

## DEVELOPMENT OF THE NORMATIVE DOCUMENTATION FOR CONTROL EXPLOITATION PIPE LINES OF SECOND SIDE NPP WITH VVER

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### Abstract

Flow accelerated corrosion is the most common mechanism of metal degradation. NPP equipment and pipelines manufactured from pearlitic steel are exposed to erosion-and-corrosion wear. Recently many problems related to life management of NPP equipment and pipelines exposed to erosion-and-corrosion wear have been solved. The present paper analyzes the development, certification in supervisory authorities, and adaptation of normative documentation on life management of secondary pipelines operation at NPPs.

Keywords: erosion, corrosion, chemical content, water chemical regime.

### 1. INTRODUCTION

Flow accelerated corrosion (flow accelerated corrosion – FAC) is relatively new mechanism of metal degradation. Before the severe accident by reason of erosion-and-corrosion ware happened on NPP “Surry-2” in USA on December 1986, it was considered that reliable operation of NPP equipment and pipeline elements is assured during the design operation life. Therefore incoming and operation inspection of NPP line wall thickness were not carried out. After the accident the study of FAC problem was of great interest.

Study of foreign experience and native investigations was the basis for the elaboration of normative documents on management of NPP secondary pipeline life in Russia [1-4].

It was discovered that prediction and elimination of dangerous erosion-and-corrosion ware is possible in the presence of normative documents that include as follows:

1. Software on calculation and prediction of erosion-and-corrosion ware.
2. Technical instructions for determination of chemical composition of the pipeline metal.
3. Rates of metal strength analysis involving erosion-and corrosion ware.
4. Programme of metal operation control involving erosion-and-corrosion ware.
5. Technical instructions for acquisition and processing of data determining erosion-and-corrosion ware.
6. Technical instructions for selection of structural material in the course of repairing.
7. Recommendations considering the effect of corrosion products deposition on operation control reliability.

The frame to be solved by each established document was specified.

1. **Software** (computer codes) provides the potential for:

- the calculation of rate and value of pipeline elements thinning to determine their safety operation life;
- the calculation of rate and value of pipeline elements thinning in the course of modification of the design or replacement of structural materials;
- the calculation of rate and value of pipeline elements thinning on modification of water chemistry;
- the selection of structural materials with previously predicted operation life during the design and in the course of pipelines repairing;
- rejection of expensive stainless steel or pearlitic steel with large wall thickness in the course of repairing;
- replacement of defective parts of the pipeline for cheaper pearlitic steel with the concentration of chromium and copper  $\sim(0.25-0.30)$  %.

2. **Technical instructions for determination of chemical composition** ensure the potential for determination of mass content of chromium, copper and molybdenum in NPP pipeline metal:

- under operation;
- in the repairing;
- in determining a fail source of pipelines.

3. **Rates of metal strength calculations** ensure the potential for calculation of permissible thickness values:

- in general thinning of pipeline walls;
- in local thinning of pipeline walls.

4. **The programmes of metal operation control** ensure as follows:

- optimization of the operation control scope of ultrasonic measuring of pipeline wall thickness exposed to FAC;
- rating of the pipelines by degree of corrosion-and-erosion exposure;
- integral use of regulatory documents on corrosion-and-erosion ageing.

5. **Technical instructions for acquisition and processing data** ensure collection of data according to:

- indications of water chemistry;
- structural characteristics of the pipelines;
- structural materials used for manufacturing pipelines;
- operation conditions of pipeline elements.

6. **Technical instructions for selection of structural material** ensure:

- integral use of regulatory documents on corrosion-and-erosion ageing to justify the selection of structural materials on designing;
- integral use of regulatory documents on corrosion-and-erosion ageing to justify the selection of structural materials on repairing.

7. **Recommendations considering the effect of corrosion products deposition on operation control reliability** make it possible:

- to consider the effect of corrosion-and-erosion ageing features on producing of corrosion products deposition;
- to consider the effect of corrosion product deposits on reliability of operation control (ultrasonic measuring of pipeline wall thickness).

What the situation with the development of regulatory documents on FAC calculation and prediction is for 2004.

The software (SW) EKI-02 and EKI-03 have been developed and are certified in the supervision authorities for Russian NPPs. The prototype of the developed Russian software is the US computer code CHECWORKS. The software EKI-02 is designed for the calculation of FAC rate in the pipelines of one-phase medium (water), and the software EKI-03 – for the calculation of FAC rate in the pipelines with two-phase medium (live and heating steam pipelines).

When calculating by means of the software sufficiently large data content on operating conditions, design philosophy and pipeline layout, water chemistry values, chemical composition of structural materials used, operation control data for each of calculated element in different operation periods, etc., should be available. Such data are not always available in domestic NPPs. That fact involves some difficulties when calculating corrosion-and-erosion ageing of the pipeline elements using the software. The development and introduction of technical instructions for acquisition and processing data ensure data collection at the stage of designing and in operation.

Figure 1 demonstrates a part of the feed water pipeline damaged on December 9, 1986, in NPP Surry-2. During the accident the feed water pipeline of 18 inches (457.2 mm) in diameter was broken. The Company-owner “ Virginia Power” informed that the broken pipeline was never examined during its operation since its life was designed for 40 years. Its maximum thinning was 11.5 mm. The pipeline was ruptured on 13 years of operation and resulted in severe consequences for NPP.

Figure 2 shows a part of the feed water pipeline damaged behind a throttling orifice in NPP Loviisa. A guillotine break in the area of welding was taken place and corrosion on the direct section behind the welding. Metal of flange coupling does not contain chemical elements preventing from corrosion-and-erosion propagation. Corrosion-and-erosion ageing of metal is less when chromium, copper and molybdenum in metal is 0.04% at the most. Damaged direct section is manufactured from carbon steel containing chromium, copper and molybdenum of 0.00 – 0.06%. Another direct section made of steel 20 is welded to the damaged direct section. Steel 20 may contain concentration of chromium and copper 0.25%.

Figure 3 presents control throttle flap in Kursk NPP. Corrosion is taken place in the area of flap welding to the valve. The section under effect of coolant flow of high velocity has damaged metal.

Table I includes the data required for the calculation of thinning resulted from corrosion-and-erosion ageing of PWR (Surry-2), WWER-440 (Loviisa 1,2) and RBMK (Kursk) NPP pipelines by means of EKI-02 software. Data given from the references below and available in NPP [5-12] were used for the calculation.

*Table I. Data determining corrosion-and-erosion ageing of pipelines of different NPPs*

№	Parameter	Designation	Dimension	NPP		
				Surry-2	Loviisa-1 Loviisa-2	Kursk
1	Coolant temperature	t	°C	190	164 – 226	255
2	Medium rate	W	m/c	5.2	3.9	3.0 ÷ 45.0
3	Value pH	pH	-	8.8 ÷ 9.2	<u>7.0</u>	<u>7.0</u>
4	Concentration of oxygen	C <sub>O2</sub>	Mcg/kg	<u>1 ÷ 4</u>	<u>≤ 1</u>	50
5	Amine used	amine	-	ammonia	ammonia	ammonia
6	Content of chromium in metal	C <sub>Cr</sub>	% (bec.)	<u>≤ 0.03</u>	<u>0.04 ÷ 0.25</u>	<u>≤ 0.03</u>
7	Content of copper in metal	C <sub>Cu</sub>	% (weight)	<u>≤ 0.03</u>	<u>0.00 ÷ 0.25</u>	<u>≤ 0.03</u>
8	Content of molibdenum	C <sub>MO</sub>	% (weight)	<u>≤ 0.03</u>	<u>0.00 ÷ 0.03</u>	<u>≤ 0.03</u>

	in metal					
9	Keller factor	$K_{KEL}$	-	0.45	0.08 ÷ 0.3	0.2 ÷ 0.9
10	Dimension-type of pipeline	D x $\delta$ , mm	mm	460x12	325x18	838x38
11	Operation time	$\tau_{OPER}$	year(hour)	13 (76600)	13.2; 12.3	13 ÷ 22

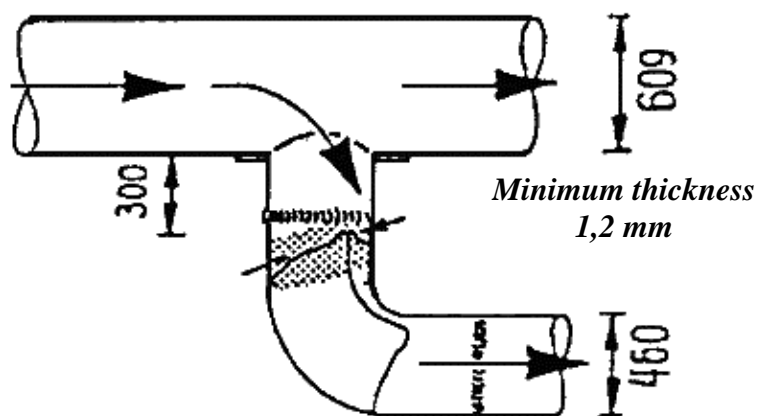


Figure 1. Corrosion-erosion ware of water pipeline (460x12,7) in NPP with PWR Surry-2, 09.12.1986 on 13 years of operation

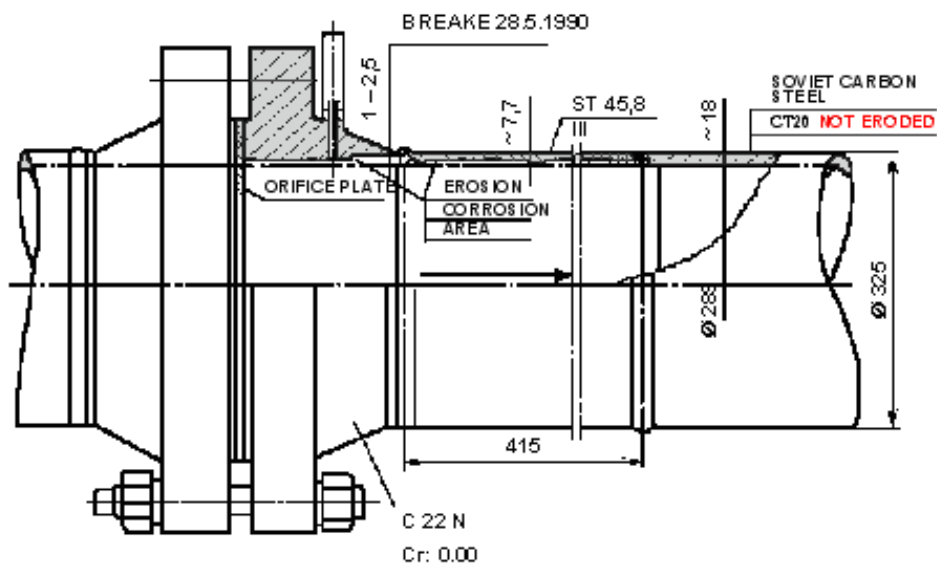
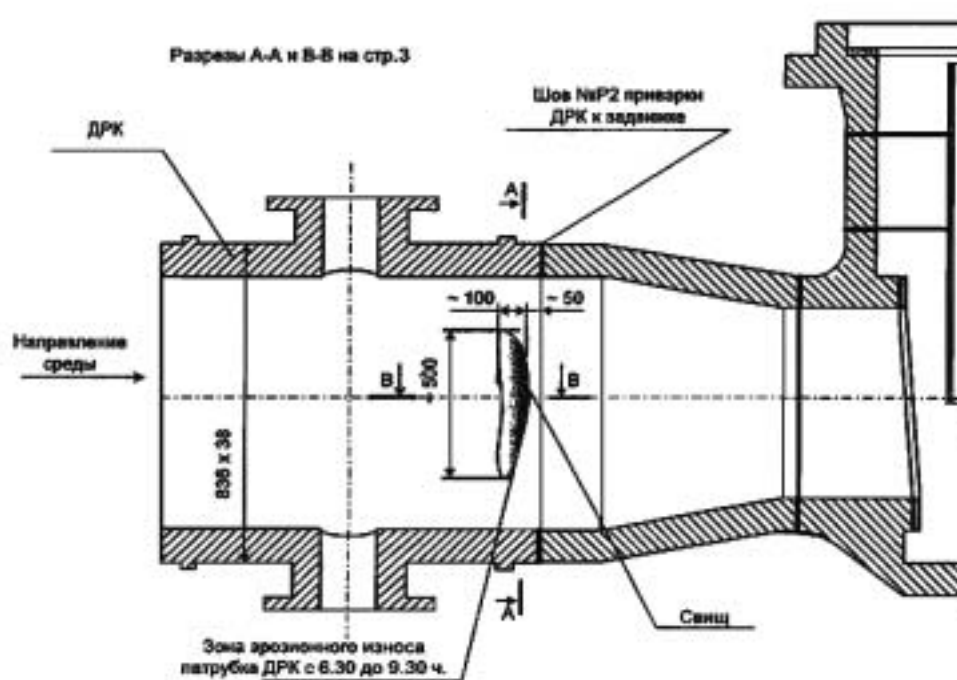


Fig.2. Guillotine break after the flow control orifice the feed water line, Loviisa 1,



1990

Figure 3. Corrosion-erosion ageing of the branch piece of throttling control valve (DRK 2MCP-21) in NPP with ПБМК.

Table II includes the calculation results of corrosion-erosion rate and thinning values of damaged sections of feed water pipelines in NPP Loviisa. The calculations were made by means of the software EKI-02. First six lines of the table represent the calculation results for welding; maximum wall thinning was about 17 mm. First three lines represent copper concentration in metal – 0.00%, in lines - 4-6 – 0.06%. On calculations the time gap was divided conditionally into two parts. The first time gap was taken up to 6.0 years from operation start, the second time gap – from 6.01 years to 13.2 years. Conditional breakdown was made because it was still a question how long feed water didn't pass through the heaters of high pressure ( $t = 164^{\circ}\text{C}$ ) and did pass ( $t = 226^{\circ}\text{C}$ ). Calculation difference was about (5 – 25)%.

Table lines 7-9 give the calculations for the damaged direct section. In this case calculation difference is about (3-15)%. The table includes the calculations only for the case when copper concentration in metal equals to 0.00%.

Table lines 10-12 represent calculations for intact direct section made of steel 20. It's assumed that the concentration of chromium in metal is 0.25%. In this concentration of chromium the wall thinning would be about 1.0 mm for 13.2 years. In the concentration of copper 0.25% the wall thinning would be 0.72 mm, and concentration of copper 0.15% - 1.31 mm.

Table II. Calculation of FAC rate and thinning of damaged feed water pipeline sections in NPP Loviisa,  $C_{Mo} = 0,00\%$ ,  $C_{O_2} = 0.5\text{ mcg/kg}$ ,  $pH = 7.0$ ,  $D \times \delta = 325 \times 18\text{ mm}$ ,  $a_{\text{mine}}$

№	T, °C	$K_{\text{KEL}}$	$C_{\text{Cr}}$ , %	$C_{\text{Cu}}$ , %	$\tau$ , year	$W_t$ , m/sec	$W_{\text{eki}}$ , mm/year	$W_{\text{eki}}$ , mm/year	$W_{\text{eki}}$ , mm/year	$\Delta S$ , mm
1	164	0.30	0.04	0.00	0 – 6.0	3.9	7.42	1.43	1.30	19.80

2	226	0.30	0.04	0.00	6.0-13.2	3.9	0.24	0.18	0.20	1.44
3	-	-	-	-	<b>0-13.2</b>	-	-	-	-	<b>21.24</b>
4	164	0.30	0.04	0.06	0 – 6.0	3.9	6.24	1.2	2.78	16.66
5	226	0.30	0.04	0.06	6.0-13.2	3.9	0.20	0.15	0.17	1.21
6	-	-	-	-	<b>0-13.2</b>	-	-	-	-	<b>17.86</b>
7	164	0.15	0.04	0.00	0 – 6.0	3.9	3.71	0.71	1.65	9.90
8	226	0.15	0.04	0.00	6.0-13.2	3.9	0.12	0.09	0.10	0.72
9	-	-	-	-	<b>0-13.2</b>	-	-	-	-	<b>10.62</b>
10	164	0.08	0.25	0.06	0 – 6.0	3.9	0.36	0.07	0.16	0.96
11	226	0.08	0.25	0.06	6.0-13.2	3.9	0.012	0.008	0.010	0.07
12	-	-	-	-	<b>0-13.2</b>	-	-	-	-	<b>1.3</b>

Table III gives the calculation results of corrosion-erosion rate and thinning of damaged feed water pipeline in NPP Surry-2. Maximum thinning of the pipeline wall in NPP Surry-2 was 11,5 mm. It is evident from the table that the calculation difference using EKI-2 is (38-43)% in this case. Error of thinning calculation by means of the software (computer codes) is determined by range of parameter change. It follows from Table II that pH values are within the range (8.8-9.2) and oxygen concentration within the range (1-4) mcg/kg. The error is taken place due to the fact that the values were not constant during operation. The less range of values the more accurate may be the calculation of corrosion-erosion rate and thinning of pipeline wall.

Table III. Calculation of FAC rate and thinning of feed water pipeline in NPP Surry-2,  $C_{Cr} = C_{Cu} = C_{Mo} = 0,03 \%$ ,  $D \times \delta = 460 \times 12 \text{ mm}$

№	T, °C	$K_{кел}$	pH	$C_{O_2}$ , mcg/kg	t, year	$W_T$ , M/sec	$W_{eki}$ , mm/year	$W_{eki}$ , mm/year	$W_{eki}$ , mm/year	$\Delta S$ , mm
1	190	0.45	8,8	1	13	5.2	4.09	0.57	1.19	15.46
2	190	0.45	9.2	1.0	13	5.2	1.9	0.27	0.55	44013
3	190	0.45	8,8	4	13	5.2	4.33	0.60	1.26	16.39
4	190	0.45	9.2	4.0	13	5.2	2.02	0.28	0.59	23193

Table IV represents the calculation results of corrosion-erosion rate and thinning of damaged throttling-control valve in Kursk NPP

Table IV. Calculation thinning of wall tubes on Kursk NPP,  $D_t = 836 \times 38 \text{ mm}$ ,  $C_{Cr} = C_{Cu} = C_{Mo} = 0.03 \%$ ,  $W = 38 \text{ m/sec}$ ,  $pH = 7.0$ ,  $C_{O_2} = 50 \text{ ppb}$ ,  $K_{Kel} = 0.90$ ,  $amin \text{ NH}_3$ ,  $\tau = 13.0 \text{ years}$

t°C	Velocity, mm/year			Thinning of wall, after 28 years, mm
	In beginning	Middle	In end	
255.0	8.36	2.43	1.17	31.6

Corrosion-erosion ageing of the pipeline elements after long-term operation in NV NPP Unit 3 was calculated by means of SW EKI-02. Design values of maximum thinning of tensile sections of feed water pipeline bends are correlated with the data of operating control with error  $\pm 20 \%$ .

It follows from the data of operating control that thinning of pipeline walls is uneven. So maximum thinning of pipeline walls of tensile section of pipeline bends in steam generators SG-1, SG-2, SG-3 does not exceed 1.0 mm, whereas in steam generators SG-4, SG-5, SG-6 it values 5.0÷6.5 mm/year. Normalizable values of corrosion thinning of pipeline walls made of pearlitic steels were 1.2 mm for the period of 30 years. Consequently, thinning of bend walls in SG-1, SG-2, SG-3 does not exceed the normalizable value, and in SG-4, SG-5, SG-6 is greatly exceeded. FAC rate of tensile section of pipeline bends in SG-1, SG-2, SG-3 is over

the range 0.03±0.05 mm/year, and in SG-4, SG-5, SG-6 –over the range 0.09±0.31 mm/year. One of the reasons for increased corrosion-erosion ageing of bends in SG-4, SG-5, SG-6 may be low content of chromium and copper in pipeline metal. In a series of measurements “thick” of pipeline walls was observed.

Table 5 gives processing of data on operating control of thickness of 38 bends of main pipelines of reactor compartment Ø 465×16 mm of NV NPP Unit 3 given in different time gaps. These data include maximum and medium thinning of tensile bend section as well as maximum and medium FAC rates. Analysis of results from operating control of UZ-thickness measuring in different time gaps make it possible to consider the reliability matter.

*Table V – Corrosion-erosion ware of the tensile section of 38 bends of main pipelines of the reactor compartment in NV NPP Unit 3*

№	Value	Years	Number of SG					
			SG- 1	SG- 2	SG- 3	SG- 4	SG- 5	SG- 6
1	2	3	4	5	6	7	8	9
1	$\Delta S_{\max}^i$ mm	85-88	<b>-3.5</b>	-2.5	-0.5	-1.0	-2.0	-2.5
2		89-91	-2.9	-	<b>-3.0</b>	-	<b>-3.7</b>	-3.5
3		92-93	-2.5	-2.1	-1.1	<b>-1.8</b>	-	<b>-4.6</b>
4		94-97	<b>-3.5</b>	<b>-3.0</b>	-1.6	-1.3	-2.2	-3.9
5	$W_{\max}^{\text{EKI}}$ mm/year	85-88	<b>-0.25</b>	<b>-0.17</b>	-0.036	-0.062	-0.22	-0.17
6		89-91	-0.16	-	<b>-0.17</b>	-	-0.185	-0.175
7		92-93	-0.12	-0.095	-0.052	<b>-0.086</b>	-	<b>-0.21</b>
8		94-97	-0.15	-0.12	-0.12	-0.054	-0.085	-0.16
9	$\Delta S_{\text{av}}^i$ mm	85-88	-1.57	<b>-1.75</b>	-0.90	-0.75	-1.80	-1.75
10		89-91	-1.80	-	<b>-1.78</b>	-	<b>-2.13</b>	-1.67
11		92-93	-1.24	-1.25	+0.12	<b>-0.87</b>	-	<b>-2.23</b>
12		94-97	<b>-2.29</b>	-1.02	-0.79	-0.33	-1.21	-1.51
13	$W_{\text{av}}^{\text{EKI}}$ mm/year	85-88	<b>-0.112</b>	<b>-0.117</b>	-0.064	<b>-0.044</b>	<b>-0.112</b>	<b>-0.117</b>
14		89-91	-0.100	-	<b>-0.099</b>	-	-0.106	-0.083
15		92-93	-0.059	-0.057	-0.006	-0.041	-	-0.101
16		94-97	-0.095	-0.041	-0.032	-0.014	-0.047	-0.060

Table V, lines 1-4, represents maximum thinning of tensile bend sections of steam generators SG 1 – 6 of NV NPP Unit 3 in different time gaps. The largest values are in thick print. It is evident from the table that first in all cases the largest thinning values exceed addition for corrosion 1.2 mm by 1,5 – 3,8 times. Secondly, maximum thinning values were not always registered during last monitoring. This is the evidence of the fact that the reliability of operation monitoring is not ensured properly.

Pipeline maintenance is accompanied by deposits formation on its internal surface. On measuring thickness by means of ultrasonic thickness gauges the thickness of unattacked metal together with the thickness of corrosion debris is registered. Special studies enable to establish that moist CP debris are registered in UZ-thickness measuring together with unattacked metal. Of total number of measurements 40038 thinning is registered in 12238 measurements (30,56% of total amount), “thick” – in 26711 (66,7% of total amount). This fact signals that thickness is registered more often during operation monitoring.

Thickness of CP debris in the same measurement point is not constant and is free both to increase and to decrease. Table 5 demonstrates that the largest thinning by 3 of pipelines SG-1 was registered in 1985 – 1988 and 1994-1997, by 3 SG – 3, 5 - in 1989 – 1991, in SG – 4, 6 - in 1992 – 1993, in SG - 2 - in 1994 – 1997. Maximum thinning of steam pipeline walls in all cases is within admissible. This fact is explained as follows: during 30 years no bends in the live pipelines of reactor compartment of the Unit has not been replaced.

Other possible reasons of thinning/thick over and undervalues of pipeline walls must be shown. Generally acceptance tests of pipeline wall thickness are not performed in NPPs. Therefore initial data of pipeline thickness are not available. It should be emphasized that wall thickness limits while manufacturing is  $-5\% \div +20\%$  with respect to rating value. This factor may favor that thickness larger than nominal one in significant thick measurements is carried out in the course of operating monitoring.

## Conclusions

1. Prediction and elimination of corrosion-erosion ageing of equipment and pipelines elements manufactured from pearlitic steel are possible with a package of normative documents.

2. Normative documentation package includes:

- software for calculation and prediction of FAC;
- methodical instructions for determination of metal chemical composition;
- strength calculation rate of metal with FAC;
- programmes of operating inspection of metal with FAC;
- methodical guidelines for data acquisition and processing;
- methodical guidelines for selection of structural materials;
- recommendations for accounting of corrosion products deposit for reliability of operation inspection.

3. Calculation performed for pipeline wall thinning by means of the software made it possible to determine that calculation error does not exceed 50%.

4. Analysis of calculation results provide a conclusion that the following factors determining pipeline wall thinning value may be referred to:

- absence or low concentration of chromium, copper and molybdenum in metal;
- composite geometry of damaged pipeline element contributing significant turbulization of coolant flow.

5. Low pH, low content of oxygen in the coolant, high velocity of the coolant, etc. is the worst case for initiation and propagation of corrosion-erosion wear.

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