STUDY OF ASPECTS RELATED TO AGEING OF VVER 440 NPP SAFETY STRUCTURES

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Abstract. In the paper NPPs and NPP safety systems (containments) are briefly described. Furthermore, attention is devoted to the detection of concrete changes or ageing, test procedures (particularly those related to structural integrity and leaktightness) and repair technologies are specified as well as prerequisites for lifetime preservation or extension.

Keywords: *Ageing of concrete structures, Assessment and elimination of ageing effects*

Introduction

The main objective of the containment system is to prevent the release of fission products into the environment in the event of a Loss-of-Coolant Accident (LOCA) in the primary system, to provide shielding against radiation during normal operation, and to assure the required leaktightness and structural integrity.

Concrete containments in nuclear power plants (NPP) consist of several components which conjointly fulfil a number of functions (i.e. to withstand loads, to shield against radiation and to provide for leaktightness). These components are first of all concrete, steel reinforcement, and metallic components which are a part of the hermetic boundary.

Concrete is a durable material and its performance when fulfilling containment functions in a NPP is good but, similarly to other safety systems in NPPs, there is a necessity to control potential age-related degradation of concrete containments. The application of efficient ageing management programmes to concrete containments proceeds from the schemes aimed at NPP life extension and from the strategy of NPP decommissioning necessitating good containment performance in the period after the normal NPP lifetime expiration.

1. VVER NUCLEAR POWER PLANTS.

Water-Water Power Reactors (VVER).

In the Slovak Republic nuclear power plants with reactors VVER 440 V230 and V213 have been built. VVER reactors are actually Soviet-designed pressurised water reactors. NPPs with VVER 440 reactors are provided with a containment housing the reactor pressure vessel (it should be pointed out that after an extensive reconstruction of the VVER 440 V230 NPP in Jaslovské Bohunice, the V230 reactor confinement features approach to those of the V213 containment). The containment structure consists of a system of mutually interconnected reinforced-concrete hermetic compartments designed to confine radioactive leakages under accident conditions. To reduce the overpressure in the event of LOCA, the containment is equipped with a spray system fed with cold water and a bubbler condenser system. Containment leaktightness is achieved by means of metallic liner applied to containment walls and other components provided with multi-layer coatings.

The containment of a VVER 440 NPP is created by reinforced-concrete walls consisting of cast reinforced-concrete blocks forming a monolith. Floors and ceilings of individual hermetic compartments are composed of either cast reinforced-concrete blocks or a combination of cast concrete and pre-cast reinforced-concrete blocks.

The hermetic boundary is provided by a steel liner and metallic components such as hermetic doors, hatches and other sealing items (mechanical and electrical penetrations, isolation valves etc).

2. AGEING OF REINFORCED-CONCRETE CONTAINMENTS.

The ageing of reinforced-concrete containments means a change of their properties as a result of on-going microstructural changes and as a result of environmental impacts.

The satisfactory performance of reinforced-concrete containments for a prolonged period depends to a large extent on the lifetimes of essential components. The methods designed to detect degradation should, therefore, concentrate on individual containment components and reinforced concrete constituents (i.e. concrete, steel reinforcement, penetrations, liner, seals and protective coatings).

Concrete.

The durability of concrete materials may be affected as a result of chemical or physical attacks.

Chemical attacks may be encountered in several forms, e.g. attacks of acids used as mediums. Chemical reactions may occur on unprotected concrete surfaces but as a result of cracks the whole cross-section of the structure may be affected.

Physical attacks include concrete degradation as a result of external effects, e.g. exposure to elevated temperatures. Changes of mechanical properties are mostly induced by a changed water content in concrete.

The primary method used to identify defects is visual inspection. Its disadvantage consists in the fact that, if visible symptoms are absent on the surface, it is incapable of revealing internal defects. To detect concrete structure degradation, a number of methods have been developed which are classified as destructive and non-destructive testing methods.

During the Integrated Leakage Rate Test (ILRT), the reinforced-concrete containment leakage rate is determined by pressurising the containment with air to a predetermined pressure level and by monitoring the leakage of air as a function of time. The leakage rate is defined by changes in containment air weight. This method may be complemented by leak detection through application of a soap solution to critical locations and subsequent visual inspection of bubble formation after containment pressurisation. Leak detection is performed all over the hermetic boundary.

Steel reinforcement.

Potential causes of steel reinforcement degradation include corrosion, elevated temperature, irradiation and fatigue. Corrosion is the major cause of ageing of NPP structures.

In the case of high-quality compacted concretes, steel reinforcement with appropriate cover concrete should not be susceptible to corrosion since highly alkaline conditions existing in the concrete (pH > 12) result in the formation of a passive layer of iron trioxide on the steel surface (i.e. metallic iron will not be available for anodic activity). If, however, the concrete pH value drops below 11, a porous oxide layer (rust) may be formed as a result of corrosion. Carbonisation or the presence of chloride ions may destroy the passive layer of iron trioxide.

The assessment of steel reinforcement includes, first of all, determination of steel characteristics (e.g. location and dimensions) and the presence of corrosion. The methods available for steel monitoring and evaluation involve mechanical and ultrasonic tests, removal of core samples with subsequent chemical and physical testing, and probe tests to evaluate the progress of corrosion.

Hermetic boundary components.

The most important component of the hermetic boundary is the steel liner anchored to load-bearing reinforced-concrete walls. In addition to providing leaktightness, the liner enables decontamination operations. Other hermetic boundary components, such as hermetic doors, hermetic hatches, vent system penetrations, piping and cable penetrations, enable personnel access, installation of mechanical equipment, operation of vent systems and penetration of cables and lines.

The sealing nodes of these hermetic boundary metallic components are implemented by welding, closing mechanisms and removable seal joints.

Repair of leaks in these sealing nodes depends on the leak size and type. Weld joints, for instance, are repaired by overlapping or by re-welding. In the case of joining stainless steel and carbon steel materials, a suitable filler material shall be used.

The leaktightness of closing mechanisms and removable seal joints is verified by local leak testing or using an imprint method. If leakage is proved, the non-functional or leaking part is replaced. Prior to replacement, rubber seals undergo a process of conservation.

Assessment and elimination of ageing effects.

The programme of remedial measures includes *diagnosis* (assessment of damage), *prognosis* (feasibility and cost effectiveness of repair), *time planning* (prioritisation), *method selection* (depending on the character of problems, adaptability of the proposed method, environment and expenses), *preparation* (scope and type of problems) and *application*.

Defects of reinforced-concrete containments.

Deterioration of reinforced-concrete structures mostly results in cracking, spalling or delamination of concrete cover. Based on experience it can be stated that, in addition to water or liquid medium (e.g. boric acid) seepage through structural joints or cracks, cracking is the most frequent problem encountered in NPP concrete structures.

As a result of various destructive factors, the following defects are most frequently encountered in reinforced-concrete structures: cracks, spalling, delamination, water seepage, honeycombs and voids.

All these defects – encountered either in individual concrete structures or the reinforced-concrete containment as a whole – finally result in an increased containment leakage rate and a reduction of static properties.

3. DEFECT REMEDIATION.

Leaks encountered may be either easily accessible leaks or the so-called hidden leaks. Hidden leaks are the leaks on the hermetic liner inaccessible due to reinforced-concrete structures of the hermetic boundary.

This section concentrates on a description of some technologies already used for the detection and repair of hidden leaks encountered in sealing nodes on the hermetic boundary and on materials used for repair as well as on a definition of new ones.

The detection of defects on the hermetic boundary necessitates the application of very costly methods able to localise and repair leaks because, in most cases, the defects are hidden leaks of the hermetic liner.

In the case of hidden leaks, a qualitatively higher level of leak detection as well as repair is required compared to common methods which need to be complemented with methods capable not only of leak detection but also able to determine the direction of leak propagation. ILRT accompanied by leak identification can guarantee success in subsequent repairs performed on the hermetic boundary.

Some of the relevant methods for leak detection are described below.

Injection of epoxide resins in locations with hidden leaks.

This method consists in a double-component epoxide resin injection into cracks in reinforced-concrete structures or in a gradual filling of the gaps between the liner and concrete. Epoxide resin (injection material) is forced into concrete cracks under pressure using special pumps.

Materials used are

- double-component epoxide resin (injection material) SIKADUR 52, and
- epoxide resin paste (sealant to close the cracks) SIKADUR 31 Rapid, both of them made by SIKA, Switzerland.

The injection is applied to cracks big enough to enable the insertion of a wire with a thickness of at least 0.3 to 0.5 mm. Then thin PVC tubes are slid on the wire to enable crack filling with injection material SIKADUR 52.

Injection of polyurethane materials in locations with hidden leaks.

Major locations with secondary leaks require repairs by means of injection materials able to assure the leaktightness of reinforced-concrete walls. These are particularly locations inaccessible for common injection (with epoxide resins).

Injection materials BEVEDAN-BEVEDOL meet this criterion and can be used for leaktight reinforcement of concrete structures. About 35 seconds after injection, polyurethane materials expand.

Materials used are

- BEVEDAN – the basic component (for all BEVEDAN systems) is polyisocyanate - MDI,
- BEVEDOL WF – the second component (polyol) is a fast-reacting resin suitable for sealing both dry and wet materials (water seepage),
- BEVEDOL WFA – the second component (polyol) is a fast-reacting resin suitable for sealing pressurised water seepage.

In a dry environment, both of the second components (WF and WFA) react without expansion.

Repair of hidden leaks after removal of the cover concrete.

This method consists in the gradual removal of the cover concrete (not being a part of reinforced-concrete structure designed to withstand accident pressure). After the concrete removal, using compressed air, a local pressure gradient up to 20 kPa is created under the liner to enable operative leak testing. Based on the test results (localised leaks), the cover concrete removal can be continued until primary leaks are detected. Detected leaks are repaired using procedures commonly applied to the hermetic liner, i.e. welding, sealing or the injection of epoxide resins.

Thermovision method of leak detection.

This method of leak detection consists in monitoring the passage of heat-transfer medium (air) through leaks in the hermetic liner into compartments with a different air temperature.

This method has been applied by our team within the scope of ILRT during underpressure and overpressure testing phases. During an underpressure test (-5 kPa), when leaks were being detected, in locations with potential leaks, air was heated from outside the hermetic boundary. Temperature (20°C) and pressure (5 kPa) gradients obtained enabled leak detection on the hermetic liner.

Pool liner leaktightness verification.

Fuel pools in general are provided with a double liner in such a way that the hermetic liner is located under the non-hermetic one. A boric acid solution penetrates through the leaks in the non-hermetic liner into the gap between the liners which affects hermetic liner corrosion.

Air inflow monitoring by division of internal compartments.

During an underpressure test within the scope of follow-up ILRT with leak identification and operational ILRT, major internal compartments are temporarily separated or divided (by means of polyethylene sheets and provisional frames). In “separation or division walls” created in such a way, the velocity and direction of air flow through circular openings are measured. After the evaluation of measured values, the share of individual compartment parts in the global containment leakage rate is determined. The results of such monitoring provide a realistic picture of leak distribution and permit to precise repairs on selected locations.

One advantage of this method is the possibility of individual division of compartments and a more precise location of leaks (if such a separation or division is not prevented by mechanical equipment disposition in the compartments).

An increasing share of hidden leaks increases disproportionally the laboriousness of their repair and, thus also, costliness.

Leaktightness enhancement in the future will be provided by leak repair performed predominantly by the application of epoxide and polyurethane injection materials and by increasing the leaktightness of isolation valves and other civil and mechanical components of the hermetic boundary. It should be pointed out that the spectrum of new selected methods for leak detection shall be sufficiently broad since their practical application in VVER 440 NPPs is limited which is apparent from research and investigations performed so far. The limitations result from the presence of disturbing effects of vibrations, the propagation of sound from mechanical equipment through reinforced-concrete structures, and pressure gradient with resultant medium flows through leaks.

Conclusions

Integrated leakage rate and structural integrity tests are performed with the purpose to verify the leaktightness and structural integrity of the reactor containment. They demonstrate the containment capability to perform its primary function, i.e. to prevent radioactive releases to the environment in the event of a LOCA type accident and to withstand maximum pressure loads, respectively.

In VVER 440 NPPs, the containment ILRT is performed prior to starting the operation and afterwards regularly at the beginning and at the end of each refuelling outage. The structural integrity test is performed before starting the operation. Repeated operational structural integrity tests are performed after a prior approval by the Regulatory Authorities.

All the tests performed so far succeeded to prove containment capabilities to perform all the expected functions.

References

1. International Atomic Energy Agency, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Concrete Containment Buildings, IAEA, Vienna, Austria
2. Standard review process IAEA-EBP-LTO-03 Vienna, Austria
3. Slovak Republic Country Information Report WG4, IAEA-EBP-LTO-04, Vienna, Austria