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INTER GRANULAR STRESS CORROSION CRACKING OF IGNALINA NPP AUSTENITIC PIPING OF OUTSIDE DIAMETER 325 MM

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Abstract
The Inter Granular Stress Corrosion Cracking (IGSCC) of Ignalina NPP main circulation circuit piping, produced from austenitic stainless steel is presented covering current performances and further "Ageing Management" related actions and plans as well as experience (lessons learned) on solving IGSCC phenomenon, which is currently under investigations and no yet comprehensive answer how to avoid it.
KEY WORDS: *Inter Granular Stress Corrosion Cracking, piping, austenitic stainless steel, welded joint, defect, crack.*

Anotacija
Pristatoma Ignalinos AE pagrindinio cirkuliacinio kontūro vamzdynų, pagamintų iš austenitinio nerūdijančio plieno, tarpkristalinės korozijos problema, apžvelgiant esamą padėtį, jos išvengimo veiksmus ir planus, bei sukauptą patirtį.
PAGRINDINIAI ŽODŽIAI: *interkristalinė korozija, vamzdynas, austenitinis nerūdijantis plienas, suvirinimo siūlė, defektas, plyšys.*

Introduction

The Ignalina NPP contains two RBMK-1500 reactors. Operation of the first unit of Ignalina NPP started in December 1983, the second unit in August 1987. The main circulation circuit (MCC) of RBMK-1500 consists of two loops, whose components are arranged symmetrically with respect to the vertical axis of the reactor. The MCC piping is produced from austenitic stainless steel 08Ch18N10T. The outside diameter of piping is 325 mm, the wall thickness – 16 mm. At normal operation conditions the internal pressure is 6.9-8.4 MPa and the temperature of coolant is 260-270°C [1]. Ignalina NPP main circulation circuit austenitic piping of one loop is shown in Fig.1..

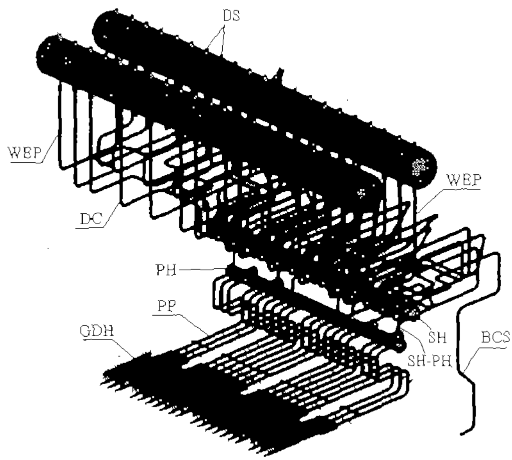


Fig.1 MCC austenitic piping of one loop (WEP – water equalizing piping; DC – downcomers; SH-PH – bypass between suction header (SH) and pressure header (PH); PP – pressure piping, connecting pressure header (PH) and group distribution header (GDH); GDH – group distribution headers; BCS – blowdown & cooldown system piping)

All welds of 325 mm outside diameter austenitic piping according to welding methodology can be separated to shop welds, assembly welds and repair welds, and according to orientation – to vertical welds (welds connecting two horizontal pipe sections) and horizontal welds (welds connecting two vertical pipe sections). After outage in 2002, MCC austenitic piping of outside diameter 325 mm has 1443 welds in the Unit 1, and 1243 welds in the Unit 2. In the Unit 1 it's corresponding to 32.3% shop welds, 52.5% – assembly welds and 15.2% repair welds. In the Unit 2 – 30.6%, 65.9% and 3.5% respectively. Regular in-service inspections (ISI) of all welds are performed.

In-service inspection of MCC austenitic piping

The X-ray technique has been used in Ignalina NPP for inspection of austenitic steel pipelines with outside diameter of 325 mm up to 1997. In 1997 at Ignalina NPP Unit 2 some initial ultrasonic tests were performed to confirm ISI results collected with X-ray probe. In 1998, X-ray and KRAB-I probe (manual UT) was used only at Ignalina NPP Unit 1. From 1999, the enhanced manual UT methodology with improved KRAB-II probes and various equipment of automatic UT was used.

In 1999 100% inspection of austenitic steel pipelines with outside diameter of 325 mm was performed. From this year the inspections are scheduled with an interval of 4 years, i.e. during 4 year interval in total 100% inspections will be performed (for example in unit 2 in 2001– 50% and in 2003– other 50%) [2].

A criterion based on crack length is used. If the detected crack length is above 100 mm then a repair is made and next year the inspection of new welds should be performed. If the detected crack length is below 100 mm, it is left for continued operation without repair with an inspection interval of one year.

Data about IGSCC damages

Performing in-service inspections, the first cracks in unit 1 were detected in 1987, and in unit 2 – in 1991. Metallographic investigations defined that crack growth mechanism is Inter Granular Stress Corrosion Cracking (IGSCC). In both units the first cracks were detected in water equalizing piping. After some time of operation the IGSCC crack also were detected in other MCC piping systems. Total 476 IGSCC-cases were identified in both units until 2002:

- 373 cases in Unit 1 (266 cases in the vertical welds and 107 cases in the horizontal welds) during 18 years of operation, and
- 103 cases in the Unit 2 (73 cases in the vertical welds and 30 cases in the horizontal welds) during 15 years of operation.

Number of IGSCC-cases per year in vertical, horizontal, and vertical & horizontal welds is shown in Fig.2. Straight lines in the figures represent average number of IGSCC-cases per year.

Comparing numbers of IGSCC cases in vertical and horizontal welds (Fig. 2a and Fig. 2b) is important to notice, that vertical welds has more defects than horizontal welds, however quantity of vertical welds is larger than horizontal welds. In Fig. 2c could be noticed significant increment of IGSCC defects in the latest 6 years. The reasons of such noticeable increment are implementation of more advanced inspection methods and increased ISI volume.

In order to determine in which welds defects occurring more often, the frequencies of IGSCC crack occurrence per weld per year were calculated. Frequencies of IGSCC defect occurrence in welds of austenitic piping systems of both units, calculated after repairs in 2002 are presented in

Fig. 3. In Fig. 3 could be noticed, that exists significant difference in IGSCC defect occurrence frequencies between suction part (DC, WEP, BCS) and pressure part (PP, GDH). Comparing frequencies of IGSCC defect occurrence of shop, assembly and repair welds, the highest frequencies are observed in shop and repair welds of majority systems; especially repair welds of SH-PH system are standout. Analysing all systems together, the highest frequency of IGSCC crack occurrence has repair welds, the lowest – assembly welds.

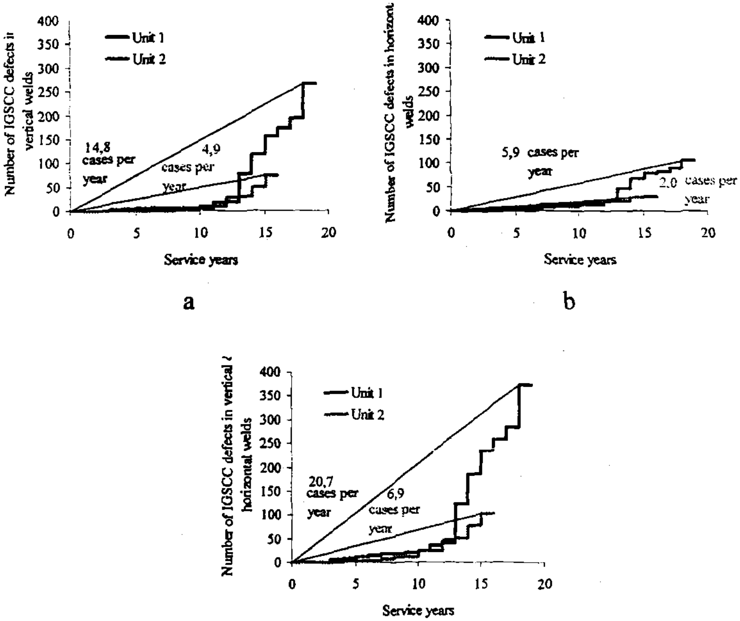


Fig. 2 Cumulative number of IGSCC cases in Ignalina NPP after repair in 2002:a in vertical welds, b in horizontal welds, c in vertical & horizontal welds

Variation of IGSCC crack occurrence frequencies during period from start of operation until 2002 is presented in Fig. 4. Comparing IGSCC defect occurrence frequencies of vertical and horizontal welds one can see, that from 1997 until 2002 (after starting to use UT inspection technique) frequencies of vertical welds are about twice higher than frequencies of horizontal welds. The reasons of such difference can be a fact, that vertical welds are welded using higher heat input than horizontal welds, because of specifics of welding. The higher heat input cause higher sensitization of HAZ and higher weld residual stresses.

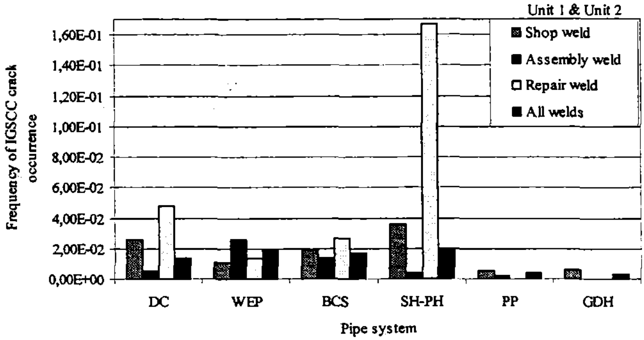
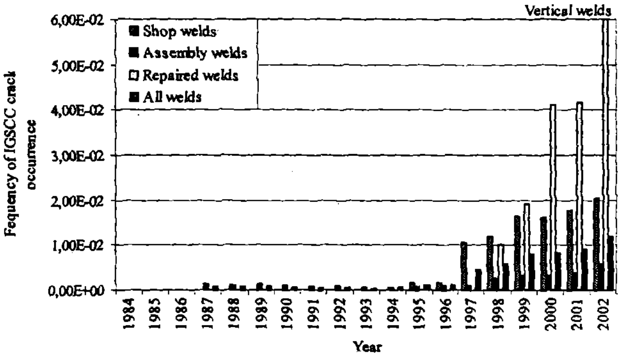


Fig. 3 Frequencies of IGSCC crack occurrence in 325 mm outside diameter austenitic piping systems in year 2002

Variation of IGSCC crack occurrence frequencies of vertical & horizontal welds together (Fig. 4c) shows, that until 1997 a frequency is almost constant, however from 1997 it increases from year to year. It shows that actions on IGSCC mitigation are not sufficient. Especially huge increase of IGSCC defect occurrence frequency for repair welds is observed. This indicates that welds repair technique is inadequate.

In Fig. 5 comparison of cut out defect sizes, measured during destructive examinations is presented. Comparison of defect sizes sowed that IGSCC crack length to depth ratio is not constant, but scattered and varies from 3 up to 38 mm. Depth of the deepest cracks reaches up to 12 mm, i.e. 75% of wall thickness. Length of the longest cracks reaches up to 280 mm, i.e. approximately 27% of circumference. Through-wall cracks were not detected in austenitic 325 mm outside diameter piping.

It should be mentioned, that all IGSCC cracks detected in MCC austenitic piping of Ignalina NPP appear at the inner surface in heat affected zone (HAZ) near to weld root and grow to outside close to fusion line. Typical IGSCC crack is shown in Fig. 6.



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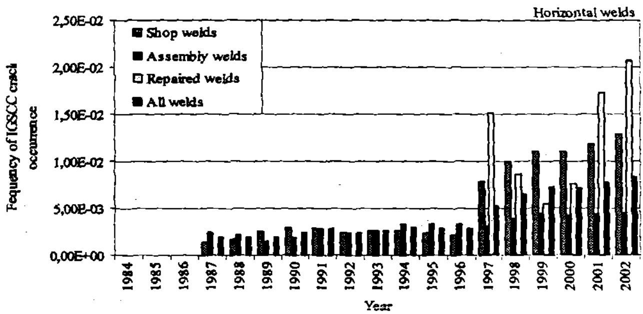

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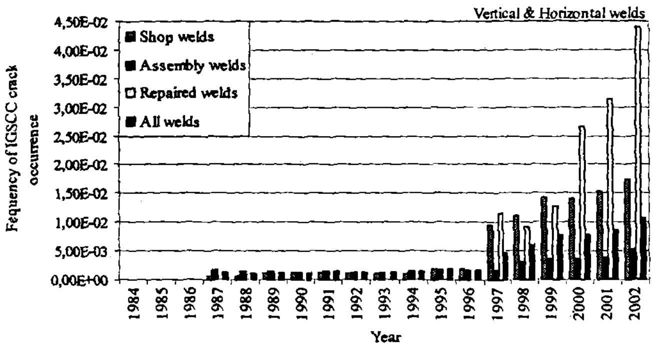

c

Fig. 4 Frequencies of IGSCC crack occurrence: a in vertical welds, b in horizontal welds, c in vertical & horizontal welds

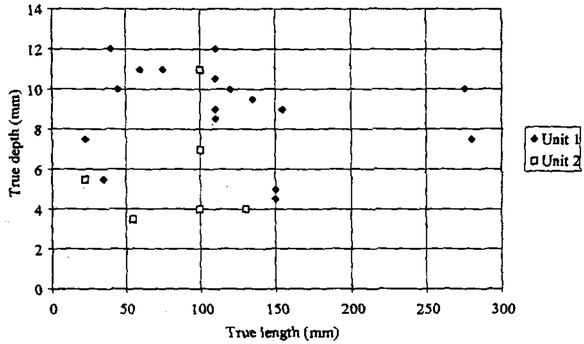

Fig. 5 True length and depth (measured in destructive examinations) of IGSCC cracks in Ignalina NPP austenitic steel pipelines with outside diameter of 325 mm

Fig. 6 Typical IGSCC crack

Root causes of IGSCC

IGSCC is associated with a combination of the following three factors: material, stresses and environment. All these factors are important for cracking.

In 2000-2001 IAEA Extrabudgetary Programme on Mitigation of Intergranular Stress Corrosion Cracking in RBMK Reactors [3] is performed. Following the Programme, an engineering judgement on the parameters affecting the observed cracking is given based on received information and on previous experience and knowledge. The main root causes of inter granular stress corrosion cracking in the stainless steel of type 08Ch18N10T can be summarised as follows [3]:

- sensitisation, which is caused by a high degree of free carbon and a low stabilisation ratio in the material and high heat input during welding;
- deformation of the pipe inner surface due to weld preparation;
- geometrical weld imperfections accelerating crack initiation;
- deformation of the material in the heat affected zone due to weld shrinkage;
- high tensile stresses (residual and/or operational), indicated by a large opening of the cracks;
- environmental parameters, indicated by chlorides on the fracture surface, known condenser leakage incidents, possible sulphate intrusions, which cannot be ruled out, water impurities and the oxidising power of the water;
- operational fluctuating stresses indicated by observation of fatigue striations on the fracture surfaces.

As mentioned above, the IGSCC cracks in MCC austenitic piping of Ignalina NPP appear at the inner surface in HAZ near to weld root and grow to outside close to fusion line. The HAZ material is susceptible to IGSCC and sensitised in most cases. The sensitisation occurs due to overheating during welding and is an important factor in the cracking behaviour. According to investigations [4], the crack growth to depth stops reaching zone of low sensitisation approximately in the middle of pipe wall. It determines the maximal height of detected cracks of 8-10 mm. However, it is necessary to mention that is not known with a certainty that only degree of sensitisation stops a crack grow. If one waits long enough without inspections there are no guaranties that the crack will not penetrate the wall thickness. Up to now no leakage has occurred.

The stresses in MCC piping occurring due to internal pressure (membrane stress), deadweight and thermal expansion (bending stress) as well as deformation during welding due to weld shrinkage (weld residual stresses). A numerical finite element simulation of welding process showed, that the axial weld residual stresses are tensile at the inside of the pipe and compressive at the outside of the pipe [5]. The operating and residual stresses are high enough to contribute the growth of cracks.

The environment inside MCC piping is oxidising. In Ignalina NPP at present time water chemistry is considerably improved and during normal operation oxygen content is very low, however it increases during start up and shutdown of the reactor, and during outages.

IGSCC management and mitigation actions and plans

1. In-service inspections. At present time the manual and automatic UT techniques is used in the Ignalina NPP for piping base metal and weld metal inspection. In some cases the manual inspection was more uncertain than automatic inspection, so now mostly automatic UT inspection is used if possible (not all welds is accessible for automatic inspection). Procedures used in the Ignalina NPP at present time allows to determine the flaw length only, and procedure which allows to determine the depth of the flaw is under development.

2. Repairs of defected welds. Repairs of austenitic piping are performing cutting out defected weld with heat affected zone and inserting a new piece of pipe. This means, that each repair increases the amount of welds. Operation experience indicates that cracking occur also in repaired welds. For repairing mainly manual welding is used. Only a few repair welds are welded using automatic welding, but in future automatic welding is planed to be used to an increasing extent. At present time Ignalina NPP developing a new welding methodology which involves minimal heat input and minimal number of passes. Hopefully it will reduce sensitization level and weld residual stresses.

3. Leak-Before-Break deterministic analysis. Analysis was performed for group distribution header, downcommer piping, and pressure piping connecting pressure header and group distribution header of Ignalina NPP unit 2. The aim was to calculate the maximal leak rates in acceptance with LBB requirements for all welds of analysed piping, and to analyse change of surrounding parameters in case of leak. Basing on analysis results, additional leak detection systems (as additional safety systems) are in installation process.

4. Participation in IAEA Extrabudgetary Programme on Mitigation of Intergranular Stress Corrosion Cracking in RBMK Reactors (2000-2001). The aim of the project was to help countries operating RBMK reactors to solve IGSCC mitigation problems using international experience. The general recommendations on remedial actions to be taken to significantly lower the risk for IGSCC are given, but each recommendation needs efforts to validate the remedial action before take into use.

5. Risk Based Inspection Pilot Study of Ignalina NPP Unit 2 (IRBIS, 2000-2001). The aim of study was optimisation of ISI program of 325 mm outside diameter piping produced from austenitic steel. The study showed, that it is possible to combine a 44% reduction of the number of future inspections with a 35% reduction of overall risk. This is possible due to a

proposed shorter inspection interval for the high risk welds. In the higher risk levels, a shorter inspection interval than 4 years is suggested. Many low risk locations are suggested not to be included in the new ISI-selection. This means that the radiation exposure to plant personnel can be reduced and resources can be redirected to other safety related issues. IRBIS results were used developing new in-service inspection programme.

6. Development of regulation document for assessment of IGSCC damages in RBMK-1500 reactors. The work is started in 2003 and is in progress. The prepared document will contain the Requirements for General Principles, Damage Tolerance Analysis, Quality Assurance and Documentation. The regulations will include the safety factors and list of necessary documentation whitch should be prepared by plant in case if detected IGSCC damage will be left to further exploitation. Thus, the plant and the regulator will have the clearly defined procedure how to manage the IGSCC damages.

Lessons learned solving IGSCC problem

1. Welding technology has evident effect on IGSCC resistance of HAZ metal of welded joints made from steel 08Ch18N10T. The influence of welding technological factors (weld joint type, number of passes, welding regimes, welding methods and cooling procedure) is complex and each factor should be taken into account.
2. Advanced non-destructive testing technique is necessary to found IGSCC cracks and to determine their length as well as depth.
3. IGSCC cracks in Ignalina NPP appearing at the inner surface in HAZ near weld root.
4. IGSCC crack length to depth ratio is not constant, but scattered.
5. Crack growth to depth rate varies at separate stages of propagation because the HAZ metal sensitisation degree is different through a pipe wall.
6. Water chemical composition should be neutral to IGSCC in all operation regimes.

Concluding it is necessary to mention, that the IGSCC phenomenon is currently under investigations and there is no yet comprehensive answer how to avoid this ageing issue.

Acknowledgements

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References

1. ALMENAS, K., KALIATKA, A., USPURAS, E., Ignalinas RBMK-1500. A Source Book, Ignalina Safety Analysis Group, Lithuanian Energy institute, Kaunas (1998).
2. IGNALINA NUCLEAR POWER PLANT, The Rules of the In-service inspection of the condition of metal of the equipment and pipelines of systems, important for safety of the Ignalina nuclear power plant with reactors RBMK-1500, PTOed-1125-B2, Ignalina NPP (in Russian).
3. IAEA extrabudgetary programme on mitigation of intergranular stress corrosion cracking in RBMK reactors. Working group 2 on comprehensive assessment techniques. Final report, IAEA (2002).
4. Technical Report No. 66173 "Determination of Downcomer Piping Joints Damage Reasons, Development of Technological Measures and Experimental Evaluation of Damaged Joints Manufactured of 08Ch18N10T Steel Durability After Definite Operation and Repair Period", PROMETEY, Sankt-Peterburg 1997.
5. BRICKSTAD, B., LETZTER, A., KLIMASAUSKAS, A., ALZBUTAS, R., NEDZINSKAS, L. and KOPUSTINSKAS, V., "Risk Based Inspection Pilot Study of Ignalina Nuclear Power Plant, Unit 2, Final Report", Report No. 10048500-4, Det Norske Veritas, Stockholm, 2001.

IGNALINOS AE 325 MM IŠORINIO DIAMETRO VAMZDYNŲ TARPKRISTALINĖ KOROZIJA

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Santrauka

Ignalinos AE yra du kanaliniai RBMK-1500 reaktoriai. Pirmojo energetinio bloko eksploatacija pradėta 1983 m. gruodžio mėn., o antrojo – 1987 m. rugpjūčio mėn. Praėjus keleriems eksploatacijos metams, pagrindinio cirkuliacinio kontūro vamzdynuose, pagamintuose iš austenitinio nerūdijančio plieno 08X18H10T, buvo aptikta daug defektų. Vamzdynų išorinis diametras yra 325 mm, o sienelės storis – 16 mm.Normaliomis eksploatacijos sąlygomis vidinis slėgis yra 6,9-8,4 MPa, šilumnešio temperatūra 260-270°C. Defektai buvo aptikti suvirinimo siūlėse eksploatacinių kontrolių metu. Atlikus metalografinius tyrinėjimus buvo nustatyta, kad šie plyšiai atsiranda ir didėja dėl tarpkristalinės korozijos. Visi aptikti defektai atsiranda vidinėje vamzdžio pusėje terminio poveikio zonoje šalia siūlės šaknies ir didėja į išorę šalia pagrindinio metalo ir siūlės metalo susilydimo linijos. Straipsnyje pristatoma Ignalinos AE pagrindinio cirkuliacinio kontūro vamzdynų, pagamintų iš austenitinio nerūdijančio plieno, tarpkristalinės korozijos problema, apžvelgiant esamą padėtį, jos išvengimo veiksmus ir planus, bei sukauptą patirtį.