Conference Paper

Aging Management in the Design of Nuclear Power Plants

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Abstract

The basic design includes: physical calculations; thermohydraulic calculations; design-basis justification of equipment strength. System-oriented and construction-oriented approaches are used during design and engineering to ensure the reliability of systems. System-oriented approaches include: analysis of prototypes; creation of systems with the minimum necessary number of components, use of redundancy, development of systems that do not allow the dangerous impacts of failure on their components (fail-safe design), optimization of the sequence of systems' element operation, preliminary calculations of the system under development reliability. This takes into account: R&D results; reference data from other nuclear facilities; aging materials and mechanisms. Aging management program is created during design and operation of a nuclear facility.

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1. INTRODUCTION

Since power generating units (PGUs) of a nuclear power plant belong to the class of unique objects with specific requirements for safety and reliability, target-oriented approach is used to justify design decisions related to their reliability.

Design requirements are set in such a way as to take into account and address the relevant mechanisms of aging, or to create the conditions for monitoring and maintenance over the life of nuclear power plant components.

In general, the design decisions are based and reflect the experience of the previous projects and their technology, the experience gained in the operation of nuclear power plants, they minimize aging of structures, systems and components of the plant, and ensure controlled plant operation during the entire lifetime of 60 years, and 100 years for the components required for decommissioning.

Figure 1 shows the place of the program for reliability in the design of nuclear power plants.

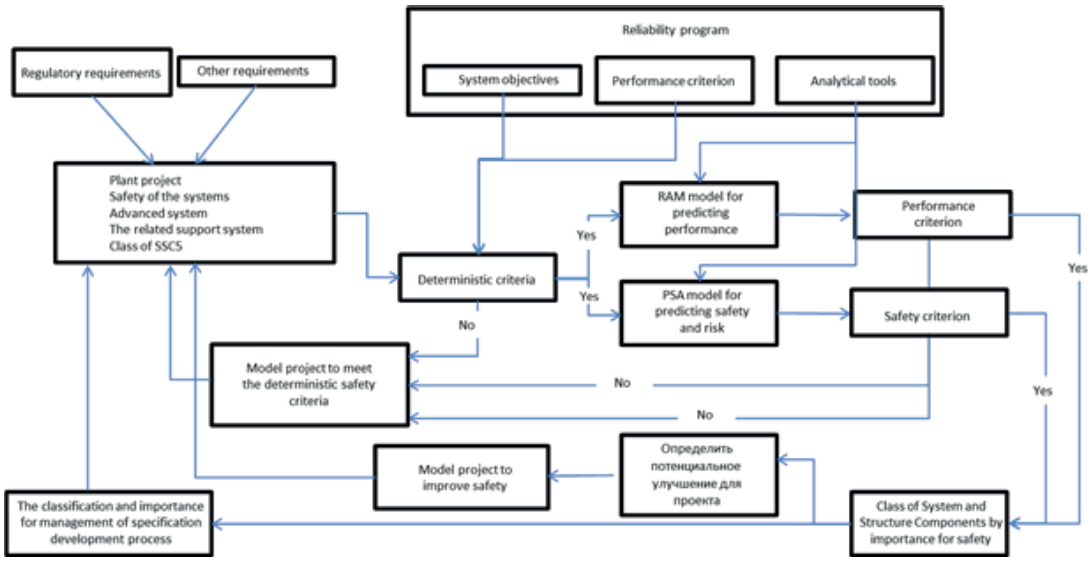

Figure 1: The place of the program for reliability in the design of nuclear power plants.

System-oriented and construction-oriented approaches are used during design and engineering to ensure the reliability of systems. System-oriented approaches include:

- analysis of prototypes;
- R&D for creation of new equipment;
- creation of systems with the minimum necessary number of components;
- use of redundancy;
- development of schemes that do not allow the dangerous impacts of failure on their components (fail-safe design);
- optimization of the sequence of systems' element operation;
- preliminary calculations of the system under development reliability.

2. REACTOR UNIT DESIGNING

The basic design of a reactor unit consists of three main parts:

- project part;
- design basis justification;
- requirements and baseline data

The design basis justification includes:

- physical calculations (neutron calculations, radiation protection calculations, calculations of fission products yield);

- thermohydraulic calculations (to justify the conditions of steady states and transients, for safety justification, for the analysis of dynamic stability, to support the design basis of process systems, etc.);
- design basis justification of the equipment strength (the analysis of the operating conditions of equipment, calculations of temperature fields, calculations of boundary conditions, strength analysis, etc.) and others.

Engineering requirements and baseline data include:

- engineering requirements for external systems (systems that provide the work of the reactor unit);
- technical specifications of the reactor equipment;
- engineering requirements for metal control systems;
- seismic requirements;
- engineering requirements for DCS;
- electrical requirements;
- engineering requirements for water-chemistry conditions;
- requirements for corrosion protection;
- manual for repair and maintenance of equipment.

Almost all the stages and phases of the development of the basic design of a reactor unit are focused on providing designed life of 60 years.

3. ACCESS TO THE COMPONENTS OF A NUCLEAR FACILITY FOR INSPECTION AND MAINTENANCE

The structure and layout of equipment and pipelines provide for their inspection, repair, hydraulic (pneumatic) tests, inspection of base metal and welded joints by non-destructive methods while in operation, individual and functional tests.

Where inspection of the base metal and welded joints cannot be done by conventional methods due to radiation conditions or layout of the equipment, appropriate means for remote inspection of equipment in these areas are provided.

4. MATERIALS AND MECHANISMS OF AGING

The materials selected for the systems and structures should have properties to withstand mechanical stresses and chemical conditions, fluid composition, flow rate,

Figure 2: A set of relationship between materials, environment and mechanical loads in an NPP.

radiation, moisture and other potential loads under normal and emergency operating modes.

The initial considerations for selection of materials used in a particular design are as follows:

- the purpose of the structure, its safety level, seismic category;
- for outdoor facilities, expected number of freeze-thaw cycles determining the required resistance to frost.

The degradation of metallic materials of the NPP comes under the influence of radiation, mechanical, thermal effects and aggressive environment.

NPP contains non-replaceable and replaceable components.

Replaceable components - fuel assemblies are exposed to corrosion in the coolant, to radiation growth, heat.

Non-replaceable components - reactor shell, piping, steam generators (30% replaceable), structural steel are exposed (in varying degrees) to radiation, thermal impact, vibrations (causing fatigue), corrosion.

Figure 3 shows a portion of the SG tube, exposed to stress corrosion cracking.

There were also cases of pit corrosion.

Under NPP conditions, resistance of tubes against stress corrosion cracking is affected by the quality of the coolant, the possibility of accumulation of corrosive impurities from the feed water.

Table 1: Impact of operating conditions under normal operating mode on various mechanisms of aging, and the possible effects.

Condition	Aging mechanisms	Effect/failure
Radiation	Changes of properties	Chemical decomposition Change in strength Change in plasticity Swelling Change in resistance Burnout
Stress (pressure)	Creep	Changes in the structure (for example, breakage or rupture)
Cyclic changes in temperature, flow and/or load Flow excited vibrations	Motion	Displacement Loose connections Destruction of the material (cracks)
	Fatigue	Damage or destruction. Deformation. Destruction of the material (cracks)
	Wear	Deterioration of surface conditions. Size change
Flow	Erosion	Change in strength
Water-chemistry conditions	Corrosion	Accumulation of radioactive substances. Reduction of strength. Leaks in equipment
Stress, deformation caused by the water-chemical conditions	Corrosion cracking under stress	Loss of integrity. Leaks in equipment Accumulation of radioactive substances

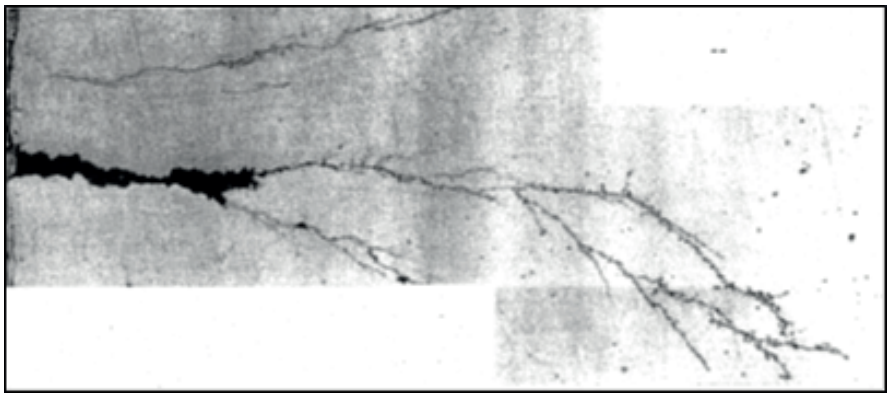

Figure 3: The crack on the tube 77-57-1-C2/3 from the SG (Specimen 1-f1, thin section No. 1).

5. AGING MANAGEMENT IN OPERATION OF NPP

In the operation of a power unit, continuous monitoring of the suitability of NPP structures, systems and components should be provided for the operation within design conditions and limits. It is necessary to control the conditions of load, processes,

and environment for a NPP component; they must remain within operating situations described in the design basis.

Condition monitoring of the components is provided by means of the project diagnostic systems in real-time, and by periodically examination of their conditions carried out by inspections, checks, tests.

Periodic monitoring of the state is carried out by inspections, checks, tests are performed both on operating units and during their shutdown in accordance with the schedules of dedicated programs.

The operating organization shall provide control over operating conditions and events that cause increased loads, beyond design basis operating conditions on the most important equipment.

The programs are developed for each structure, component or group of structures or components selected on the base of analysis.

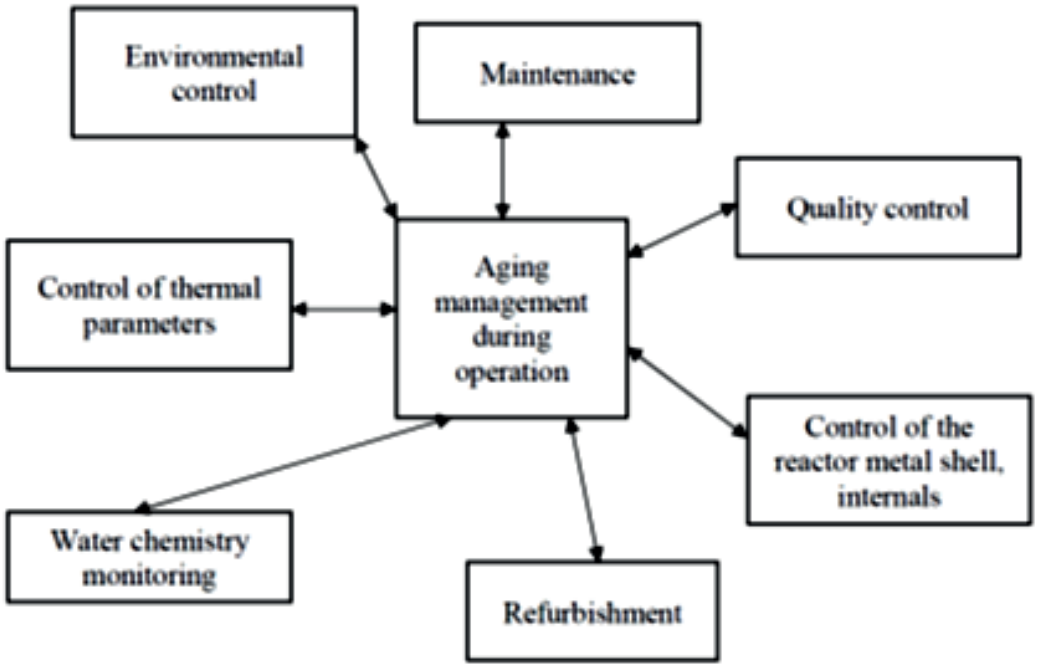

Figure 4: Aging management in the operation of a nuclear facility.

Equipment and pipelines as part of nuclear power plant systems must operate in accordance with the design limits and parameters of normal operation, except for failures leading to transition processes and the direct consequences of the failure.

The main reason for the degradation of the component due to aging are operating conditions under which certain mechanisms of aging are increased, and which, in the case of improper management of aging lead to the loss of an component's ability to perform a safety function.

The following is developed during operation:

- Technical control program during operation.
- Maintenance program.
- Condition control.
- The program for monitoring and analysis of structural fatigue.
- Radiation control program.
- The program for the control over the chemical composition of aquatic environments and monitoring the state of the metal corrosion.
- Other programs.

The additional programs may be developed during the life cycle if they are suitable.

In order to timely resolve arising issues, the management of interaction between the programs is created.

When performing tests, hidden defects of the components are revealed. Timely measures to eliminate the defect reduce the duration of the components malfunction.

6. EXTENSION OF THE SPECIFIED LIFE AND DECOMMISSIONING OF NUCLEAR POWER PLANTS

5 years before the specified (designed) service life is over, the program for examination of the actual state of the NPP, and the decision is made on compliance with the applicable safety requirements, the possibility of extending nuclear power plant life with the modernization, renovation for 5 to 15 years, or on the preparation for decommissioning.

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