [5], fatigue, corrosion fatigue, irradiation embrittlement and wear. These degradation processes affect metal components in two ways:

- they affect the microstructure of the material and its mechanical properties,
- they impose physical damage on the component by cracking or by metal loss.

The detection of degradation processes is an important issue in plant-life management. Detection techniques make possible the direct evaluation of a component’s degradation and also the monitoring of parameters important for the degradation mechanisms. The monitoring of the degradation processes includes online monitoring (water chemistry, temperature,
pressure, neutron flux, etc.), in-service inspection, and periodic testing of specimens made from plant material. Standard destructive testing (metallographic, hardness, tensile, impact, fracture toughness, etc.) and non-destructive testing methods (visual, liquid penetrant, magnetic particle, ultrasonic, radiography, eddy current, etc.) that satisfy the regulation requirements are used.

Table 1 shows some of the degradation mechanisms and the effect on the component [6].

Table 1: Some of the degradation mechanisms and the possible effect on metal

<table>
<thead>
<tr>
<th>Change of mechanical properties</th>
<th>Irradiation</th>
<th>Thermal ageing</th>
<th>Fatigue</th>
<th>SCC</th>
<th>Erosion-corrosion</th>
<th>Corrosion</th>
<th>Wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>cracking</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall thickness</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Deformation</td>
<td></td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td>●</td>
</tr>
</tbody>
</table>

Here, SCC is used to mean stress corrosion cracking. Table 2 shows some of the degradation mechanisms and the possible effect on the component.

Table 2: An example of the degradation mechanisms and the possible effect on some components

<table>
<thead>
<tr>
<th>Component</th>
<th>RPV</th>
<th>RPV head</th>
<th>CRDM housing</th>
<th>Reactor coolant pipeline</th>
<th>RC pump</th>
<th>Steam generator tube</th>
<th>Pressuriser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embrittlement</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cracking</td>
<td>●</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCC</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Wear</td>
<td></td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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4 ACCEPTANCE CRITERIA

Before making any decision on the residual life of a critical component, an acceptance criterion must be known. There are as many acceptance criteria as there are determined key components. These criteria can be divided into safety-related and economic-related criteria.

Safety regulations and industrial standards necessarily include margins and limits because of allowances for unknown factors. Safety requirements can change as a result of new regulations. With increased operating experience and with research and development results the limits may be reduced. Nevertheless, the priority must always be to maintain the safety and reliability of the NPP, to protect the environment and the public and to reduce the level of occupational exposure.

Each plant operator has to make an economic analysis of the management of key components. In most cases maximising the profit, reducing the cost of the operation, and maintenance are influential factors to be considered. However, the most influential is the cost of generating the electricity.

5 DATA COLLECTION AND ANALYSIS

For plant-life management the analysis must show that the plant will continue to operate within its design limits. Where a change in operation is desired there will be a need for safety analyses to cover the new operational conditions. The future challenges need to have an adequate knowledge of the current design basis of the plant, to have a correct picture of the actual state of the plant and to define the analyses needed to support the operation beyond the design life. This requires relevant data collection and analyses. The required data are in the following areas:

• generic information (degradation mechanisms, tribology, corrosion, material properties, equipment operation, operation history, etc.),
• specific plant information (initial condition, fabrication, plant configuration, codes and standards used, maintenance and repair, QA programme, technical specifications, etc.),
• ISI and surveillance programme,
• equipment test results and trends.

An analysis of the collected data will provide information about the condition assessment, the safety and the operational life prediction and economics of the operation.

6 DECISION

On the basis of the data collection, the data analyses and the acceptance criteria the operator of the nuclear power plant has several possibilities:

• if the estimated remaining component life is considerably greater than the target component life, no action is necessary,
• if the estimated remaining component life is close to the target NPP life, then preventive maintenance and improved operational procedures are needed,
• if the estimated remaining component life is less than the target component life, measures to slow down the degradation mechanisms must be taken, such as enhanced inspection, repair or replacement.

The decision on repair or replacement must be based on a safety evaluation, economics, reliability and other factors. In some cases the results of the evaluation might result in a shut down of the NPP.
7 CONCLUSION

This paper presents a short overview of the steps and possible considerations in plant-life management, which depends mainly on the components and equipment that are subjected to degradation mechanisms. Knowledge about ageing processes is needed, and implementing this knowledge into the lifetime assessment is one of the priorities of plant-life management. Important features of the approach to nuclear-power-plant life management are:

- a determination of the key plant components, based on screening criteria,
- the remaining life of a component is determined using available data analysis, as-built design documentation, the relevant regulatory requirements, the detected degradation mechanisms, the operational data, the in-service inspection results and other data,
- a comparison of the remaining life with the target life of the plant.

Significant research and development efforts on ageing, structural integrity and lifetime management have been made to maintain safe and economic operation. The integrity and ageing management of major mechanical components and systems significant to safety play a key role in all decision-making procedures.

REFERENCES


