Implementation of Containment Inspection Program at NPP Krško

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ABSTRACT

The main nuclear components in Nuclear Power Plant Krško (NEK) are installed within a containment building which is the biggest and most recognizable structure in the power plant complex of NEK. The containment building consists of an inner steel containment vessel and an outside concrete shield building, which provides biological shielding, weather protection of the inside containment vessel and a relatively leak-tight structure to permit the use of the containment annulus ventilation and filtering system for minimizing the escape of radioactive particles to the environment by maintaining a slightly negative annulus air pressure. The inner steel containment vessel with an inside diameter of 32 m and a total height of 70 m is designed to contain the energy and radioactive material that could result from the postulated loss-of-coolant accident (LOCA) and to ensure a high degree of leak tightness during normal operation and under accident conditions. NEK's containment building is safety related component and therefore subject to inspection requirements given by the ASME Boiler and Pressure Vessel Code, section XI; Rules for Inservice Inspection of Nuclear Power Plant Components, subsection IWE; Class MC and CC Components.

The article is about the implementation of inspection requirements for the inner containment steel vessel given by the ASME code and managed by the NEK's Containment Inspection Program (CIP). For better understanding, basic design features of the NEK's containment are explained and compared with the other common containment design types. Presented are the performance of containment inspections in the NEK required by the CIP, Non-Destructive Methods (NDE) used and specific findings and operational experience obtained through implementation of the NEK's CIP and industry experience.

***Keywords**: containment, Krško, pressure vessel, NDE*

1. INTRODUCTION

Reactor pressure vessel, pressurizer, steam generators, and other critical nuclear components of a nuclear power plant are usually contained within a resistant containment building, which is designed in a manner to prevent releases of radioactive material into the environment during nuclear accidents, loss of coolant due to pipe break (LOCA) for example. The importance of containment buildings was shown in the following events. In 1986, in Chernobyl's nuclear power plant, unit 4 accident happened, design of the power plant did not include a containment building. Therefore, all the nuclear material was spread into the environment with catastrophic consequences. Before that in 1979, an accident with the core meltdown happened in the US power plant Three-mile Island unit 2. In this case, the design of a powerplant included a containment building and because of that most of the radioactive material was contained inside the reactor containment building, there were just some gaseous releases into the environment without any long-term impacts. The latest nuclear accident in the Fukushima power plant also showed the importance of containment structures, because affected Boiling Water Reactor power plants (early types) did not have containments designed in such a manner as PWR powerplants, but rather small in volume, limited just to reactor vessel and some other components. The impact on the environment due to the lack of proper safety structures to contain radioactive material was significant.

These cases show the great importance of containment structures in cases of nuclear accidents. There are several design types of containments, but common to all is that they are robust, designed to withstand design-based earthquake and to withstand elevated pressure and temperature during a loss of coolant accident due to pipe brake, maintain integrity, and retain any radioactive material and prevent its uncontrolled release in the environment. Common to all types of containments is also that they need to be kept in good condition to perform their function when needed. Inspections and tests shall be performed in accordance with regulatory codes and standards. Control and maintenance of containment structures depends on the design of a containment building, in the case of nuclear power plant Krško (NEK), concrete structure of the shield building is managed by a civil maintenance department, and a steel containment vessel is managed by an in-service inspection department. Pressure tests are in the domain of the operations department. Hence, maintaining the integrity of the NEK's containment is an interdisciplinary task that is managed by a team of experts from different fields of operation. This article is about implementing NEK's Containment Inspection Program (CIP), which includes inspections of the steel containment vessel and its subcomponents.

Figure 1: NPP Krsko (NEK) with its class MC containment building. (Photo: R. Germovšek)

2. TYPES OF CONTAINMENTS ACCORDING TO ASME CODE

ASME code, which is followed by the most of western nuclear power plants (including NEK) recognizes two types of containments: class MC - metallic containment and class CC - concrete containment. From the outside look, it is hard to differentiate between these two types, outside look is more or less the same, visible is only a concrete part of the containment.

Figure 2: NPP Barakah, 4 units with class CC containment buildings. (Photo: L. Pušnik)

For the class MC containment is typical that a concrete shield building - biological shield and inner steel containment vessel are separated with an annulus space. A steel containment vessel is self-standing, thick (up to 40 mm), and rigid enough to support a polar crane, and can withstand design-based pressure. Steel pressure vessel is shielded by an outer reinforced concrete building with a thickness of up to 800 mm, which is relatively airtight, to permit the use of the containment annulus ventilation and filtering system for minimizing the escape of radioactive particles to the environment by maintaining a slightly negative annulus air pressure.

Class CC containment differs in a manner that there is no annulus space between the concrete and steel portion of the containment. Concrete building is made from pre-stressed concrete, which can carry loads produced by elevated pressure. From the inside, steel plates are lined to the concrete surface, the so-called liner. In some designs, liner plates can be embedded into concrete wall. Liner plates are much thinner than plates forming class MC containment (usually the thickness of a liner is between 9-15mm). Liner provides air tightness and the pre-stressed concrete necessary load-bearing structure.

According to data obtained from the Framatome Owners Group (FROG) containment working group, there are more class CC containments worldwide than class MC containments. For the class CC containment less steel is needed and much less welding involved, hence the reason for that choice may be predominantly financial. New power plants such as APR-1400 (NPP Barakah, Figure 2) and EPR-1600 (NPP Olkiluoto) have class CC containments, new Russian VVER 1200 type powerplants incorporate similar design too. This design is to some degree not so passive as the class MC containment. Concrete by itself cannot carry significant tensile loads, so it must be pre-stressed in a way that can resist forces created by an inside pressure. Compressive loads in concrete are achieved with the tension cables (tendons) in circumferential and vertical directions. Tension cables are susceptible to corrosion and loss of tension and are therefore subjected to inspections, tension testing, and must be periodically replaced according to acceptance criteria, regulatory requirements, and specifications. Class MC containments are not so widespread among nuclear power plants; however, the design has its safety benefits, and it is used in the latest Westinghouse AP-1000 power plant. Similar to class MC design is also a German KWU containment type with concrete shield building, annulus space, and spherical pressure vessel. The containment building of the NPP Krško is also a class MC containment.

3. NEK CONTAINMENT VESSEL

The containment vessel [1] is a steel, pressure-retaining structure consisting of a cylinder, a hemispherical dome and a torispherical bottom. The containment vessel rests on a concrete base which is part of the concrete mat. This mat is a common foundation for the major structures of the power plant. The containment vessel is designed, fabricated and erected in accordance with the requirements of the ASME Code, Section III, for MC components.

Neither the shield building nor the interior concrete structure contacts the freestanding containment vessel. Sufficient clearance is provided to ensure that contact does not occur under any of the postulated load combinations.

The containment vessel is designed to contain the energy and radioactive material which result from the postulated loss-of-coolant accident (LOCA) and to ensure a high degree of leak tightness during normal operation and under accident conditions.

The containment vessel is a Seismic Category I structure with an internal free air volume of 40013 m^3. It is designed for a maximum internal pressure of 3.15 kg/cm^2 relative with a coincident temperature of 128°C under accident conditions and a maximum external pressure differential of approximately 0.10 kg/cm^2 due to accidental operation of the Containment Spray System. Design of the containment vessel considers dead load, live load, construction loads, temperature gradients and the effects of penetrations for accident conditions (including seismic considerations) as well as normal operating conditions.

The steel containment vessel is designed to have a low strain, linear response to all design loads, thereby ensuring that its integrity as a pressure barrier is never breached. Maximum design leakage rate for the containment vessel is 0.2 percent by weight of the contained atmosphere at 3.15 kg/cm^2 relative pressure and 128°C.

The material chosen for the fabrication of containment vessel are SA516, Grade 70 carbon steel plates which are formed and welded into the desired shape.

The interior structures consist of an irregular system of walls and reinforced concrete floors at three elevations discounting a sub-basement level. The walls form the reactor cavity and steam generator compartments. They supply structural support, radiation and missile shielding. The reinforced concrete floors transfer the dead and live loads to the foundation through peripheral, reinforced concrete columns and the compartment walls.

The basic dimensions of the containment vessel (see Figure 3):
Cylinder inside diameter, 32.08 m.
Cylinder height, 44.55 m.
Hemispherical dome radius, 16.05 m.
Torispherical head, 22.167 m radius, 6.10 m knuckle radius.

Nominal material thickness (see Figure 3):
Cylinder wall, 38 mm.
Top dome wall, 20 mm.
Bottom head wall, 32 mm.

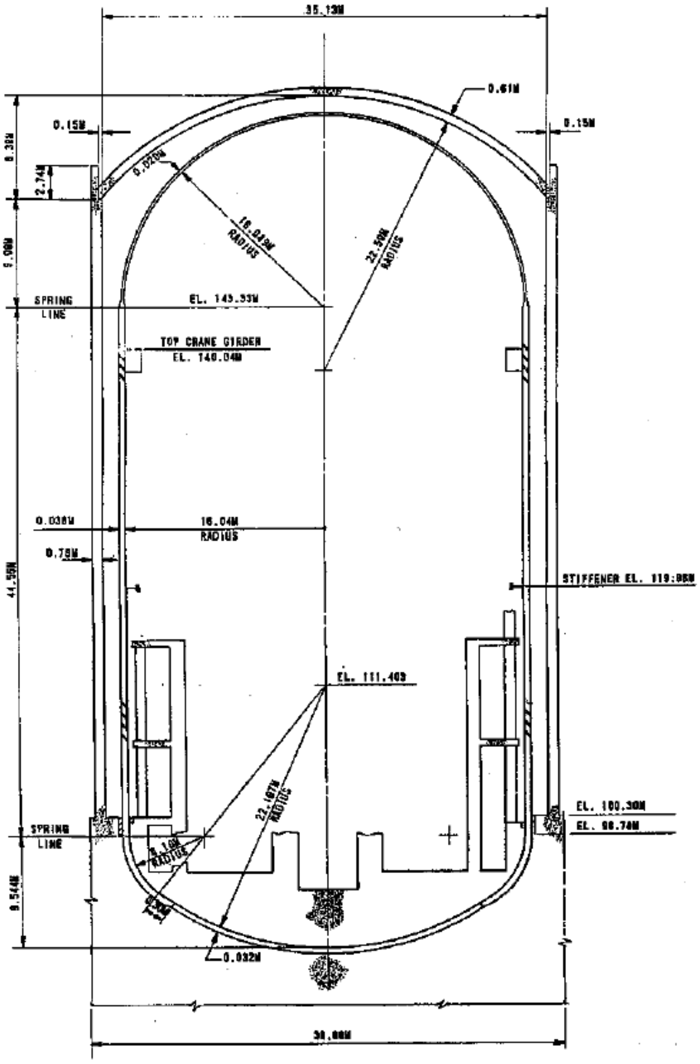

Figure 3: Drawing of NEK's steel containment vessel. [1]

4. Containment Inspection Program

NPP Krško's Containment Inspection Program (CIP) [2] describes its purpose, objectives, and responsibilities and establishes requirements for inspection, program plans, and component identification drawings. In general, the Containment Inspection Program might be considered as the part of NPP Krško Inservice Inspection Program. CIP is also credited for management of aging effects in accordance with requirements defined in NEK Aging Management Program.

In Federal Register, dated August 8, 1996, the US Nuclear Regulatory Commission amended its regulations to incorporate by reference the 1992 Edition and Addenda of Subsection IWE of Section XI of the ASME Code. Subsection IWE gives the requirements for in-service inspection (ISI) of Class MC (metallic containments) of light-water-cooled power plants.

The amended rule became effective on September 9, 1996, it requires the licensees to incorporate the new requirements into their ISI plans and to complete the first containment inspection within five years (i.e., no later than September 9, 2001) which should include the scope planned for the first period of the inspection interval.

During the period 2000 - 2002 NEK performed, as the baseline, examinations planned for the three inspection periods of the inspection interval, as specified in draft of Containment Inspection Program TD-2H. Between 2002 and 2012, first 10-year Inspection Interval was performed in accordance with the Inspection Program B and the requirements of Subsection IWE of ASME Section XI (Edition 1995 with Addenda 96). The designation of Containment Inspection Program was TD-2H/1. In July 2012 NEK started a second 10-year Inspection Interval for which TD-2H/2 Program is prepared based on requirements of USNRC, 10CFR50.55a, June 2011 and Subsection IWE of ASME Section XI (Edition 2007 with Addenda 08). In July 2022 NEK started a third 10-year Inspection Interval for which the current TD-2H/3 Program is prepared based on requirements of USNRC, 10CFR50.55a, June 2020 and Subsection IWE of ASME Section XI (Edition 2017) [3].

A maintenance manager is responsible for the implementation of the Containment Inspection Program in accordance with Program Plans, and administrative and technical implementing procedures. Responsible engineer from in-service inspection group is responsible for: development and maintenance of Containment Inspection Program, program plans and administrative and examination procedures, conduct of the program of examinations, and recording of the results of examinations including corrective actions if necessary.

To carry out the program of examinations the following activities and tasks are required:

- Preparation of written examination procedures.
- Preparation of schedules extracted from the Program Plan for examinations
- foreseen to be performed during an outage.
- Verification of qualification to the required examination method and level of
- personnel who perform examinations.
- Performance of required examinations.
- Recording and evaluation of examination results.
- Maintenance of examination records, such as examination data, drawings
- and evidence of personnel qualifications.
- Retention of examination records for the service lifetime of the containment.

NEK’s ISI program, which is a program developed for specific ten-year interval, with 3 periods within that interval. CIP is considered as a part of ISI program; therefore, inspection interval and inspection periods coincides with the ISI program. Table 1 shows the extent of inspection scope acquired during each inspection period.

Table 1: Extent of inspection scope acquired during each inspection period [3]

Inspection Period, Calendar Years of Plant Service	Minimum Examinations Completed %	Maximum Examinations Credited %
3	16	50
7	50	75
10	100	100

5. Examination requirements

In the tables (2.1, 2.2, and 2.3) typical examination categories are shown, as defined in ASME section XI, subsection IWE with examination methods used and inspection and implementation requirements. For example, accessible surface areas; Examination category E-A, Item E1.11 (containment plates) must be inspected in 100% extent in each inspection period, and Bolted Connections; Examination Category E-G, Item E8.10 (pressure retaining bolting) must be inspected in 100% extent during a ten-year inspection interval. For some instances, augmented inspections are required if (previous) relevant conditions are recognized (e.g., pressure-retaining component corrosion or erosion that exceeds 10% of the nominal wall thickness, or is projected to exceed 10% of the nominal wall thickness prior to the next examination) which are defined in the ASME section XI, subsection IWE, paragraphs IWE-3521 and IWE-3522 [3].

Table 2.1: Class MC examination requirements. [3]

CLASS MC EXAMINATIONS REQUIREMENTS				
Examination Category E-C, SURFACES REQUIRING AUGMENTED EXAMINATION				
Item No.	Component and Parts to be Examined	Examination Method Acceptance Standard	Examination Requirements	Implementation
E1.10	Containment Vessel Pressure Retaining Boundary			
E1.11	Accessible Surface Areas	Visual, General VE IWE-3510	100% during each Inspection Period	See chapter of General Part of this program
E1.30 E1.31	Moisture Barriers Accessible caulking, flashing, and sealants	Visual, General VE IWE-3510	100% during each Inspection Period	Examination shall include accessible moisture barrier materials intended to prevent intrusions of moisture into inaccessible areas of the metal containment shell or liner at concrete-to-metal interfaces.

Table 2.2: Class MC examination requirements. [3]

Examination Category E-C, SURFACES REQUIRING AUGMENTED EXAMINATION				
Item No.	Component and Parts to be Examined	Examination Method Acceptance Standard	Examination Requirements	Implementation
E4.10	Containment Surfaces Areas			
E4.11	Visible Surfaces	Visual VT-1 IWE-3521	100% of Surface Area Identified by IWE-1242 during each inspection period	As necessary
E4.12	Surface Area Grid Minimum Wall Thickness Location	Ultrasonic thickness IWE-3522	100% of minimum wall thickness locations during each inspection period, established in accordance with IWE-2500 (b)(3) and (b)(4)	As necessary

Table 2.3: Class MC examination requirements. [3]

Examination Category E-G, PRESSURE RETAINING BOLTING				
Item No.	Component and Parts to be Examined	Examination Method Acceptance Standard	Examination Requirements	Implementation
E8.10	Bolted Connections	Visual, VT-1 IWE-3530	100% of each bolted connection. Examination shall include bolts, stud, nuts, bushings, washers, and threads in base material and flange ligaments between fastener holes.	Examination may be performed with the connection assembled and bolting in place under tension, provided the connection is not disassembled during the interval. If the bolted connection is disassembled for any reason during the interval, the examination shall be performed with the connection disassembled. Deferral of inspection to end of interval is permissible.

5.1. Procedure

In NEK, inspection of containment structures is managed by the CIP, however the inspection itself is performed by the dedicated procedure for the containment inspection which incorporates requirements given by the ASME code section XI, subsection IWE. The procedure gives the prerequisite for the inspection, certification requirements for the inspection personnel, requirements for visual inspection, acceptance criteria for different examination categories and other plant-specific administrative requirements which must be followed. The procedure is periodically checked and revised when any new inspection or administrative changes are applied.

5.2. Non-Destructive Examinations (NDE) used

According to the requirements given by the ASME code and followed by the NEK's containment inspection procedure, the following NDE methods are used for the inspection:

5.2.1. Visual examinations

Visual examination [4] shall be performed in accordance with the NEK containment inspection procedure which refers to ASME code requirements [3]. Painted or coated areas shall be visually examined for evidence of flaking, blistering, peeling, discoloration, and other signs of distress. Noncoated areas shall be examined for evidence of cracking, discoloration, wear, pitting, excessive corrosion, gouges, surface discontinuities, dents, and other signs of surface irregularities. There are two different types of visual examination appropriate for conducting this program:

General visual examinations (GVE) shall be performed to assess the general condition of containment surface - items E1.11 and E1.30. General visual examination shall be performed to detect evidence of degradation using adequate illumination.

VT-1 is used for the inspection of examination category E-G, pressure retaining bolting, and for category E-C, surfaces requiring augmented examination. VT-1 is stricter than GVE, illumination must be at least 550 lx, maximal distance from the examiners eye to the inspection surface is limited to 600 mm, etc. A VT-1 can be performed direct or indirect with a use of remote inspection equipment (e.g. borescope or inspection camera) when demonstrated, that the same degree of resolution is achievable.

5.2.2. Surface examinations

Surface examinations [4] shall be conducted in accordance with ASME code section XI, subarticle IWA-2220. Surface examinations are intended to detect the presence of discontinuities open to the surface of material. Techniques for surface examination include liquid penetration (PT) and magnetic particle (MT) method. These methods are intended to be used if any relevant conditions are found and additional information regarding degradation is needed.

5.2.3. Volumetric examinations

Ultrasonic testing [4] is meant for augmented inspection of steel containment plates but not limited to. Ultrasonic thickness measuring shall follow the requirements of ASME Section XI, Appendix I, Article I-2500. Basically, it is a method of UT thickness measurement using pulse-echo technique. Measurements are performed on a grid pattern at the interest area.

5.2.4. Supplemental examinations

Supplemental inspections are not specifically defined with the ASME code or with any NEK procedure. In general, any NDE may be used to determine the character of the flaw or degradation. Industry experience shows that Acoustic Emission – AE technique can be successfully used for locating an untight spot (usually if the pressure test criteria is not met and there is a suspicion of a leak). Bubble test with vacuum box can be used after repair replacement activities or as a method to determine leak tightness of susceptible area. There are several research activities in progress about using of non-conventional NDE involving principles of different modes of ultrasonic wave propagation, acoustic emission and measurements of electric potential of embedded components for determining the integrity of embedded steel portions of containment and rebar. In any case, every “new” method must be qualified for its use before application.

5.2.5. Pressure testing

Pressure testing [5] of NEK’s containment is currently performed by a ten-year interval. Combined Integrity Leak Rate Test (CILRT) is in the domain of the operations department. It is performed following plant specific procedures and NEK’s technical specifications. During the test, a design pressure is established of 3,15kp/cm2. Results of the tests performed are shown in Table 3. The last test was performed in 2016 with the acceptable result of leak rate achieving 26,35% of the maximum allowable leak rate.

Table 3: CLIRT results from the start of operation for NEK. [5]

	CILRT ‘89	CILRT ‘92	CILRT ‘96	CILRT ‘99	CILRT ‘07	CILRT ‘16
0.75*La(t)(%/24h)	0.106	0.106	0.106	0.150	0.150	0.150
UCL (%/24h)	0.053	0.055	0.046	0.072	0.047	0.034
UCL / (0.75*La(t))	50%	51.9%	43.4%	48%	32.19%*	26.35%*

*accounted “leak penalties” (LLRT) for penetrations not prepared for CILRT

6. Implementation of containment inspections in NEK

6.1. Planning

According to CIP implementation program plan, components and parts of containment that are subject to inspection are recognized and divided into groups (e.g., inside of containment and annular space). Work orders are prepared within the designated system window for inspection. All the necessary drawings, inspection tables, and applicable inspection procedures are attached to the work orders. Work order includes work permits for work in radiologically controlled area – RCA, confined space, fire protection permit for rescue purposes etc. Special care is taken to safety at work. The first concern is ALARA approach. For example, annular space is inaccessible during fuel transfer because of the elevated radiation in the region of the entrance/exit to annular space which is in proximity to the fuel transfer channel. The inspections are planned in the time when fuel is stored in the spent fuel pool and radiation doses are relatively low. The second concern is work at height. Containment is a large structure and most of the time inspection is performed using ladders, platforms and special safety equipment for working at height is needed. All the equipment must be listed in the safety section within the work order, so inspection workers have all the information about the safety equipment needed before work starts. Inspection workers must also know how to use safety equipment and be trained to work at height. The third concern is confined space. The whole annular space is considered a confined space. Work must be organized in such a manner that work safety is not compromised at any time. For the annular space, the quality of the atmosphere is measured before entry, two workers are entering together, fall prevention tools must be used for equipment, use of headlamps and flashlights is necessary, because of the insufficient ambient lighting for inspection and safety purposes. All the workers involved must be familiar with the rescue plan for the annular space before entering. It is necessary to inform the fire brigade, which is responsible for rescue operations, before and after entering the annular space.

In general, the work order shall contain all information needed for inspection purposes as well as additional safety information. In the NEK, work orders for containment inspections are prepared by a responsible in-service inspection engineer.

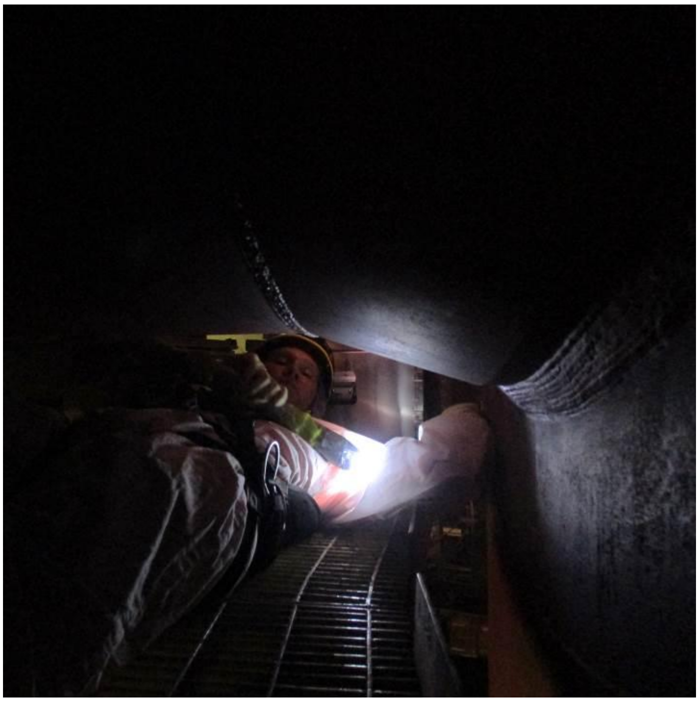

Figure 4: Inspection of personnel access penetration - circumferential weld (annulus side).

6.2. Preparation

The location of inspections and start/end times are dependent on the work order. Before the start of the work order, a pre-job briefing is taken involving all the inspection personnel. The purpose of the pre-job briefing is to check the inspection scope, inspection requirements, and procedures, work permits as well as safety requirements and safety and inspection equipment needed. Usually, all inspections are performed by a team of two inspectors, an ISI engineer and ISI technician, or a hired ISI support worker. When a work order is approved for work by a shift manager and operation is started by a work order coordinator, work can begin.

Work is performed within a radiologically controlled area - RCA and rules for work in the RCA must be followed. Workers must wear orange underwear (trunks, t-shirt, socks), white cotton jumpsuit, cotton gloves, latex gloves, shoes for RCA, shoe covers, and respiratory protection when needed. The use of dosimeters is necessary.

Safety equipment consists of a climbing helmet, climbing harness, rail guard connection, Y connection ropes, static connection rope, and oximeter when required.

The inspection equipment pack usually consists of a bag or backpack, work order package, pen, marker, headlamp, flashlight, tape measurer, mirror, photo camera, action camera, binoculars, and fall prevention equipment (carabines, ropes, special bags, etc.) to prevent fall of the equipment to lover elevations and to prevent possible foreign material events. For VT-1 inspection luxmeter and visual inspection test chart are added.

6.3. Inspection

Inspection is performed according to procedure requirements for the given scope defined in the work order. For example, item E.1.11 (table 2.1) accessible containment surfaces plates. Walkdown is performed from both sides of the containment; inside and from outside (annular space). During the walkdown, all the accessible containment plates are identified and inspected. A checklist is fulfilled during inspection and any relevant indications are noted and recorded with a camera. If any relevant indications are observed, additional inspection is performed at the same time during the initial inspection, or later with the use of other supplemental NDE methods. Inspection is usually performed in a circular pattern from lower to higher elevations (Figure 5).

Figure 5: Detail from inspection, electrical penetration area.

During containment plate inspection, other components from the scope are inspected simultaneously if they are on the way. In that case, inspection of the containment plates is interrupted, and a component is subjected to its inspection requirements (e.g., VT-1 for bolted connection, item E8.10) before the inspection continues. According to our experience, this approach ensures that the inspections are performed in the shortest time possible, minimizing the exposure to radiation and minimizing the time being spent in a confined space or other unfavourable situations. All the time during the inspection special care must be kept to work safety. There is a lot of climbing involved and personnel as well as the equipment must be properly secured at any time. Workers take care of each other while climbing or moving on the platforms. At the end of work, all the equipment is counted and checked for integrity. The inspection scope is also checked to identify if all inspection positions/components have been inspected. Operation is then stopped, the work order is finished, and de-briefing follows. The purpose of de-briefing is to identify any safety deviations or safety concerns and to recognize any good practices used.

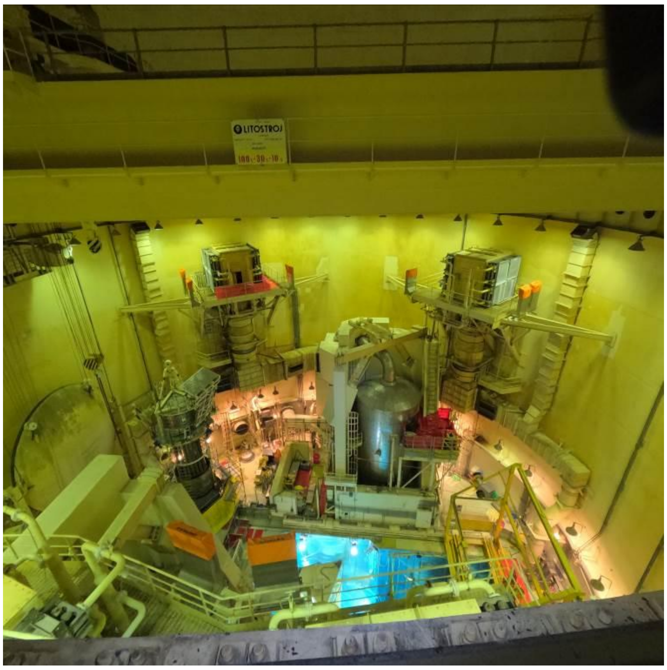

Figure 6: Inside of the containment vessel. Photo taken from polar crane girder.

6.4. Reporting

After the inspection, all the inspection data from the checklist are transferred to a digital report form. Recordings from cameras are stored in the inspection folder and filed into the reports when needed. Reports are added to the work order which is then completed. If there are any deviations found from the expected state of inspected components, a Corrective Action (Corrective Action Program - CAP) is initiated and required corrective actions are taken thereafter. After the completion of all work orders related to the containment inspection program for the designated outage, a final report is created. The final report is archived, and a copy is sent to the Slovenian Nuclear Safety Agency.

7. Lessons learned

Since the beginning of the implementation of the CIP in the NEK, we accumulated a lot of operating experience about containment and its subcomponents. The inspection scope is synchronized with the NEK's ISI program. The preparation and the inspections are made routinely. A lot of knowledge and operating experience were gained from participating in various industry-based organizations and working groups. Counting that, we know which portions are potentially more susceptible to degradation and need more detailed inspections which are performed more often than demanded by regulations.

Additional to mandatory inspections, in 2022 we tried to inspect the otherwise non-accessible containment plates - areas behind some concrete structures with the use of a remote-controlled camera-equipped crawler with magnetic wheels (Figure 7) to obtain additional information of the state of those surfaces. The inspection was only partially successful due to the uneven concrete wall face and the too-narrow gap between both structures in some areas.

Since the beginning of the inspections, some personal safety issues were also addressed. Some platforms inside the annulus space were improved and a new ladder (Figure 11) for the top of the dome access was installed in 2021.

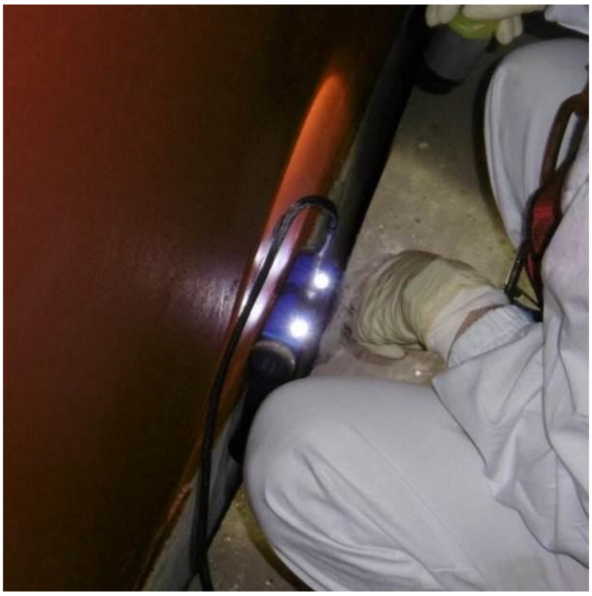

Figure 7: Inspection of gap behind a concrete neutron shield wall with remote-controlled crawler in 2022.

Most of the industry-based operating experience comes from the corrosion of the containment plates (class CC containment liner plates). Foreign operating experience shows several cases of thru-wall corrosion in the liner plates caused by a piece of wood which was left in the concrete behind the liner plates during the construction phase. In the case of NEK containment, that issue is not applicable because of the class MC containment which is accessible from both sides and is not in direct contact with the concrete (except the lower embedded portion). Some issues were reported on leak chase channels, which is also not a feature of the NEK's containment. Tension cables and the issue with tension, concrete cracking etc. are also not an issue for a class MC containment. In a class MC containment, a potential weak spot can be the transition area from the embedded part to the self-standing part of the containment. This area is protected with a moisture barrier (Figure 8), which is installed in the outer and inner side of the steel containment and prevents water intrusion trough the gap between concrete and steel and thus preventing corrosion. Moisture barrier must also be able to compensate for deformations of containment during operation and pressure tests. The material of the moisture barrier inside the containment vessel is a Thiokol sealant (rubbery compound) and from the outside is cork (because of its ideal Poisson ratio of 0 and including its inert nature, impermeability, flexibility, sealing ability, and resilience). The degradation of the moisture barrier inside containment in the NEK is presented later in the article.

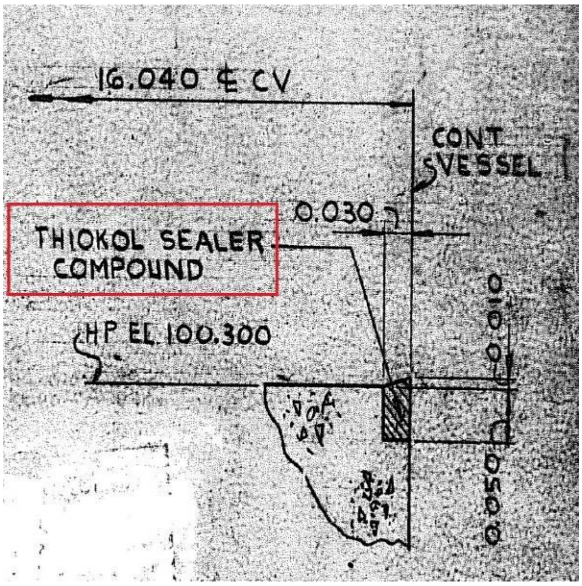

Figure 8: Construction detail of moisture barrier inside containment.

Since the CIP implementation, we do not record any structural defects such as cracks or other mechanical deformations. There was a possible crack discovered in the 2016 inspection. At the location of equipment hatch penetration meeting stiffener ring at the elevation of 119 from the inner side of the containment, there was a crack like indication discovered. It looked like the crack was present at the weld area. After initial surprise, it was discovered that a weld slag was left on the part of the weld and painted over. During the time, weld slag loosened, and a crack-like indication appeared. Weld slag was removed, and an intact weld was revealed underneath yet surface corrosion on the exposed weld was present. Corrosion was removed and exposed area protected with paint.

Figure 9: Inside of the containment dome. Inspection can be performed along the whole circumference (polar crane girder) and from the polar crane itself.

Corrosion is potentially the most significant degradation mechanism. From the outer side, from annulus, there is a controlled warm and dry atmosphere present which works against corrosion. During inspections from the annulus side, an area has been found on the upper containment dome that is not painted and there are no signs of corrosion due to unfavorable conditions for its development (Figure 10).

Figure 10: Unpainted part of the containment dome, no development or progression of corrosion due to dry atmosphere.

From the inner side, conditions for corrosion development are much better. From the inside, a warm and humid environment may be present. There is also possible condensation on the containment surfaces or leaking of condensate from cooler pipes to the containment walls and structures. Surfaces not protected by a paint or coating may develop corrosion. There is great care taken to recognize possible affected surfaces and ensure the cleanliness of these surfaces so that any corrosion can be detected easily and in the initial stages. So far, some minor corroded areas (initial surface corrosion) with non-sufficient or chipped coating due to mechanical damage have been reported and taken care of.

Figure 11: Rotating ladder for the top of the dome access. The original ladder was replaced with a new one in 2021 to provide safer access.

8. Moisture barrier issue

Moisture barrier from the inner side of the containment may be the most critical region of the class MC containment types. In the NEK, it is located at elevation 100 at the transition of concrete floor to steel containment. That particular area is subjected to spilling, condensate accumulation, washing (decontamination), and mechanical damage due to equipment transportation, etc. Since the time of installation, flexibility and adhesion of the sealing compound Thiokol may have also deteriorated to some degree. Because the area behind the moisture barrier is not directly visible, the possible corrosion could propagate undetected and compromise the integrity of the steel containment vessel.

The first instances of degradation were reported in 2016 and were recognized as local cracks on the floor at the moisture barrier location. Since then, additional inspections have been performed every outage to trend existing conditions and to find any new ones. After the 2018, a part-time solution was implemented; to seal existing cracks with a resistant coating with the purpose of preventing any possible water intrusion. In the meantime, some minor corroded areas (approximately coin sized) in the region just above the moisture barrier were also repaired. In the NEK's design, there is no physical protection over the moisture barrier as in some other power plants, therefore some physical damage occurred due to equipment manipulation (loading the area of a moisture barrier or paint chipping in the area directly above).

Inspection results obtained in the outage 2022, have shown that current state of the moisture barrier is not suitable for a long-term operation and a replacement is needed. An action plan for replacement was developed by a civil engineering department. A replacement like for like was the chosen option with the replacement to be done in the following and subsequent outages. Because the moisture barrier is located around the inner circumference of the steel containment vessel, it is not practical to perform the replacement at once due to the blockage of transport ways.

In the outage 2024, a replacement at two locations in the total length of 30 meters was completed. Firstly, an old sealant was extracted, and an initial visual inspection was performed. After that, surface preparation and pouring of the Thiokol sealant compound was performed. At the end, some final touches were made to ensure a better surface joint and a good final look.

Visual examination revealed some corrosion in the areas between the moisture barrier and steel containment plates. There was no correlation observed between previously detected cracks above the moisture barrier areas and the as-found state. There was no corrosion damage present, all the corrosion was surface corrosion without any visible in-depth propagation. Most of the area uncovered was without any corrosion with good adhesion of the Thiokol sealant to the metal surface.

Replacement of the moisture barrier was according to the results obtained done just at the right time. The presence of corrosion was a sign, that existing material is degraded to the point that cannot effectively provide its sealing function, yet the corrosion damage on a larger scale did not occur and the integrity of the steel containment was not compromised.

With the completion of the replacement of the moisture barrier (inside containment) in subsequent outages, we will eliminate a possible weak point and ensure component integrity for long-term operation in the power plant's extended lifetime. For the moisture barrier outside containment, there is currently no need for replacement.

9. Conclusion

The containment inspection program is just one of many programs related to ensuring the integrity of the safety barriers, containment building is the last barrier before nuclear material can escape to the environment in the case of a nuclear accident. Therefore, great care must be taken to ensure that all the regulatory requirements are met as a minimum. Foreign operation experience shall also be considered and evaluated for their impact on NEK's containment building and performance of the CIP. Well-educated and committed inspection personnel are also important for the good performance of the CIP. Most of the US and European nuclear power plants are getting older and are already in a period of extended operation. The importance of keeping existing components in good shape and maintaining their integrity throughout that extended period is a key significance. The transfer of knowledge between generations is also a challenge. With our approach to CIP implementation, we are trying to be one step in front of the industry, to understand design and to find possible weak spots, to recognize possible degradation prior any more serious issue could develop.

New inspection techniques and inspection accessories are tested throughout the industry. In the NEK, we tend to keep pace with the industry and implement proven solutions to keep the performance of the CIP on a comparable level to other power plants and to fully comply to all regulatory requirements.

References

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[4] NEK ISI-4.035; VIZUALNA ISPITIVANJA (VT-1 I GVE) KOMPONENTI KONTEJNMENTA rev.4
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