Challenges in Ageing Management of VVER Main Components for LTO

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ABSTRACT

The planned operation of VVER nuclear power plants for 60 years and the consideration of operation up to 80 years require the continuous development of ageing management programs and periodic reassessment of component ageing effects. The key objective is to demonstrate the long-term integrity and functionality of structures, systems, and components important to nuclear safety while maintaining sufficient safety margins throughout the extended service life.

This presentation focuses on the Ageing Management Review (AMR) of major VVER reactor components and the challenges associated with increasing operating lifetimes. Particular attention is devoted to the reactor pressure vessel and reactor internals, with emphasis on ageing mechanisms relevant to long-term operation, including irradiation embrittlement, fatigue, irradiation-assisted degradation, radiation swelling, and dimensional changes.

For VVER reactor internals, the main challenge is radiation-induced swelling and related dimensional changes, whereas for the reactor pressure vessel the focus is on the evaluation of surveillance program results, irradiation embrittlement assessment, and the potential implementation of vessel annealing or other configuration changes to support further lifetime extension.

Long-term operation beyond the 60 years requires continuous improvement in the understanding of ageing phenomena and the corresponding refinement of ageing management processes. Challenges for operation beyond 80 years should be established, and once a common framework has been agreed, the research and industry activities should commence.

Safe and Sustainable Long-Term Operation and Optimised Lifetime Extension of Nuclear Power Plants

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ABSTRACT

Safe, reliable, and sustainable long-term operation of nuclear power plants has an important role in low-carbon and stable electricity generation. Through its over 45 years of experience on safe and efficient operation of Loviisa Nuclear Power Plant, including two successfully executed life-time extensions, Fortum has wide expertise and long experience on systematic plant lifetime management and continuous holistic development of power plant's operations to enable long-term operation. Loviisa consists of two VVER-type PWR units, commissioned in 1977 and 1980, which have been granted operating licences until 2050, enabling up to 70 years of safe operation. Safe and sustainable long-term operation means proactive investments, modernization, and robust lifetime management—so the plant remains safe, reliable, and profitable for decades. Successful lifetime extensions are founded on detailed assessment on the power plant's condition, and evaluation necessitated modernization actions to enable prolonged operation with related business case assessments to justify the economical feasibility of the life-time extension. For the economical feasibility and power plant's reliable operation, it is then important to ensure that the necessitated modernization projects, e.g. related to plant's I&C, will be executed efficiently. This presentation will provide insights on Fortum's lessons learnt on large scale modernisation projects. Important factors include for example strong hold on owner's scope, clear design bases and effective configuration management. Besides the life-time extensions and related modernization projects, the presentation will provide an overview of Fortum's effective holistic plant lifetime management approach, including systematic ageing management a dedicated integrated plant lifetime management organization, graded classification of systems, data-driven monitoring, and long-term outage and maintenance optimization. Overall, a strong safety culture, operational excellence, vendor independency, and

technical ownership are some of the key enablers for successful and sustainable long-term operation of PWR nuclear power plants.

Development and Implementation of Safety Upgrades for VVER Reactors in Support to Long Term Operation

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ABSTRACT

The Fukushima Daiichi accident, together with the need to ensure safe long-term operation of nuclear power plants, triggered a large number of modifications and modernization programs at VVER plants worldwide. The primary focus has been placed on enhancing plant robustness against external hazards and implementing measures for severe accident management and mitigation. Initially, severe accident management strategies were expected to ensure containment pressure control during the first 72 hours following accident initiation. However, based on recent studies and international operating experience, the recommended coping period has been extended to more than a week.

Analyses supporting the identification and implementation of plant improvements have traditionally been based on deterministic approaches. In recent years, however, an increasing number of utilities have recognized the inherent uncertainties associated with severe accident progression and the need to incorporate probabilistic insights through risk-informed decision-making. This approach combines deterministic safety assessments with probabilistic risk analyses to support decision making regarding the necessity, prioritization, and effectiveness of safety upgrades.

Furthermore, risk-informed methodologies can be extended to plant operation and maintenance activities, resulting in significant benefits such as increased operational flexibility through reduced shutdowns, outage duration reduction through online maintenance, optimization of surveillance and testing intervals, and reduced radiation exposure through risk-informed in-service inspection programs.

In this framework, Westinghouse initiated a development program focused on both the design and qualification of advanced safety systems for VVER reactors and the implementation of risk-informed applications aimed at operational improvement. As a result, two new safety systems have been successfully delivered to VVER plants, and a practical framework for the implementation of risk-informed applications has been developed based on accumulated Westinghouse industry experience.

This presentation summarizes Westinghouse's experience in the implementation of safety upgrades for VVER reactors. Specifically, it presents insights from the design, development, qualification, and licensing of the Containment Filtered Venting System (CFVS), based on the Dry Filter Method, for Temelín NPP Units 1 and 2, and the Long-Term Containment Cooling System (LTCCS) for Rivne NPP Units 1 and 2. In addition, the presentation introduces a framework for the deployment of risk-informed applications in VVER reactors and discusses the associated safety and operational benefits.

Assessment and Monitoring of Thermal Aging from an LTO

Perspective

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ABSTRACT

The planned extension of operation at Paks Nuclear Power Plant from 50 to 70 years requires reassessment of ageing effects on safety-related mechanical components. This presentation discusses thermal ageing assessment and monitoring in support of long-term operation (LTO), linking material behaviour, structural integrity and ageing management.

A material- and component-specific approach combines susceptibility screening, operating conditions and available material data. Different assessment strategies are considered for carbon and low-alloy steels, wrought austenitic steels, and cast austenitic components and welded joints, with particular attention to ageing-induced changes in fracture resistance.

For susceptible cast austenitic components, conservative aged-state J–R curves provide inputs for evaluating postulated flaws and margins against fracture instability. Long-term embrittlement saturation and uncertainties in material properties are addressed. The assessment of main isolation valve bodies illustrates the application of this approach to plant components.

Monitoring builds on experience with periodic instrumented indentation testing to track mechanical-property changes and support verification of assessment assumptions, while recognising the limitations of indirect fracture-toughness estimates. The overall emphasis is on integrating analytical assessment and targeted monitoring to support the continued validity of time-limited ageing analyses and identify appropriate ageing management measures for extended operation.

Keywords: thermal ageing; Paks NPP; long-term operation; structural integrity; instrumented indentation teszting.

Impact of Thermal Ageing on the LTO of VVER Piping and Components

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ABSTRACT

This study evaluates the thermal ageing of VVER primary circuit materials based on investigations conducted within the EU-funded DELISA-LTO project. The core of the DELISA-LTO project involved experimental programs, comprising tensile, Charpy impact, fracture toughness, and Small Punch testing, which were performed on VVER-440 and VVER-1000 structural steels and welds that experienced up to 30 years of operational thermal ageing and simulated artificial thermal ageing equivalent to 60 years. To accelerate the 60-year thermal ageing process in a laboratory environment, an Arrhenius equation approach was applied.

The primary objective of this work is to determine the onset of thermal ageing and evaluate the resulting material degradation. To achieve this, a comprehensive literature review was performed to collect and analyze existing thermal embrittlement models, leading to the selection of candidate models for verification against the DELISA experimental dataset. To mitigate data scatter caused by confounding variables, such as specimen size effects, extraction locations, and specific loading conditions, the datasets from each participating testing laboratory were analyzed independently.

Finally, this paper quantifies the impact of thermal ageing on the mechanical properties, transition temperature, reference temperature, and fracture toughness of ferritic and austenitic primary circuit piping and components. Critical conclusions regarding the applicability and accuracy of existing predictive models are also presented.

A Coordinated Framework for Proactive Materials Aging Management in Nuclear Power Plants

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ABSTRACT

The EPRI Materials Degradation Matrix (MDM) and Issue Management Tables (IMTs) form a coordinated framework supporting the proactive management of materials degradation in nuclear reactor primary systems. The MDM and IMTs are updated periodically to reflect the current state of knowledge and operating experience. Together, these documents provide utilities and industry stakeholders with a structured basis for identifying, understanding, and prioritizing degradation phenomena and associated research and development (R&D) needs. The MDM summarizes the current state of industry knowledge on degradation mechanisms across water-cooled reactor types (boiling water reactors (BWRs), pressurized water reactors (PWRs), water-water energetic reactors (VVERs), and Canadian deuterium uranium (CANDU) reactors), while the IMTs translate these insights into prioritized R&D gaps and actionable program requirements that guide long-term materials management strategies, with the objective of ensuring that primary system components remain serviceable throughout plant life, including long-term operation.

A historical perspective is presented, describing the evolution of IMTs from their initial development in the mid 2000s as comprehensive component-based assessments to their current role as gap prioritization tools informed by MDM results, operating experience, and completed R&D. Successive revisions reflect continuous updates driven by new data, industry learning, and changing asset management priorities, including closure of resolved gaps and identification of emerging issues. The status of revisions across reactor types is summarized, emphasizing ongoing efforts to refine gap prioritization, incorporate international operating experience, and maintain consistency across programs. Recent updates demonstrate both reduction in the number of open gaps through research progress and refinement of priorities as plants age and knowledge evolves.

Finally, ongoing and future development plans are outlined. These include continued integration of MDM insights into IMT updates, expansion of international scope, enhancement of predictive capabilities for key degradation mechanisms such as stress corrosion cracking, and continued alignment of R&D priorities with long-term operation challenges. The combined use of MDM and IMTs remains central to ensuring that nuclear reactor materials degradation is understood, monitored, and managed in a proactive, risk-informed manner supporting safe and economical nuclear power plant operation.

Assessment and repair of stress corrosion cracking in steam generator divider plate connecting welds

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ABSTRACT

In June 2022, during a routine inspection that was part of the annual planned outage of the Gösgen Nuclear Power Plant, three linear crack indications were found on the hot side of the divider plate of steam generator 20. The cracks were located on the lower half of the weld between the tube sheet and the divider plate, and had lengths of 32 mm, 39 mm and 79 mm, which was long enough to require mandatory evaluation by the national regulation ENSI-B03 due to exceeding the maximum allowable fault length of 14 mm. A schematic representation of the steam generator floor and divider plate is provided in Figure 1.

A two-step plan was created to rectify the issue with minimum downtime. First, the risk of total failure was assessed on plant safety and structural-mechanical grounds to show that the steam generator could be run safely for an additional operational cycle, which provided the necessary time to devise a repair concept accounting for any flaw depth and the physical tool to facilitate the repairs, an innovative, rack-mounted and remote-controlled repair apparatus that could hold and utilize the necessary tools to erode away and weld over the damaged welds to create a new, undamaged surface, all without exposing workers to high levels of ionizing radiation. This paper

reports the implementation of this novel method for handling a potentially serious safety issue in a difficult-to-replace component without any unplanned downtime, and provides recommendations for plants that might experience similar issues.

Practical Experience in Fuel and Material Qualification Supporting Nuclear Plant Long-Term Operation

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ABSTRACT

As nuclear power plants worldwide pursue Long-Term Operation (LTO) beyond their original design lifetimes, the need for reliable fuel and material qualification becomes increasingly important for maintaining safety, regulatory compliance, and economic performance. Studsvik, with decades of experience in nuclear fuel testing, hot-cell examinations, materials research, and ageing management, provides independent technical support to utilities, vendors, regulators, and research organizations throughout the entire nuclear fuel and material lifecycle.

This presentation highlights how Studsvik supports LTO programmes through advanced experimental testing, post-irradiation examination (PIE), transport of irradiated materials, and the development of ageing management methodologies. Special attention is given to two international collaborative programmes operated by Studsvik: the Studsvik Cladding Integrity Project (SCIP), addressing fuel reliability, cladding behaviour, accident performance, and spent fuel storage challenges, and the Studsvik Materials Integrity Life Extension (SMILE) project, which provides critical data on ageing mechanisms affecting reactor pressure vessels, core internals, welds, and other safety-significant components.

The presentation demonstrates how access to irradiated materials from both operating and decommissioned reactors enables the generation of high-quality experimental data and the

validation of predictive ageing models. These insights support plant life extension programmes, operating licence renewals, and informed decision-making for ageing reactors. The presentation also discusses recent developments in qualification of advanced fuel components and materials for future nuclear applications.

Through international cooperation and unique testing capabilities, Studsvik continues to play a key role in reducing technical uncertainty and supporting the safe, reliable, and sustainable operation of light water reactors well beyond their original design life.

Radioactive Liquid Waste Treatment Using Nures® Ion Exchange Technology for Safe and Cost-Efficient Long-Term Operation

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ABSTRACT

Fortum's NURES® liquid waste treatment technology is designed to efficiently purify radioactive liquids with high selectivity inorganic ion exchange materials. Fortum's own NURES® product portfolio includes four granular ion exchange materials, CsTreat®, SrTreat®, CoTreat®, SbTreat®, designed to remove cesium, strontium, cobalt, and antimony, respectively. The NURES® materials have been in use for decades in Finland and globally in both operational NPPs as well as in plants under decommissioning and proven effective in decontaminating large volumes of radioactive liquid with high volume reduction and decontamination factors. These materials are applicable for a variety of radioactive waste liquids e.g. high salt evaporator concentrates, spent fuel pool waters and contaminated sea water.

NURES® materials offer multiple advantages compared to many other currently available ion

exchange materials, such as high selectivity, radiation tolerance, physical and chemical stability, thermal resistance, and effective performance even in solutions with high salt concentrations. Moreover, they can achieve notable volume reductions contributing to significant cost savings in final disposal and minimizing the environmental burden. Such qualities make them a valuable element for safe and cost-efficient long-term operations. Effective management of radioactive wastes also positively contributes to the public opinion towards production of nuclear energy.

The product development and production are done in Finland where the ion exchange materials were first used in Fortum's own Loviisa NPP operating two VVER-440 reactors. Through the operating experience, Fortum has gained knowledge on liquid waste treatment needs and has been able to assist other numerous nuclear facilities to optimize their waste treatment processes. Using the NURES® technology, the decontaminated liquids can be released to the environment or disposed of as non-radioactive waste which results in major cost savings in final disposal expenses.