BgNS TRANSACTIONS volume **24** number 1 (2019) pp. 68–77

Extension of the Lifetime of the Existing NPPs

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Abstract. This paper presents the activities undertaken by Kozloduy NPP to operate the units 5 and 6 beyond an established time frame defined by the licence and the original plant design - so called Long Term Operation /LTO/ which should be justified by safety assessment. Among the topics covered by the safety assessment, specific consideration were given to adequate management of the ageing processes that can affect the SSCs within the scope of the evaluation for long term operation and to ensuring that those SSCs will retain their capability to perform their intended safety functions throughout the planned period of long term operation.

The activities for units 5 and 6 plant life extension (PLEX) were allocated into two main stages:

Stage I: Comprehensive assessment (ageing management review) and residual lifetime evaluation of the equipment and facilities of Kozloduy NPP units 5 and 6. This stage was completed in 2012–2014.

Stage II: Implementation of Preparatory Programmes for Kozloduy NPP Units 5&6 Lifetime Extension. Regarding unit 5, this stage was completed in 2014-2016.

The Plant Life Extension (PLEX) project final reports justify the possibility of extending the operating life of unit 5 by 30 years, i.e. to 2047.

In November 2017, the plant operating licence for unit 5 was renewed. The licence renewal period of 10 years is the maximum as per the Bulgarian legislation.

Keywords: Long Term Operation [LTO], Ageing Management Review [AMR], Repair and Maintenance [R&M], SSCs [Structure System Components].

1 Introduction

Extension of the lifetime of the existing NPPs is one of the most important tendencies at the modern stage of development of the nuclear power industry and is the most efficient direction for financial investments for preserving generating capacities. This is determined by two major factors:

- the design-basis lifetime of 30 years for the existing NPPs was determined in the 50-60ss and reflects the conservative design basis for its justification at the moment when actual operating data on the tear and wear of nuclear power plant equipment were not available;
- works undertaken to extend the lifetime demonstrated that specific financial expenses ensuring the possibility of securing a license for the operation of the power unit beyond the assigned lifetime from a regulatory authority are significantly lower compared to commissioning of new generating capacity.

2 Bases for Service Life Extension of Kozloduy NPP

At present time power generation in Bulgaria depends on imported energy resources. In 2010 the import share in the total energy consumption was 66%. Over the recent 15 years the dependence of the primary energy resources consumption on the imported energy resources has failed to go below 60%. As the Bulgarian economy was growing, this dependence only increased, and during the crisis (2008) a share of import in consumption of the primary energy resources exceeded 75%.

Nearly all amounts of natural gas and oil being consumed are imported. Even coal, which accounts for most part of consumption of the primary energy resources, is imported in an amount of more than 25%. Development of nuclear power facilitates reduction of hydrocarbons supplies and carbon dioxide emissions to the atmosphere. Protection of climate and reduction of carbon dioxide emissions to the atmosphere is one of the main tasks of the European Union's energy policy. EU has certain commitments in terms of reduction of carbon dioxide emissions to the atmosphere in frames of its obligations under the Kyoto Protocol (an international agreement adopted in Kyoto (Japan) in December 1997 as a supplement to the UN Framework Convention on Climate Change (FCCC)).

In 1991-2002 Kozloduy NPP operated six power units meeting nearly 50% of total electricity needs of the country. In 2003-2006, to fulfill obligations undertaken in frames of Bulgaria's joining the European Union, Kozloduy NPP suspended operation of four first power units with

VVER-440 reactors before exhaustion of their design service lives. Thus, in 2012 the share of Kozloduy NPP in the national power generation was 33.5%. In this conditions service life extension of Kozloduy NPP was an important and timely objective.

The assigned service life of Kozloduy NPP Unit 5 expired in 2017 and 2021 for Unit 6 respectively. The Chief Designer defined the design service life as 30 years what corresponded to the basic calculations at the time of construction. At the present time, owing to many-year operating experience and actual operational data of the equipment wear-out, there is a possibility to extend service life of the existing power units. This is possible because of the following factors:

- the conservatism of the adopted basic calculations of the justification of the 30-year service life of existing NPPs;
- a large scope of modernizations implemented during the design service life;
- specific financial expenditures of service life extension of power units are significantly less than that of commissioning of any new power units (by Russia's experience, the specific costs are US$ 200–300 per 1 kW of power).

Kozloduy NPP with VVER-1000/320 reactors is similar to Russian power units with VVER-1000 reactors, many of which underwent comprehensive assessments and documentarily confirmed as feasible for service life extension beyond the design period. In 2008 the large-scale multifaceted modernization program was completed at Kozloduy NPP Units 5 and 6; the program was started in 2000. It pursued two goals, i.e. to improve safety and operating efficiency. This program took account of the IAEA recommendations given in the report IAEA-EBP-WWER-05, "Safety issues and their ranking for WWER-1000 model 320 NPPs", and included activities in the following areas:

- Generic issues and operating safety;
- The core and systems, inclusive, and the containment;
- Component integrity;
- Electric equipment and I&C;
- Internal and external risks;
- Accident analyses.

The work in these areas was carried out as separate measures in the period until 2008 (a total of 212 separate measures), and then was inspected by an IAEA Mission invited by the Government of Bulgaria, Bulgarian Nuclear Regulatory Agency and Kozloduy NPP. The goal of the Follow-up Mission was to assess compliance of the program implementation results and data of 1995 and the 2000s to the Agency's recommendations as to modernization of power units with VVER-1000 reactors (IAEA-EBP-WWER-05). The Follow-up Mission's findings demonstrated excellent grades and confirm uniqueness and completeness of the work done in frames of this program.

The duration of Kozloduy NPP Unit 5 operation beyond the design service life was determined with the account taken of technical and economic factors that include:

- Feasibility of ensuring and maintaining safety in operation of the NPP power unit;
- Availability of sufficient residual service life of irreplaceable and non-restorable equipment of the NPP power unit;
- Possibility to temporarily store additional quantity of spent nuclear fuel or its removal from the NPP site;
- Feasibility of ensuring safety in management of radioactive waste to be generated during the extended operation period.

In 2009 the Nuclear Regulatory Agency renewed operating licenses for Kozloduy NPP Units 5 and 6. The licenses were granted for eight years for Unit 5 and for ten years for Unit 6. They were granted in accordance with Article 22 of the "Licensing and Permitting Provision for the Safe Use of Atomic Energy," specifically, renewal of the previous license because of its expiration. The license was granted to Kozloduy NPP Unit 5 for operation of a nuclear device in accordance with the license conditions. Considering the above conditions and factors in regard of service life extension of Kozloduy NPP Unit 5 and basing on the Terms of Reference "Comprehensive Examination of the Actual Condition and Residual Life-time Assessment of Equipment and Structures at Kozloduy NPP Units 5 & 6" produced by Kozloduy NPP and "Proposal on Order Execution," in 2012 the work was started to comprehensively examine the actual condition and assess residual life-time of SSC under Contract signed by the Consortium OJSC "Concern Rosenergoatom - EDF" and Kozloduy NPP.

The license for operation of Unit № 5 was valid until 2017 and 2019 respectively for Unit 6. For the purposes to continue the operation of Units 5 and 6 of Kozloduy NPP (hereinafter referred to as Units 5 and 6) beyond their assigned service life, Kozloduy NPP initiated activities to extend their service life.

The activities to extend the service life (PLEX activities) for Units 5 and 6 of "Kozloduy" NPP were implemented in two stages.

During PLEX, Stage One, the following activities were implemented:

- comprehensive assessment of the actual condition and residual lifetime analysis of equipment and facilities for Units 5 and 6.
- detailed safety assessment of Units 5 and 6;
- putting together the scope and the range of works on preparation of Units 5 and 6 for LTO;
- assessment of economic viability of Units 5 and 6;

Based on the results of the work implemented were developed the programs for preparation for LTO which incorporate PLEX activities, Stage Two, for each power unit.

3 Methodology and Results

The general approach for performing comprehensive assessment of the actual condition and residual lifetime analysis of equipment and facilities for Units 5 and 6 was described in developed methodology.

In development the methodology the experience of OJSC "Rosenergoatom" and expertise of EDF were used in the field of management of ageing equipment and facilities and extension of the life of NPP units. The approaches to plant lifetime extension used in the Russian Federation and in France meet the requirements and recommendations of the relevant IAEA documents.

The main objective of the activities described in the methodology was the assessment of the actual condition and preliminary residual lifetime analysis of the equipment and facilities (hereinafter referred to as SSC- structures, systems, components, as accepted internationally) for Units 5 and 6 to determine the possibilities and conditions of lifetime extension and the development of programs for preparation of Units 5 and 6 for LTO.

In the course of comprehensive assessment were identified:

- SSC technical condition with identification of the dominant and potential ageing mechanisms; SSCs which residual lifetime is sufficient and which operation may be extended for a specified period of time during LTO for the power units;
- SSCs which technical condition and lifetime characteristics can be recovered or maintained through R&M during LTO for the power units;
- SSCs which by the preliminary (experts') opinion have a sufficient residual lifetime during LTO, for which there is the need for additional assessment, analysis and justification of the residual lifetime using special techniques and/or programs with involvement of specialized organizations;
- SSCs which lifetime will be exhausted at the time of the assigned service life of the power unit and which replacement is reasonable at the phase of NPP unit preparation for its operational life extension;
- efficiency (technical and economic) of the current system of maintenance and repair, including in-service inspection which allows to evaluate operational integrity of SSCs during LTO;
- ability to maintain SSC in sound condition throughout LTO of the units;
- the adequacy of the implemented scheduled activities to ensure the reliability of components and timely detection of their reaching the limit condition;
- ability to provide storage of spent nuclear fuel and radioactive waste generated at the phase of LTO;
- ability to safely handle radioactive waste, in particular during LTO.

Information and outcomes obtained during the comprehensive assessment of Units 5 and 6 was reliable and sufficient to determine the capabilities and conditions for PLEX of the power units, development of activities for preparation for LTO.

The scope of SSCs for Units 5 and 6 of "Kozloduy" NPP covered by the comprehensive assessment were conducted in accordance with the following five criteria [1]:

Criterion 1 – SSC important to safety, that retain their functional characteristics during the postulated initiating events to preserve the integrity of the coolant circuit, to possibly shut down the reactor and maintain it in the safe shutdown condition, to be able to prevent or mitigate the consequences of accidents;

Criterion 2 – Non safety related SSCs which failure could prevent performance of safety functions of other SSCs important to safety;

Criterion 3 – SSCs not safety-related, which must ensure functioning within the lifetime, with the failure of the scram system to actuate and with the complete loss of electric power;

Criterion 4 – Not safety-related SSCs which must ensure the functional integrity within the lifetime in accordance with the requirements of fire safety and.

Criterion 5 – Conventional plant or site SSCs required for sustainable electric energy generation during additional lifetime period.

In the process of comprehensive assessment of SSCs for Units 5 and 6 the following activities were implemented and the following objectives were addressed:

- collection, classification and analysis of SSC information, their operating history;
- identification of the ageing effects and degradation mechanisms, establishment of the decisive parameters of technical conditions and limit criteria (including, if possible, the experts' opinion);
- analysis of the existing repair and maintenance system. Assessment of the possibility to restore/maintain the lifetime characteristics of SSCs through R&M during LTO for the power units;
- analysis and assessment of the applied facilities and techniques for in-service inspection (diagnostics) in terms of efficiency in identification and description of the ageing mechanisms for different types of SSCs during LTO;
- development of recommendations to ensure during LTO the required technical conditions, SSC lifetime characteristics , to bring them in conformity with the requirements of the current TSD;

- preliminary assessment (experts' opinion) of the technical condition and residual lifetime based on the comparison of the actual condition of the critical SSCs components (with consideration for operating conditions) and requirements of engineering, design, and regulatory documentation;
- identification of the range of the additional activities for SSCs residual lifetime analysis;
- assessment of the feasibility to further operate SSCs or need for their replacement (modernisation);
- development of lists for SSC which technical condition and lifetime characteristics can be restored or maintained through R&M;
- development of lists for SSCs which residual lifetime is sufficient and which operation may be extended for a specified period of time during LTO;
- development of the lists for SSC for which it is necessary to perform additional work for the assessment, analysis and justification of the residual lifetime by using special techniques and/or programs with involvement of the specialized organizations;
- development of working and summary reports on the implemented SSC comprehensive assessment.

The following sources were used to collect the information on SSC operation history:

- design and construction documentation, equipment certificates, specifications, etc.;
- operating routines, manufacturing instructions on equipment operation and organization of production, process drawings and technical descriptions and other documentation;
- documented changes to the design decisions, replacements (projects, solutions, engineering decisions);
- reporting documents for R&M of components (including in-service inspection, testing, assessment s and trial runs);
- reporting documents for control of water chemistry and corrosion state of components;
- reports of violations in operation of units 5 and 6 of "Kozloduy" NPP;
- existing databases for reliability, defects, repairs, including for the entire period of operation;
- documentation on accounting of equipment working time, number of equipment working cycles;
- verbal information and assessments from the personnel;
- reporting documentation for earlier assessments and analyzes.

Analysis of the effectiveness of the current system of repair and maintenance included:

- assessment of the optimality of the adopted R&M strategies;
- assessment of the possibility of detecting and identifying the mechanisms of components ageing;
- assessment of the efficiency and timeliness of implementation of monitoring and recovery measures for components lifetime characteristics;
- assessment of the availability of the required range and quantity of spare parts;
- analysis of the documentary evidence of the effectiveness of repair and maintenance in terms of discovery and description of the aging mechanisms and implementation of monitoring and recovery of lifetime characteristics.

Based on the comprehensive investigation results no obstacle was detected for feasibility of safe and reliable operation of Kozloduy NPP Units 5 and 6 during the extended lifetime. As a result of activities completed within the first stage of Kozloduy NPP Unit 5 lifetime extension, the Program for preparation of Kozloduy NPP Unit 5 lifetime extension was developed, in which measures for implementation of the second project stage were planned. The measures intended for the justification of Kozloduy NPP Unit 5 lifetime extension, additional safety analyses, calculations and quantitative assessment of the residual lifetime time of the components of the safety related systems and generation related systems, form an essential component of the Program [2].

In pursuance of this program, an Agreement was concluded between Rusatom Service JSC – Concern Rosenergoatom – EDF Consortium (hereinafter referred to as the Consortium) and Kozloduy NPP Plc. for the performance of the work entitled "Development of feasibility justification for Kozloduy NPP Unit 5 lifetime extension to 60 years, analysis, calculations, and quantitative assessment of the residual lifetime of the SSCs".

A range of works was conducted to implement the second stage of the lifetime extension project for Kozloduy NPP Unit 5 from late 2014 to the end of 2016 under this Agreement.

In the frame of the second stage of the project the performed activities were divided into three main tasks:

- Assessment of the technical condition and substantiation of the residual lifetime of the equipment and pipelines of the reactor plant;
- Assessment of the technical condition and substantiation of the residual lifetime for other equipment and pipelines;
- Assessment of the technical condition and substantiation of the residual lifetime of buildings and structures.

Works on investigation, assessment of the technical condition and substantiation of the residual lifetime of the equipment and pipelines of the reactor plant were performed in the following sequence:

- Development of methodologies for investigation, assessment of the technical condition and substantiation of the residual lifetime of the equipment and pipelines of the RP;
- Development of programs for investigation, assessment of the technical condition and substantiation of the residual lifetime of the equipment and pipelines of the RP;
- Determination of the mechanical properties of the base metal and welded joint metal of the RP equipment and pipelines for the period at the end of the lifetime assigned by the design;
- Development of the working program for inspection of mechanical properties of the base metal and welded joint metal of the RP equipment and pipelines;
- Performing on-site inspection of mechanical properties of the base metal and welded joints metal of the RP equipment and pipelines;
- Development of the technical report based on the results of processing and analyzing the results of the on-site inspection of the mechanical properties of base metal and welded joints metal of the pipelines and equipment under investigation.
- Performance of neutron fluence calculations for the reactor vessel, reactor internals, reactor vessel fixing elements and definition of the values of radiation energy releases in the reactor internals and in the core barrel equipment for the strength calculations;
- Development of input data for the strength calculations for the RP equipment and pipelines;
- prediction of the mechanical properties and characteristics of RP equipment and pipelines materials;
- prediction of the mechanical properties and characteristics of reactor pressure vessel irradiated part materials (base metal and welded joints metal);
- performance of strength calculations;
- Development of conclusions on the technical condition and the residual lifetime of the RP equipment and pipelines.

The following was performed as part of works for assessment of the technical condition:

- technical documentation analysis;
- determination of the metal degradation mechanisms for the reactor plant equipment and pipelines;
- defining the key parameters and criteria of the metal condition assessment for the reactor plant equipment and pipelines.

The following was determined based on the results of assessment of the technical condition:

- compliance of the current condition of the considered RP equipment and pipelines with the regulatory and design documentation;
- sufficiency of the existing in-service inspection or necessity for additional metal inspection for the RP equipment and pipelines;
- determination of predominant ageing mechanisms and analysis of their influence during lifetime period extension, discovering additional requirements for considering these mechanisms when performing the residual lifetime extension works;
- compliance of the actual values of key metal condition parameters of the RP equipment and pipelines with the values established by the design and regulatory documentation;
- compliance of the actual loading parameters and their number with the design-basis values.
- In addition, as part of the technical condition assessment, work was performed to determine the mechanical properties of the base metal and metal of welded joints of MCP, pressurizer, surge line of the pressurization system, SG, reactor upper block, reactor vessel, supporting ring of the reactor plant of Kozloduy NPP Unit 5 to the end of design-basis lifetime period.

Upon the results of works performed as per the investigation programs based on the assessments of the technical condition, conclusions on the technical condition of the RP equipment and pipelines were issued for each piece of equipment or pipeline system. The conclusions summarize the results of the technical condition assessment works as of date of issue of the conclusion and allow making a conclusion whether it is expedient to perform works for the residual lifetime substantiation calculation for LTO period.

The following calculations were made as part of the residual lifetime assessment works:

- Static strength calculation;
- Cyclical strength calculation;
- Strength calculation under dynamic impacts;
- Justification of discovered defects and deformations;
- Brittle fracture resistance calculation.

The static strength calculations were performed to confirm that stresses (loads) at all the values of mechanical loads and temperatures in the loading modes prescribed by the design and actually implemented in the equipment and pipelines operating conditions do not exceed the allowable values defined as per the regulatory and technical documentation.

The cyclical strength calculations were performed as justification of impossibility of macro-crack appearance due to cyclical loading. As a result of the cyclical strength calculation, the accumulated cyclical damages were determined considering the extended lifetime period.

The strength calculations under dynamic impacts were performed for the combined effect of the operational and seismic loads and for the external dynamic impacts stipulated by the design. The strength of the equipment, pipelines and their supporting structures was assessed based on the allowable stresses and the cyclical strength criteria.

The defect development kinetics under cyclical and/or static loading was determined in the strength calculations for substantiation of the discovered defects. The result of the calculation was determination of the equipment lifetime.

The deformation calculation was performed to determine the strength of the reactor core baffle considering thermocycling caused by changes in the reactor power in the process of operation. The core baffle was analyzed as to non-uniform radiation swelling of structural steel of grade 08X18H10T and thermal stresses caused by non-uniform temperature field.

The brittle fracture resistance calculations were performed as the substantiation of the impossibility of brittle fracture initiation in NOC, AOC and DBA conditions if a structural element has a postulated defect in the form of a crack with the given dimensions, location and orientation. The calculations were made for linear-elastic conditions (considering SIC) and for elastoplastic conditions (calculation of J-integral).

The input data for the above calculations were the results of the following works:

- Creation of the input data base for thermo-hydraulic calculations and for the calculation of neutron fluence to the reactor vessel;
- Prediction of the number of loading cycles for the RP equipment and pipelines during the extended lifetime period;
- A complex of thermo-hydraulic calculations;
- Calculations of boundary conditions and temperature fields;
- a complex of hydrodynamic calculations;
- Performance of neutron fluence calculations and determination of radiation energy releases.

The results of the thermo-hydraulic calculations were the integral values of pressure, temperature, flow rates and level of coolant in the calculation cells that were used for calculation of heat transfer boundary conditions and temperature fields for the RP equipment and pipelines.

The calculations of heat transfer boundary conditions and temperature fields for the RP equipment and pipelines were performed for cyclical strength substantiation and BFR calculations.

The purpose of hydrodynamic load calculations was to determine the dynamic loads on the reactor plant equipment and pipelines that appear during pipeline breaks. The following was determined as a result of the hydrodynamic load calculations:

- dynamic loads on the reactor internals during breaks of the primary circuit
- system pipelines;
- dynamic loads on the reactor core fuel assemblies during breaks of the primary circuit system pipelines;
- reactive forces applied to the equipment vessels and pipeline bends;
- dynamic loads on the discharge pipelines during valve actuation;
- increase of total pressure in NPP rooms where RP safety-related systems are located.

The fast neutron fluence calculation and the calculation of radiation energy releases in the reactor internals and in the core barrel equipment were performed for BFR calculation of the reactor vessel, strength calculations of the reactor internals and the core barrel equipment.

The purpose of the calculation of neutron fluence to the reactor vessel, reactor internals, and the fixing system elements of the reactor vessel was the following:

- Determination of the fluence values for fast neutrons with energy above 0.1 MeV for the core baffle and the core barrel for the design-basis and the extended lifetime period;
- Determination of the damaging dose values for the core baffle and the core barrel for the design-basis and the extended lifetime period;
- Determination of the fluence values for fast neutrons with energy above 0.5 MeV for the reactor vessel, the supporting truss and the supporting ring for the design-basis and the extended lifetime period.

The purpose of the calculation of radiation energy releases in the reactor internals and in the core barrel equipment was to determine the density of radiation energy releases in the reactor internals, the reactor vessel and the core barrel equipment (thermal insulation of the cylindrical part of the reactor vessel, the supporting truss, the supporting ring, the dry shield and the ionization chamber channels).

Upon the results of all works performed for assessment of the technical condition and the substantiation calculation, conclusions on assessment of the technical condition and residual lifetime of the RP equipment and pipelines were developed for each piece of equipment or pipeline system. The conclusions summarize the results of all works performed, provide conclusions about the feasibility of subsequent operation of the RP equipment and pipeline in LTO period and describe, when required, the conditions of LTO and recommendations for their fulfillment.

Works on investigation, assessment of the technical condition and the residual lifetime substantiation of equipment and pipelines were performed as follows:

- input data analysis;
- development of programs for investigation, assessment of the technical condition and substantiation of the residual lifetime of SSC (hereinafter referred to as - programs for investigation);
- SSC technical condition control;
- assessment of the technical condition and substantiation of the residual lifetime of SSCs.

The input data analysis included:

- analysis of technical, design and operational documentation submitted to Kozloduy NPP at the stage of comprehensive investigation, results of comprehensive investigation of Kozloduy NPP Unit 5 SSCs;
- analysis of operating conditions, failures and damages of thermomechanical equipment and pipelines, changes in the project;
- specification of damaging factors, predominant and potential ageing mechanisms of the thermomechanical equipment and pipelines at the stage of comprehensive investigation of Kozloduy NPP Unit 5 SSC;
- determination of available data completeness and the need to obtain additional information and/or implement additional types of technical condition monitoring.

Such analysis specified:

- predominant and potential equipment, ageing mechanisms, damage growth processes in the material during operation and locations of such damages;
- assessment criteria for the technical condition and the residual lifetime;
- the list of standard representatives of the equipment and types of technical condition control for the inspection.

A list of additional data required to carry out further work was determined and appropriate programs for investigation, assessment of the technical condition and the residual lifetime substantiation of the SSC were developed as a result of a preliminary analysis. Programs for investigation are developed for each equipment unit and/or for a number of the same-type equipment units. The programs identified:

- criteria to assess the technical condition and the residual lifetime (description of damaging factors, predominant and potential metal ageing mechanisms, criteria to assess the technical condition and lifetime characteristics);
- list of SSCs required to perform follow-up inspection of the technical condition;
- procedures applied to assess the technical condition (assessment methods, scope and areas subject to technical condition investigations, assessment of the technical condition procedure, justification of chosen typical equipment);
- procedures applied to assess the residual lifetime (assessment methods, calculation models, lifetime characteristics/residual lifetime assessment procedures, types and methods of the technical condition follow-up investigation).

Metal condition is assessed according to the developed programs for investigation, including the following:

- SSC external and internal checks;
- non-destructive defect detection;
- metal hardness measurement with assessment of metal mechanical properties;
- existing defects/damages growth control using data on defects during previous operating periods;
- metal structure checks;
- possible failure cause analysis (availability in metal and welded connections of defects in workmanship, mounting, repair or damages owing to operation, which may lead to equipment destruction;
- changes of dimensions and equipment form as a result of plastic deformation, corrosion and erosive wear, etc.).

Conclusions on the technical condition and the residual lifetime of thermomechanical equipment and pipelines are developed according to results of works performed according to the Program for investigation. The conclusion contains recommendations for further operating conditions, including:

- M&R optimization;
- modernization of elements or their components;
- use of additional methods and technical condition monitoring and diagnosis equipment;
- change (mitigation) of operation conditions and modes;

- replacement of individual units and parts due to their technical condition or lifetime expiry.

Within the scope of Task 3 the Methodology for investigation, assessment of the technical condition and substantiation of the residual lifetime of the unit buildings and facilities of Kozloduy NPP Unit 5 was developed.

The methodology describes general approach, procedure and requirements for performance of works on investigation, assessment of the technical condition and substantiation of the residual lifetime of building constructions of buildings and structures of Kozloduy NPP Unit 5. Works on investigation, assessment of the technical condition and substantiation of the residual lifetime of Civil structures of B&S of Unit 5 at Kozloduy NPP included the following main stages [3]:

- carrying out the analysis of OD (including repair documentation), operational history, results of the previous monitoring of current condition (including the results of periodic investigations, of regulated maintenance, etc.) to identify problem areas and elements since the comprehensive investigation;
- carrying out the analysis of the state of Civil structures of B&S to determine the areas that require visual, instrumental control and laboratory research;
- development and coordination of Programs for investigation, assessment of the technical condition and substantiation of the residual lifetime of Civil structures of B&S;
- carrying out the investigation of Civil structures of B&S in accordance with the programs for investigation;
- development and drawing up of the relevant deliverables for investigation in accordance with the programs for investigation;
- carrying out the substantiation calculations;
- development and drawing up of conclusions on the technical condition and the residual lifetime of Civil structures of B&S, which are being developed on the basis of the results of the investigation (including operational control), of assessment of the technical condition and substantiation of the residual lifetime of Civil structures of B&S.

Analysis of the following information was performed:

- operation history (results of investigations and seismic monitoring; operating conditions; monitoring of precipitation and structure heeling; stress-strain state of the containment taking into account the results of the recent lift-off tests performed);
- detected degradation processes in materials and dynamics of their development;
- operational documentation including the results of operational control of the elements of Civil structures of B&S, sensor readings of monitoring equipment, readings of force measurement sensors in the stressed reinforcing ropes (for containment), information on repairs, modernizations, etc.
- entries from supervision inspectors.

The external inspection was carried out during the visual investigation:

- for elements of Civil structures of B&S from all sides at areas accessible for investigation;
- for places of application of concentrated loads;
- for places of run of communications (penetrations, air ducts, cables) for corrosion on metal surfaces, defects in welds or other damages that can affect the integrity of the seals;
- for places of connection of Civil structures of B&S with other Civil structures of B&S (technological, transient racks, reactor auxiliary compartment the containment, etc.).
- for places of additional visual inspection identified in the Program.

According to results of visual investigation, the amount and types of further instrumental investigation were determined, in particular, places: for the instrumental determination of mechanical properties of concrete; assessment of reinforcement and coating corrosion, sampling for laboratory tests. During the instrumental investigation of Civil structures of B&, the following was determined:

- parameters of visible defects detected by visual investigation (deposit, crack width and length of cracks, their locations, and others);
- physical and mechanical, chemical properties of materials using non-destructive and destructive methods of control;
- degree of corrosion of the metal coating;
- thickness of concrete and its degree of carbonization;
- state of reinforcement in structures (corrosion);
- if necessary, and by measurement capability – diameter of reinforcement, the degree of corrosion damage;
- degree of corrosion of reinforcement according to the specific ohmic resistance of concrete, according to electrochemical potential in the areas inadmissible due to crack width.

During steelwork investigation, the following parameters were recorded:

- deviation of sections, lengths of elements, general dimensions of structures from the geometric dimensions adopted in the project, contributing to the weakening of the elements and eccentric load application;
- deviation of metal structures from design-basis position; structural deformation;
- curving of elements of metal structures exceeding the permissible values;
- local curving of elements of metal structures; cuts that weaken the cross-section of elements; misalignment and inaccurate adjustment of the elements in the nodes of connection; brittle or fatigue cracks in the parent metal; cracks in the welds;
- disorder in bolted and riveted joints; destruction of protective coatings and corrosion of metal.

The following was determined in damaged areas of the structure:

- geometric dimensions of the elements;
- condition of components of connection;
- depth of concrete damage;
- depth of concrete carbonization;
- degree and depth of corrosion of reinforcement.

Determination of the strength characteristics of concrete of Reinforced Concrete Structures of NPP was carried out using combined method consisting of non-destructive methods: ultrasonic method for determining the strength (BDS 15013:1980), shock pulse method (or rebound, or plastic deformation) and the method for determining the strength of the concrete by separation with shear fracture (BDS EN 12504-2,3) and determination of water tightness (BDS EN 12390-7). The combination of methods allows to achieve more reliable test results. The size and number of samples were determined by the requirements of the relevant standards for this type of control. Test methods according to BDS EN 12504-1,2 (in terms of determining the compressive strength) were used to carry out concrete investigations. Determination of frost resistance was conducted acc. to BDS EN 12390-8 (method of determining of the frost resistance is determined on the basis of the number of selected core samples of concrete and the required time to complete the tests). To determine the leak tightness, BDS EN 12390-7 was used. ISR investigations (internal Sulfate corrosion) for selected samples of Civil structures of B&S being investigated were made. For prestressed concrete samples taken from the containment, further ASR investigations (alkali-silica reaction) were carried out on the X-ray tomograph or by method of X-ray difractometry. As part of the investigation, assessment of the technical condition and substantiation of the residual lifetime of buildings and structures of Kozloduy NPP Unit 5, determination of the actual characteristics of the ground base under the RC and spray ponds with determination of the necessary scope of field geological and geophysical investigations, laboratory tests by the procedure for performing field and laboratory investigations was carried out [4].

For reinforced concrete structures (RCS), the main parameters, that determine the technical condition of Civil structures of B&S, were:

- physical and mechanical, chemical properties of concrete;
- long-term strength of concrete;
- stress state and width of major cracks in RCS.

For metal structures (MS), the main parameters, that determine the technical condition of Civil structures of B&S, were:

- deformation of elements - deflections, heelings, change in shape of crosssections;
- physical and mechanical properties - steel grade (using a hardness tester);
- change of profile wall thickness, including with regard to corrosion (with thickness indicator).

Condition of Civil structures of B&S was assessed by the system of design-basis criteria. The readings of all full-time measurement systems, investigating instruments were compared with these criteria. Also, the visual assessments of the state of the surfaces of bearing structural elements was taken into account [4].

4 General Conclusions

As the result of works on assessment of the technical condition and the residual lifetime of Kozloduy NPP Unit 5 elements in accordance with the methodologies and programs, the Rusatom Service JSC – Concern Rosenergoatom JSC – Électricité de France Consortium (with assistance of specialized organizations) has prepared 55 conclusions on the technical condition and the residual lifetime of SSC according to the SSC list. On the basis of these documents it was established that the equipment and systems investigated are in operable condition and, in consideration of the existing M&R system, may be operated up to 2047 if subject to management of lifetime properties in accordance with the RTD valid at Kozloduy NPP and recommendations set forth in these conclusions. For assessment of the residual lifetime, the technical requirements for equipment, as well as appropriate regulatory and technical documentation on design, construction and operation of the relevant SSC were taken into account. Assessment of the residual lifetime was performed for critical elements of equipment that experience during the operation the action of mechanical, hydrodynamic and thermal loads in a wide range of cycles, levels of stress and strain, defect sizes, environmental impacts. Assessment of the technical condition of the equipment was carried out by methods and means of nondestructive testing according to current standards (diagnostic, defectoscopy) with the establishment

of the following main parameters being used for residual lifetime calculation: loading characteristics (stresses, deformations, temperatures); characteristics of defects, especially cracks (their size, location areas and orientation); characteristics of properties of construction materials (base metal, weld metal and claddings). During the calculation and experimental assessment of the residual lifetime of SSC, the following was taken into account: cumulative cyclical, temporary, corrosion, etc. damages, as well as main constructive, technological and operational factors that change the features of limit states. The data obtained (with introduction of margins on stresses, deformations, durability, critical temperatures, sizes of the cracks) was used to determine the lifetime up to exhaustion of the calculated residual lifetime or up to the next inspection and assessment of the state of NPP equipment analyzed. Diagnosis of the basic parameters of strength, lifetime and operational safety of technical systems is characterized by the historical-made sequence of formation of basic scientific foundations for development of engineering methods of their calculations and tests, creating the design and manufacturing norms and rules, ensuring the functioning within the prescribed limits of design-basis modes and parameters [5].

References

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