

## CORROSION MONITORING PROGRAMMES FOR LIFE TIME EXTENSION OF NPP COMPONENTS

### **Martin BREZINA**

*VUJE Inc., Okružna 5, 918 64 Trnava,  
Slovak Republic*  
Phone: +421(33)5991563  
Fax: +421(33)5991502  
E-mail: brezina@vuje.sk

### **Ludovit KUPCA**

*VUJE Inc., Okružna 5, 918 64 Trnava,  
Slovak Republic*  
Phone: +421(33)5991560, Fax:  
+421(33)5991502  
E-mail: kupca@vuje.sk

### **Peter BENO**

*VUJE Inc., Okružna 5, 918 64 Trnava, Slovak Republic*  
Phone: +421(33)5991561, Fax: +421(33)5991502  
E-mail: beno@vuje.sk

### **ABSTRACT**

The important part of the life extension analysis is current corrosion information about components. Corrosion monitoring systems provides substantial set of this information. In the paper are presented the corrosion monitoring systems operated in Slovak NPP's, main technical parameters of these systems and the up-to-date results. These monitoring systems are based on the principle of surveillance samples, i.e. all specimens made from original materials are placed into the original environment and loaded with stresses similar to the operational ones.

**Keywords:** corrosion, monitoring, stainless steels, stress corrosion cracking, corrosion loop

### **1. INTRODUCTION**

Corrosion stability monitoring of WWER-440 NPPs safety related components are in VÚJE Trnava Inc. one of the main objects of interest. From the operational experience and from the demands of the national regulatory bodies follows that it is necessary to have monitoring possibilities of corrosion behavior of the structural materials. As the respond to this requirement, several technical solutions were prepared for the long-term corrosion processes monitoring of NPPs materials. All these monitoring systems are based on the principle of surveillance samples. It means that samples made from original materials are placed into the original environment and loaded with stresses similar to the operational ones. The main advantages of these systems are:

- simply construction,
- the same operational history,
- original environment,
- practically zero operational cost.

On the other hand there are some disadvantages resulting from operational conditions:

- limited access to the samples,
- surface contamination,
- no possibility to change working environment, etc.

In this contribution there are briefly described the monitoring systems, that were designed and realized by VUJE Inc. for WWER-440 type NPPs in the Slovak Republic.

## 2. PRIMARY CIRCUIT CORROSION LOOPS

Corrosion loops are the unique equipments that have been installed in primary circuits and provide the possibility to expose sets of samples in original conditions of primary circuit. At present there are two corrosion loops kept in operation:

- a) The first and the old one has been working in Unit 3 Jaslovske Bohunice NPP since 1992. Five sets of samples have been already exposed in the loop and the sixth set is being exposed now.
- b) The second corrosion loop was put into operation in 1999 in Unit 1 Mochovce NPP and since that time the exposition of two sets of samples has been already finished and two sets of them are being exposed now.

The base principal both loops are the same. The corrosion chambers with samples are connected between the outlet and the inlet of the main coolant pump in the primary circuit and the water flowing through the chamber is as the result of pressure difference between the outlet and the inlet of the main coolant pump.

### 2.1 Construction of the loops

The main parts of the loop are:

- corrosion chamber(s) with support construction,
- feeding piping,
- cut-off valves,
- drainage piping.

The basic technical information of the corrosion loops is shown in Table 1. A view on the installed corrosion loop illustrates Figure 1. The main difference between corrosion loops in Bohunice NPP and Mochovce NPP is in the number of corrosion chambers. Whereas the corrosion loop in Bohunice has been constructed as single chambers, the corrosion loop in Mochovce consists of two independent chambers. One chamber is used for short-term expositions, another one is used for long-term monitoring.

The complete set of samples is fixed by a special holder and inserted in the corrosion chamber. Figure 2 shows the first set of samples in the holder before putting into the chamber.



Fig. 1 Global view on the corrosion chamber



Fig. 2 Set of samples in the support construction

Table 1: The basic technical parameters of the corrosion loops

PARAMETER	VALUE	
	BOHUNICE #3	MOCHOVCE #1
Operational temperature	270°C	
Operational pressure	12,3 MPa	
Number of chambers in the loop	1	2
Dimensions of the chamber	Ø 168x12-600 mm	Ø 160x14-600 mm
Volume of the chamber	8,8 dm <sup>3</sup>	7,4 dm <sup>3</sup>
Weight of the filled chamber	cca 65 kg	
Feeding piping	Ø 22 x 2,5 mm	Ø 18x2,5 mm
Construction material	08Ch18N10T	steel STN 17 247.4
Corrosion medium	primary coolant	
Flow rate	cca 57 dm <sup>3</sup> /min	cca 45 dm <sup>3</sup> /min
Decrease of temperature	< 1°C	< 1,5°C

## 2.2 Monitoring samples and experimental materials

Next types of samples have been used for corrosion monitoring:

- double U-bend,
- circular bead weldment specimens,
- crevice bent beam (CBB),
- reverse U-bend,
- pre-stressed tension specimens,
- pre-stressed CT specimens.

Majority of the specimens have been made from the original primary circuit structural material of the Bohunice and Mochovce NPPs, which is the austenitic stainless steel grade 08Ch18N10T. The chemical composition of the 08Ch18N10T stainless steel is shown in Table 2. In some cases, another types of materials were used. For example using of exposed materials from others NPPs with long-term operational history enabled to compare the influence of operational history on their corrosion resistance.

Table 2: Chemical composition of the steel 08Ch18N10T

Steel	CHEMICAL COMPOSITION [mass. %]							
	C	Mn	Si	Cr	Ni	Ti	P	S
08Ch18N10T (AISI 321)	max. 0,08	max. 2,0	max. 1,0	17,0 ÷ 19,0	9,5 ÷ 12,0	min. 5x%C	max. 0,045	max. 0,030

## 2.3 Main results

Up to now 11 sets of samples have been all together prepared for the corrosion loops, thereout 5 sets have been already evaluated, 3 sets are being evaluated and 3 set are under exposition. The complete overview of all sets of samples shows Table 3.

After the exposure, each corrosion chamber is cut off, opened and all samples are decontaminated by dilute methods and evaluated using several structural analysis methods.

These main results follow from the evaluation:

- no corrosion attack was observed on the samples prepared from the original structural materials,
- small corrosion cracks were found on circular bead weldment specimens prepared from the sheet,
- corrosion cracks were observed on CBB specimens made of a special heat with high contents of Ti inclusions.

Table 3: Exposure table of corrosion loops

UNIT #	SET #	EXPOSITION TIME	REMARK
BOHUNICE UNIT 3	EBO 1	1 year	evaluated
	EBO 2	2 years	evaluated
	EBO 3	3 years	evaluated
	EBO 4	3 years	evaluated
	EBO 5	3 years	is being evaluated
	EBO 6	aprox. 3 years	under exposition
MOCHOVCE UNIT 1	EMO 1.1	1,5 year	evaluated
	EMO 1.2	2 years	is being evaluated
	EMO 1.3	aprox. 5 years	under exposition
	EMO 2.1	aprox. 3 years	is being evaluated
	EMO 2.2	aprox. 5 years	under exposition

### 3. CORROSION MONITORING OF THE STEAM GENERATOR

A simple equipment enables a long-term exposition of various samples inside the steam generator above the primary collector flange. The samples are placed on a special holder into secondary circuit conditions.

The first charge contained two sets of CBB type specimens. All test samples were prepared from the primary collector material (steel 08Ch18N10T) with the aim to assess the influence of different repairing technologies on corrosion stability. The specimens were exposed one and two years, respectively. From the metallographic evaluation followed that no corrosion cracks have been found, only small corrosion pits were observed.

Next sets of samples were prepared from primary collector bolts. The bolts are made from steel ChN35VT and suffer from IGSCC. The chemical composition of the steel ChN35VT is shown in Table 4. Next of samples were used for the new monitoring program:

- crevice bent beam (CBB),
- pre-stressed tension specimens,
- pre-stressed CT specimens.

A view on the new set of samples in the holder illustrates figure 3. The first set of is under evaluation now and the preliminary results will be presented.

Table 4: Chemical composition of the steel ChN35VT

Steel	CHEMICAL COMPOSITION [mass. %]								
	C	Mn	Si	Cr	Ni	Ti	W	P	S
ChN35VT	max. 0,12	1,0 ÷ 2,0	max. 0,60	14,0 ÷ 16,0	34,0 ÷ 36,0	1,1 ÷ 1,5	2,8 ÷ 3,5	max. 0,025	max. 0,015



Fig. 3 Set of samples prepared from primary collector bolts in the holder

#### 4. CORROSION MONITORING EQUIPMENT PLACED IN THE WATER-SHIELDING TANK OF THE UNIT 2 IN JASLOVSKÉ BOHUNICE NPP

The water shielding tanks, which are placed around the V-1 NPP RPV's, are the ones of safety related components. The shielding tanks are made of the carbon steel marked by the Slovak standards (STN) steel 11 375. (S325JRG2 by EN 10025-94). The tank capacity is 68 m<sup>3</sup> of demineralized water with addition of K<sub>2</sub>CrO<sub>4</sub> as a corrosion inhibitor. The maximal temperature of the shielding water is 60°C.

The set of corrosion samples is fixed in the tank by a special holder (see Figure 4), which is placed beneath the water surface. The first three sets of corrosion samples were prepared from the original structural material of the tanks and they were exposed since 1995 to 2001, when the last set was evaluated. The two new sets of samples were prepared after preliminary results of the first sets. The new sets were prepared from the equivalent model material and they contained weld joint. These sets were exposed since 2000 to 2004, when the last set was evaluated and the monitoring program was finished.



*Fig.4 Corrosion monitoring system for the water-shielding tank*

Next types of samples have been used for corrosion monitoring in the water-shielding tank :

- corrosion coupons,
- U-bend specimens,
- specimens for a metallographical evaluation,
- pre-stressed tension specimens,
- specimens for the crevice corrosion monitoring by ASTM G-48,
- corrosion coupons placed in the water level fluctuation.

From the results after the long-term exposition follow:

- mass lost of the corrosion coupons was minimal in every sample sets,
- U-bend samples – no corrosion cracks were found,
- no differences between results obtained from original and equivalent materials,
- corrosion situation of the tank from the long-time point of view is stabilized.

#### 5. CORROSION MONITORING IN THE SPENT FUEL INTERIM STORAGE

The spent fuel interim storage (SFIS) in the nuclear power plant Jaslovske Bohunice makes use a wet storing. Principally the spent fuel assemblies, which are placed in casks, are stored in large water pools. This way of storing makes heavy demands on a long-term corrosion stability of used structural materials. From this point of view, it is necessary to have monitoring possibilities of corrosion behavior of the structural materials.

##### 5.1 Structural materials

The main structural material used for the SFIS is a CrNi austenitic stainless steel stabilized by Ti, grade 08Ch18N10T (equivalent to AISI 321). Chemical composition is given in Table 2.

In the SFIS a special grade of stainless steel is used for hexagonal tubes of compact casks. The steel is marked as “ATABOR” and in substance, it is based on the AISI 304 stainless steel alloyed by boron. The chemical composition of ATABOR steel is shown in Table 5.

Table 5: Chemical composition of the steel ATABOR

Steel	CHEMICAL COMPOSITION [mass. %]								
	C	Mn	Si	Cr	Ni	Ti	P	S	B
ATABOR	max. 0,03	max. 2,0	max. 0,8	18,0 ÷ 20,0	10,0 ÷ 12,5	---	max. 0,035	max. 0,025	min. 1,10

### 5.2 Corrosion environment in the storage pools

In storage pools the casks with spent fuel assemblies are submerged in cooling water, this represents the corrosion environment. The quality of cooling water in the storage pools is periodically analyzed. Some limit values and typical measured values are given in Table 6. The table shows that the quality of the cooling water is kept on very good parameters due to periodical cleaning. All pools are opened to air, therefore the amount of dissolved oxygen depends on the temperature and it ranges from 8 to 10 mg.kg<sup>-1</sup>.

Table 6: Basic parameters of the cooling water in storage pools

Parameter	Dimension	Limiting value	Measured value
pH	–	5.5 ÷ 8.0	5.8 ÷ 6.5
Cl <sup>-</sup>	mg.kg <sup>-1</sup>	< 0,1	< 0,02
electrical conductivity	µS.cm <sup>-1</sup>	< 3	1 ÷ 1,5
suspended particles	mg.kg <sup>-1</sup>	< 0,5	< 0,4
<sup>3</sup> H (T)	Bq.m <sup>-3</sup>	< 3,7.10 <sup>9</sup>	10 <sup>5</sup>
total activity	Bq.m <sup>-3</sup>	< 4,1.10 <sup>7</sup>	10 <sup>2</sup> ÷ 10 <sup>3</sup>
temperature	°C	< 50	20 ÷ 50

### 5.3 Main requirements for the monitoring program

The main requirements for the monitoring program are:

- monitoring of a corrosion state of the structural materials,
- in time warning on potentially corrosion problems,
- to give the possibilities for verifying changed operating conditions influence on the structural materials corrosion stability.

### 5.4 Experimental material

There will be used three resources of the experimental material:

- stainless steel plates, grade 08Ch18N10T – base metal and weld joint,
- stainless steel plates, grade ATABOR – base metal and original weld joint of hexagonal tubes from the compact casks,
- old parts of the SFIS equipment – details removed during the reconstruction – preserved original surface without decontamination.

### 5.5 Test samples

Following types of samples are proposed for the monitoring program:

- corrosion coupons,
- Crevice Bent Beam (CBB) specimens,
- circular bead weldment specimens,
- U-bend specimens,
- specimens for metallographical evaluation.

### 5.6 Samples holder

In each storage pool is placed one monitoring system. A set of samples belonging to each system was fixed in a special holder (figure 5). The holder in the form of a “basket” had to conform to the next requirements:

- simple and flexible construction,
- easy mounting and dismantling of samples,
- fixing of samples in their right positions,
- free access of the corrosion medium to all samples,
- not disturbing the regular operation of the SFIS,
- possibility to add new set of samples.



Fig.5 Corrosion monitoring system for SFIS

### 5.7 Samples location

The sets of samples fixed in the holder are divided into two groups. The samples of the first group will be all time submerged beneath the water surface. The second group of samples will be fixed in the place of the water level fluctuation.

### 5.8 Schedule of samples evaluation

The basic evaluation interval of the set of samples is 4 years and in each storage pool is placed one monitoring system. Therefore, every year can be evaluated one set of samples. After the first favorable results, the evaluation interval can be extended. If the operation conditions change, then it will be possible to evaluate an extra set of samples to estimate the influence of these changes on corrosion stability of structural materials. Time schedule of samples evaluation is shown in Table 7.

Table 7: Time schedule of SFIS monitoring program

Pool No.	Year												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
116/1	I	E+A				E+A				E			
116/2	I		E+A				E+A				E		
116/3	I			E+A				E+A				E	
117	I				E+A				E				E

I – installing of the system with initial set of samples

A – adding new samples from new compact casks

E – evaluation of the samples

### 5.9 Preliminary results of the first sets of samples evaluation

Table 7 shows, that up to now 4 sets of samples has been already evaluated. From the results obtained from the evaluated samples followed that no corrosion attack has been observed.

## **5. CONCLUSIONS**

- Corrosion monitoring provides important information about corrosion situation of both materials and equipments.
- All presented monitoring systems are based on the principle of surveillance samples.
- From the results of evaluation follows that no significant corrosion attack was found.
- From the corrosion point of view – used structural material is stable in given standard condition and makes possible to extend the life of NPPs.