CORROSION STABILITY COATED PARTICLES IN WATER COOLANT AND SUPERHEATED STEAM

1. CP test in PWR coolant (350^{0}C, 19 Mpa, PWR water -chemical mode)

1.1. Water stand

The water stand intended for tests for corrosion of CP simulators in the water coolant of PWR-type reactors with nominal parameters and natural circulation. The water coolant structure (mg/kg) of PWR-type reactor: B - 1000, Cl` <0.1, F" <0.15, Li - 2, O_2 <0.1. Parameters of water coolant are given in Tab. 1.

Table 1. Parameters of the water stand

Parameter	Normal	Limiting
1. Pressure, bar	190±5	200
2. Temperature in containers, ^{0}C	350±5	360
3. Temperature at inlet of heater, ^{0}C	330±5	-
4. Coolant flow, kg/hour	20	
5. Power of electroheater, KW	0.7	1.5

The basic elements of the water stand are given in Fig.1.

The water stand includes test model, pressurizer, filling tank, measuring tank, container with nitrogen, metering pump for filling the stand by water and for hydraulic test, system of testing instruments and automatics. The basic elements of the water stand are given in Fig.1..

The test model consists of the high pressure case with diameter 48x4.5 mm with flat cover and bottom with thickness 12 mm, pipe 30x2.5; electroheater is placed in the top part of this pipe and containers with CP simulators are placed in bottom part of it. The pipe 30x2.5 has thermal isolation as steel foil with thickness 0.2 mm, wire distance winded on a pipe 30x2.5. Electroheater and two shells for thermocouples are welded to the bottom. Two shells for thermocouples and 1 union D=10 are welded to the top for connection with the pressurizer. There are 2 unions on cylindrical surface of the high pressure case for connection with manometer and for filling a circuit by water. Test model case has no flanges. For unloading of containers from a test model the cover is cut by turning machine tool and is welded after loading.

The design of test model is given in Fig 2 . Material of all elements of construction - stainless steel 12Cr18Ni10Ti.

The container for CP simulators is made from pipe 25x2. Grid is welded to this pipe from below. The groove for nut is made in the top part of pipe 25x2, the nut is made also from a pipe 25x2. This nut presses to end faces of the container demountable grid. The openings in the grid are less than diameter of CP simulators. There are 10000 CP simulators of 0.9 mm diameter in the container. Material of all elements of the container is also steel 12Cr18N10Ti. The design of the container is given in the Fig.3.

Electroheater is made as U-figurative pipe, its power is 1.5 KW, voltage is ≤ 36 V.

Pressurizer is made from pipe D=48x4.5, its height is 1000 mm, bottom is flat, cover thickness is 12 mm. One union is welded to the bottom and one union is welded to cover for

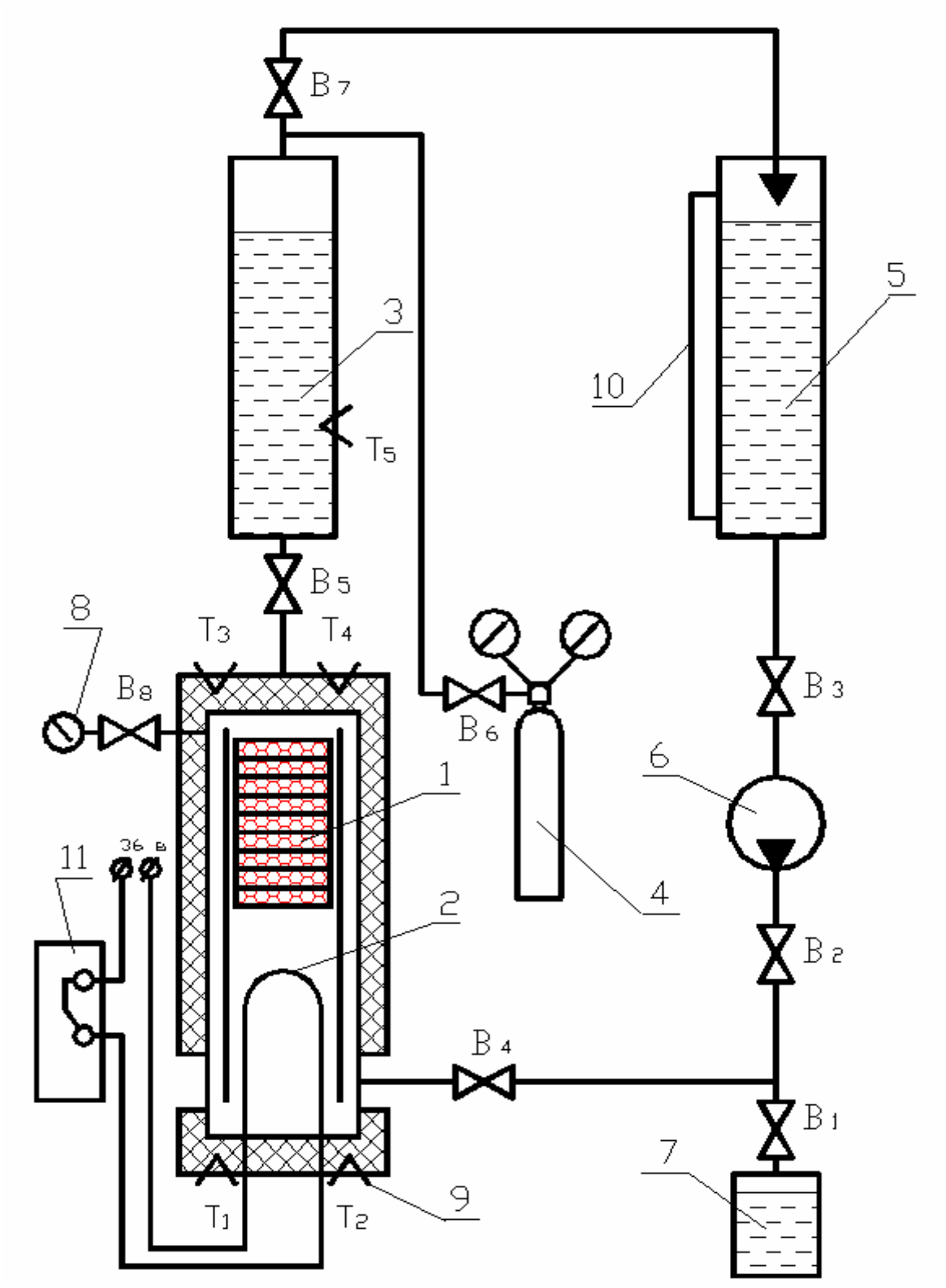

Fig.1.The basic elements of the water stand
1-test model with container of CP, 2- electroheater, 3- pressurizer, 4-nitrogen ballon, 5-water tank, 6-poump, 7-messurement volume
8-manometer, 9-thermocouples (T1-T5), 10 11-transformator, B1-B8-armatures

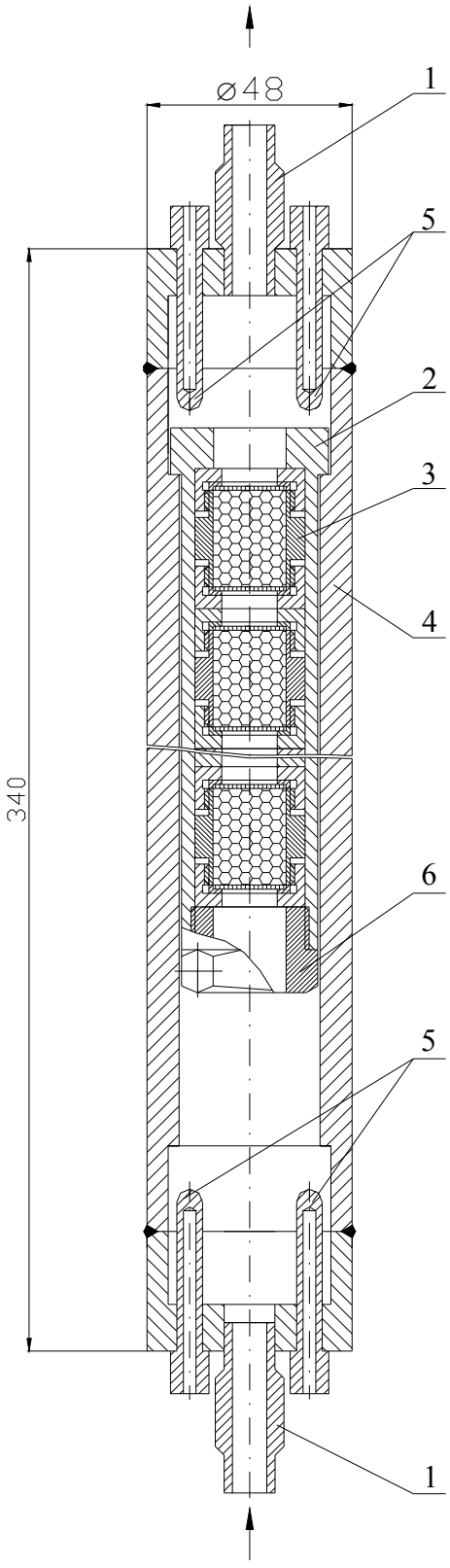

Fig. 2. The test model.
1 – штуцер; 2 – penal; 3 – container for CP; 4 –case;
5 – channel (shall) for thermocouples;
6 - nut

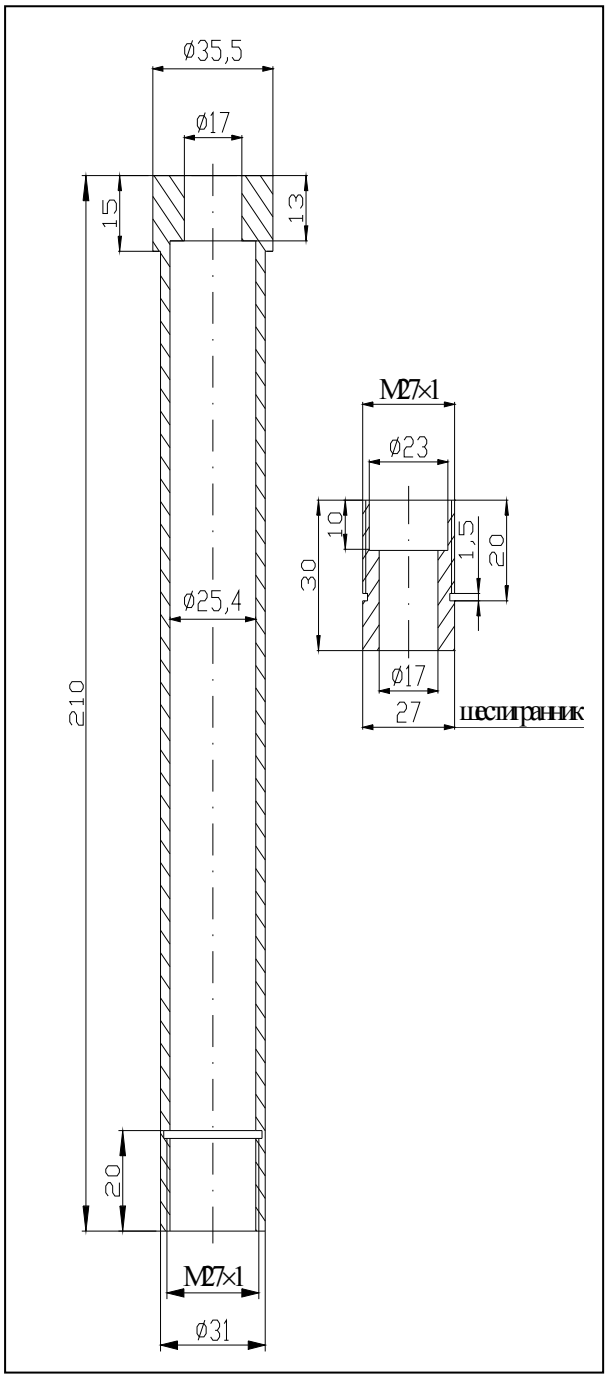

Fig 3. Penal

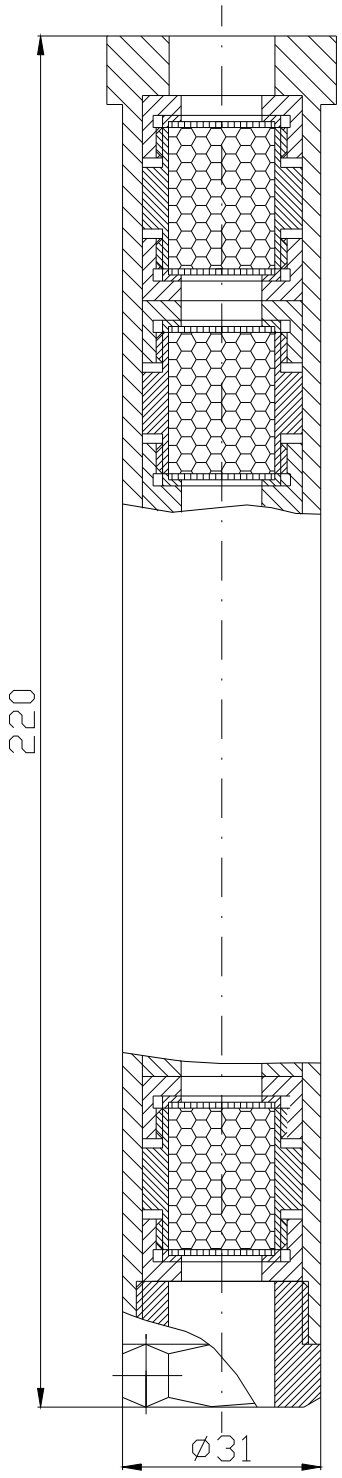

Fig. 4. The test model (the containers into penal)

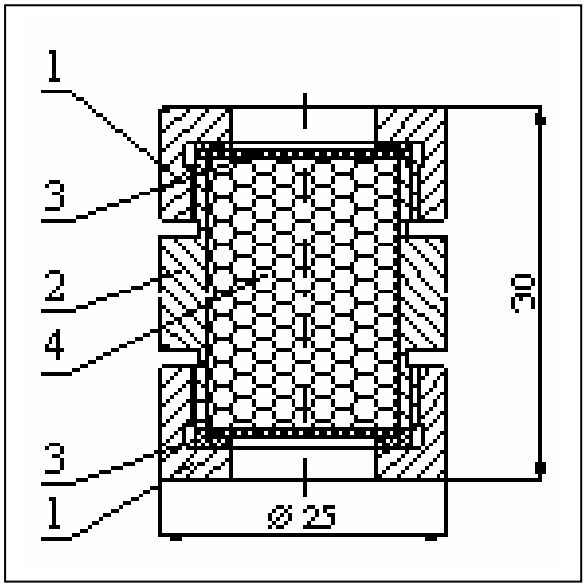

Fig. 5. Container for CP
1 – nut; 2 –case; 3 –grid; 4 -CPs

connection with test model, pump and cylinder with nitrogen. The case of the pressurizer is has thermal isolation.

Table 2. Measured parameters and protection parameter of the water stand

Parameter	Position in Fig.1	Device	Interval	Class of accuracy
1. Pressure, (protection from excess of pressure), bar	П-6	Manometer	0-250	0.6
2. Temperature before heater, ^{0}C	П-1, П-2	Thermocouple	0-400	0.6
3. Temperature after heater, ^{0}C	Ï-3	The same	0-400	0.5
4. Temperature in pressurizer, ^{0}C	Ï-5	The same	0-400	0.5
5. Temperature of the top part of test model, ^{0}C (protection against excess of temperature)	Ï-4		0-400	1.0
6. Level in the pressurizer, %	Ï-7	Sapphire	0-100	0.5
7. Magnitude of current, A	Plugs	Ammeter	0-30	1.5
8. Voltage, V	Heaters	Voltmeter	0-50	1.5

2. STEAM STAND

2.1. Purpose and characteristics of the steam stand

The steam stand is intended for test for corrosion stability of CP simulators in superheated steam with natural coolant circulation. The basic parameters of superheated steam are given in Tab. 3.

Table 3. Parameters of the steam stand

Parameter	Working	Limiting
1. Pressure, bar	100 ±5	112
2. Temperature in containers, ^{0}C	550±5	560
3. Minimal temperature in circuit, ^{0}C	100-310	-
4. Coolant flow, kg/hour	< 4	-
5. Power of electrical furnace, KW	3.8	

Volume of circuit measured with specimens is 1.95 litres

2.2. Design of the steam stand

The basic elements of the steam stand are given in Fig.6. Stand includes: test model, in which the containers with CP simulators are placed; evaporator and steam superheater of coil pipe type, which is made from a pipe D=10x2 mm with outside diameter 60 mm; condenser also made as coil pipe from a pipe D=10x2 mm and condensate collector. Trap for not condensed gases is placed in the most top part of circuits. The trap is connected to the condenser. Filling tank and pump are used in the steam stand for water filling and for hydraulic tests, the same as for the water stand. Heating of evaporator and steam superheater

is carried out by muffle electric furnace, which are placed inside it. The test model of the steam stand consists of high pressure case (pipe D=8x4.5) with flat cover and bottom with 12 mm thickness, internal cover from pipe 30x2.5, in which the containers with CP simulators are placed.

The test model of the steam stand consists of high pressure case (pipe D=8x4.5) with flat cover and bottom with 12 mm thickness, internal cover from pipe 30x2.5, in which the containers with CP simulators are placed. The bottom and cover are supplied with the union for connection to the technological circuit and two shells for thermocouples placement. The cover is welded to the case. For loading and unloading of containers the cover is cut by the turning machine tool, and after loading of containers it is again welded. Material of all elements - stainless steel 12Cr18Ni10Ti. All elements of circuit after its installation are heat-insulated. Thickness of insulators: of the test model is 150 mm, of condenser - 60 mm, of condensate collector and of trap - 75 mm. Design of test model is given in Fig. 4 and 5. Muffle electric furnace and pump are the loads of the electric power. Power feeds the furnace through single-phase voltage regulator.

3.3. Measured parameters and protection parameters of the steam stand

The list of measured parameters, characteristic of measuring devices and protection parameters are given in Tab. 4. Parameters were measured on chart tape and was registrated each hour.

Table 4. Measured parameters and protection parameters of the steam stand

Parameter	Position in Fig.6	Device	Interval	Class of accuracy
1. Pressure, (protection from excess of pressure), bar	П-12	Manometer	0-160	0.6
2. Pressure in trap, bar	П-13	Manometer	0-160	0.6
3. Inlet temperature of condensate collector, ^{0}C	П-1	Thermo-couple	0-600	0.5
4. Temperature in the furnace, ^{0}C	П-2	The same	0-600	0.5
5. Temperature at inlet of test model, ^{0}C	П-3	The same	0-600	0.5
6. Temperature at inlet of test model, ^{0}Ñ (protection against excess of temperature)	П-5	Thermo-couple	0-600	1.0
7. Temperature at outlet of test model, ^{0}C	П-4, П-6	Thermo-couple	0-600	0.5
8. Temperature in trap, ^{0}C	П-7	That	0-600	0.5
9. Temperature in condenser, ^{0}C	П-9, П-10, П-11	That	0-600	0.5
10. Magnitude of current in furnace, A	Plugs	Ammeter	0-75	1.5
11. Voltage in furnace, V	Heaters	Voltmeter	0-250	1.5

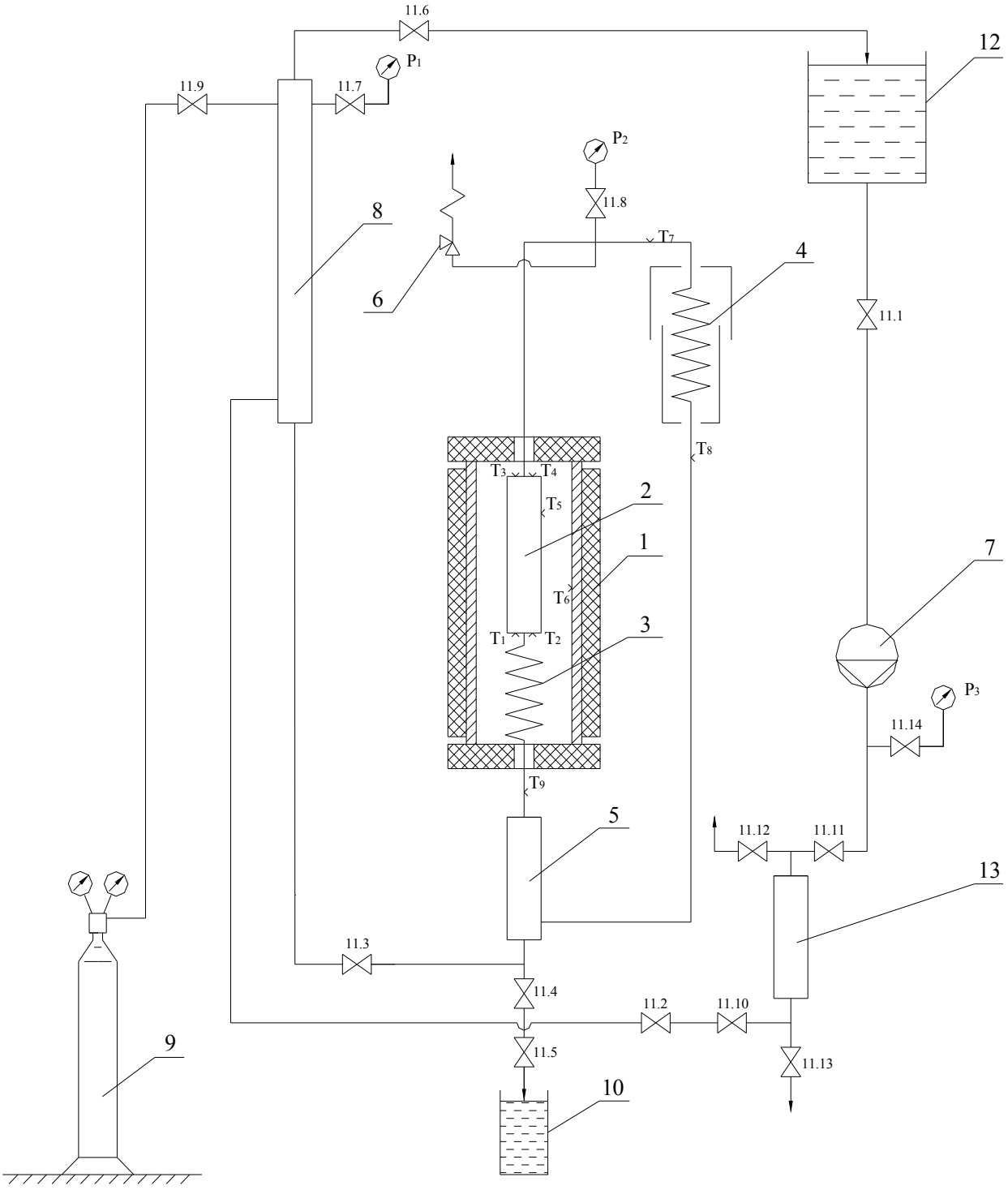

Fig. 6. The steam stand technological circuit
1 – muffle electric furnace; 2 –test model; 3 – evaporator and steam superheater; 4 – condenser; 5-collector; 6 –valve; 7 –filling pump; 8 –pressurizer; 9 –gas ballon; 10, 12 - filling tank; 11 –armature; 13 – measured volume.

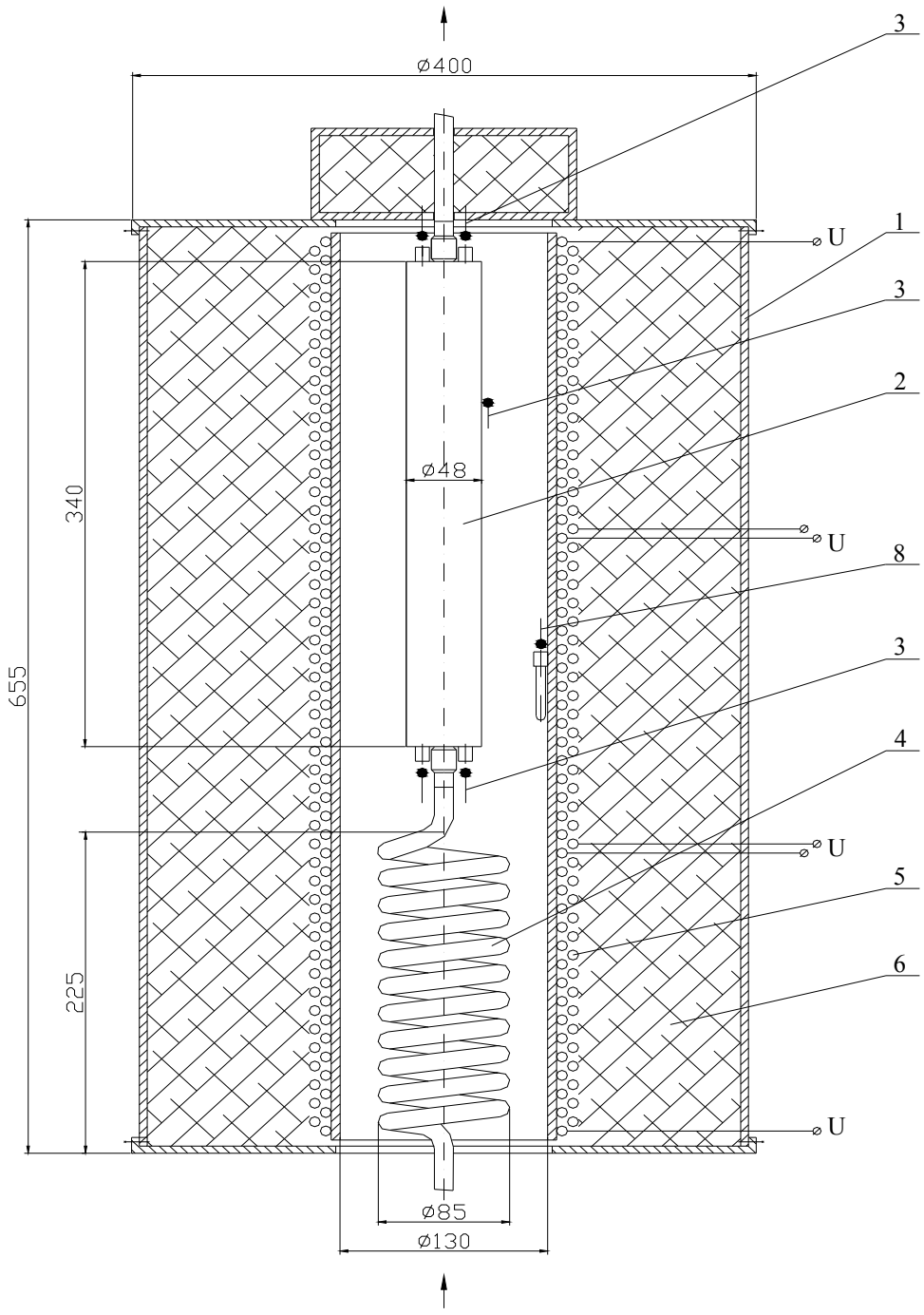

Fig. 7.Electro muffle with test model.
1 –case; 2 – test model; 3 – thermocouple of test model;
4 – heater; 5 – electroheater (NiCr wire Ø2 mm); 6 – isolation; 7 –muffle
8 – thermocouple.

3. The characteristics available CP

The characteristics available CP are given in Tab. 5.

Table 5. The characteristics coated particles

	The name of a batch					
The name	P-45	P-5	X-4	4X78	3X78	21VOP11X78
Enrichment of U, %	21	21	6,5	21	21	21
Density UO_2, g/sm^3	10.3	10.16	8.8	9.5	9.5	9.1
Diameter UO_2, micron	500	445-535	1300-1500	860	860	400-630
Thickness (density) PyC-1, micron (g./sm^3)	85 (1.0)	1.1 **	25 (1.0)	25-30 (1.1)	25-30 (1.1)	30 (1.1)
Thickness (density) PyC-2, micron (g./sm^3)	26 (1.6)	1.6 **	50 (1.8-1.9)	35-40 (1.7)	35-40 (1.7)	18 (1.8)
Thickness (density) PyC-3, micron (g./sm^3)	55 (2.1)	135 (1.8) *	-	-	-	35 (1.62)
Thickness (density) SiC, micron (g./sm^3)	51 (3.2)	46 (3.14)	125 (3.1)	140 (3.14)	80 (3.14)	80 (3.14)
Thickness (density) PyC-4, micron (g./sm^3)	50 (1.9)	57 (1,83)	-	-	-	80 (1.4)
Quantity) CP, pieces	218000	53400	5340	15200	-	18400
Diameter CP, micron	1000 **	980	1800 **	1260 (60	1150 **	1000 **
Diameter the annealing external PyC, micron	900	865	1800	1260	1150	840

* total thickness of three layers PyC up to a layer SiC

** A settlement estimation, the nameplate data are absent

Three batch CP, given in TAB. 1., have an outside covering from PyC and three batch have initially outside covering from SiC. For research it is supposed to use all batch CP with an outside covering SiC. CP batch P-45 are supposed to be used annealing of an outside covering PyC in the furnace with temperature 800^{0}C in air medium).

4. Results of the water and steam test

4.1. Characteristic of a water-chemical mode

The results of research of water -chemical mode for all time of test (15 months in water and 11 months in steam) are given in Tab. 6. and Tab. 7.

Table 6. The characteristics of a water -chemical mode of the water stand

The name of operation	B, mg/kg	Cl' mg/kg'	F`, mg/kg	Li, mg/kg	O_2, mg/kg	N_2H_4OH mg/kg	Turbidity mg/kg
Technical project requirement	1000	<0,1	<0,15	2,0	<0,1	-	-
Filling 08.12.97	1000	0.14	0, 167	2,17	-	excess	-
Extraction(853 h) 13.01.98	1030	1,16	0,533	2,0	-	excess	6,9
Filling 13.01.98	1000	0,15	0,167	2,4	-	excess	-
Extraction(1520h) 10.02.98	1010	0,85	0,25	2,54	0,08	0,96	3,4
Filling 11.02.98	1060	0,14	0,14	2,27	-	excess	-
Extraction(3000 h) 21.04.98	830	1,88	0,20	2,0	0,08	-	0,61
Filling 05.05.98	960	0,14	0,15	2,2	-	excess	-
Extraction(4520 h) 05.07.98	900	0,532	0,50	2,0	0,08	-	5,37
Filling 05.07.98	950	0,132	0,125	2,0	-	excess	-
Extraction(6500 h) 20.09.9	910	0,95	0,125	2,6	0,08	-	3.13
Filling 20.09.98	1000	0,13	0,12	2,0	-	excess	-
Extraction(10800 h) 02.06.99	970	0,52	0,18	2,0	0,1	-	2.0
Filling 02.06.99	1030	0,15	0,15	2,0	-	excess	-

Table 7. The characteristics of a chemical mode steam

The name of operation	O_2, mg/kg	Cl' mg/kg	F', mg/kg	Turbidity, mg/kg
Technical project requirement	<0,1	-	-	-
Filling 16.01.98	<0,1	-	-	-
Extraction(270 h)	<0,1	-	-	-
Filling 29.01.98	<0,1	-	-	-
Extraction(700 h) 12.02.98	0,08	1,164	0,600	-
Filling 12.02.98	<0,1	-	-	-
Extraction(1500 h) 23.04.98	0,09	0,36	1,25-	0,61
Filling 22.09.98	0.08	-	-	-
Extraction 22.10.98(2200 h)	0,08	1,2	1,00	5,16
Filling 22.10.98	<0,1	-	-	-
Extraction (4500 h) 16.11.98	0.28	2.4	0.13	29.0
Filling 16.11.98	<0,1	-	-	-
Extraction (7900 h) 02.06.99	0.08	0.14	0.36	1.32
Filling 16.11.98	<0,1	-	-	-

4.3. The base result of CP corrosion

After delivery in containers were washing to water (2 day) and then were dried at temperature 100^0C and in natural conditions before complete stabilization of weight. In process drying the control behind weight of containers was carried out. (Total of series of weighing - 9. Each series consists of 3-5 weighing).

After the CP were taken out from containers and their five-multiple weighing was carried out. The results of weighing of CP are given in Fig. 8 and Fig. 9.

4.4.Conclusion

- loss of weight of CP tested in water coolant, lays in limits (4.7-5.0) mg, that corresponds to its relative change (4.3-4.4) $\cdot 10^{-2}$ %;
- loss of weight of CP tested in steam has made about 48 mg, that there corresponds to its relative change - 0.42 %;

The changes of weight with tests in water for 13 and 15 months and for 11 months in steam are close to similar sizes at the previous stages of tests, i.e. has a place stabilization of loss of weight after 1-2 months of test in water and steam. Loss of weight 3 % after 3 months of test in steam are a casual deviation.

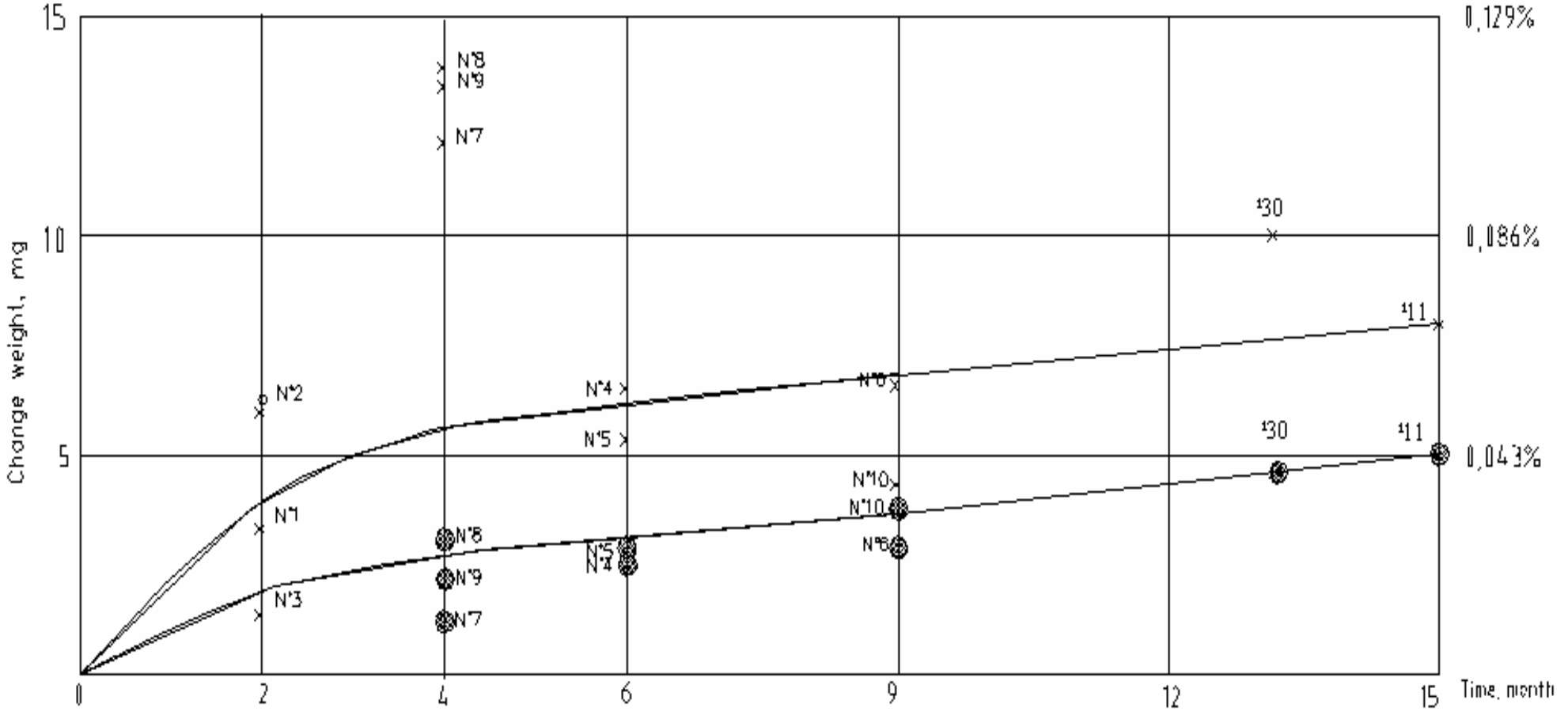

Fig.8. The water test change CP weight of the time function

O Without anneling, **x** – after anneling

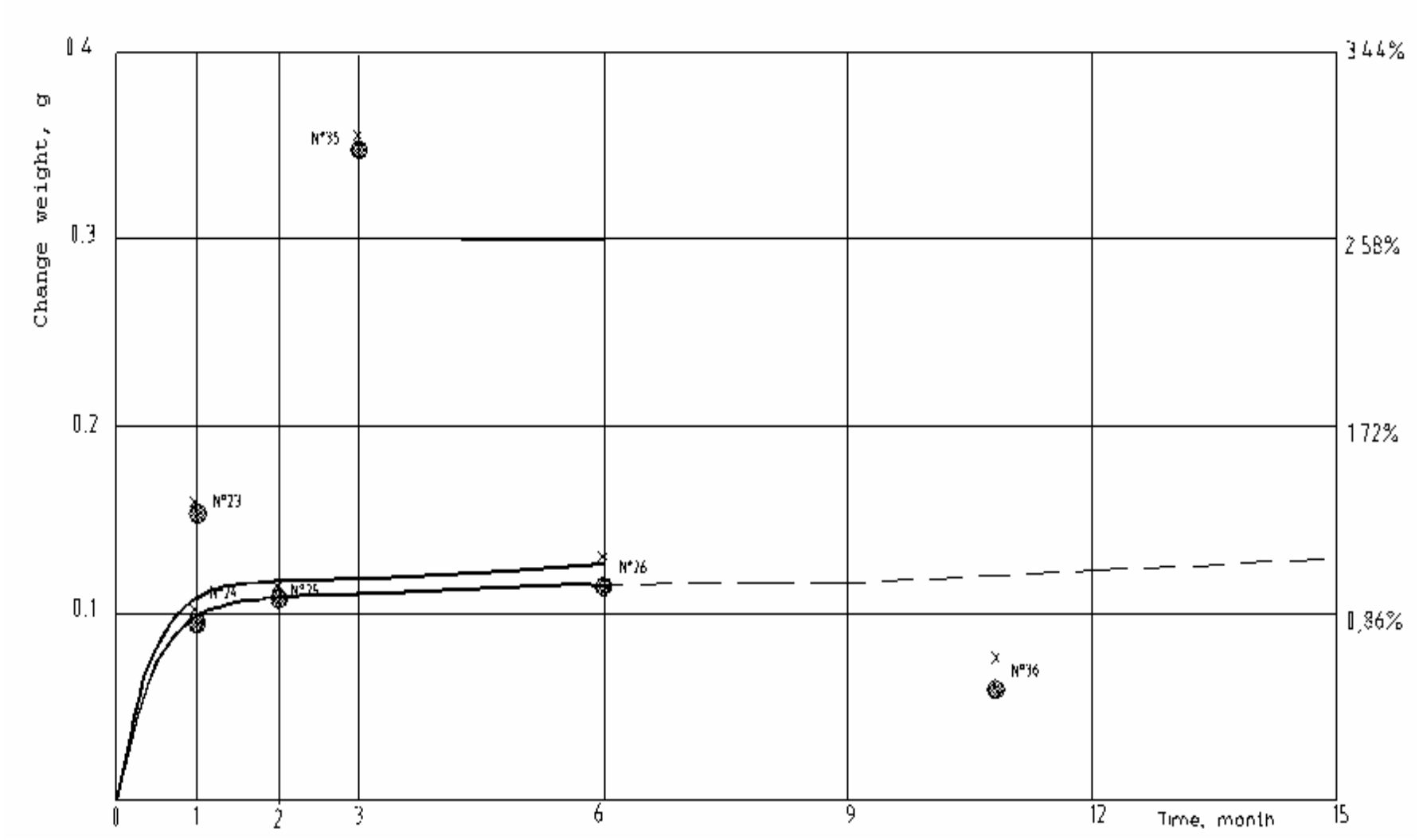

Fig.9. . The steam test change CP weight of the time function

O Without anneling x – after anneling

5. The test programme for another samples of the CP and material

VNIIAM have follow:

-water stand (19 Mpa, 350^{0}C);
-steam stand (10 Mpa, T=550-950^{0}C);
-supercritical stand (24 Mpa, T>550^{0}C)
-gas flame stand (0,1 Mpa, 1700^{0}C)
-water–chemical mode laboratory
-personal and method for research state of CP and another material

Programme include testing and research CP or another material after 1, 2, 3, 6 month.
20 type CP and material may be test simultaneous
The cost of this testing and researching is 25000 $ US for one stand.
The cost of each follow 3 month testing and researching is 11500 $ US

Table 8. Programme and cost for the test and research (for water or steam stand)

Name	Time, month	Cost, $ US
1. Water or steam stand tuning	1/2	1000
2. Research of CP before test	1/4	500 (weigh)
3. The test first month	-	-
3.1. The test	1 month	3500
3.2. Research of CP after test	1/4	500
3.3.Control water-chemical mode	-	500
4. The test second month	1+1/4	4500
5. The test third month	1+1/4	4500
6. The test (another 3 month)	3+1/4	(3500x3)+500+500=11500
7. Report	1+1/4	500
8. Total	9	25000

Table 9. Programme and cost for gas flame test and research

Name	Time, day	Cost, $ US	Note
1. Gas flame stand tuning	15	2000	Change Ir-Pt couple
2. Research of CP before test	7	500	
3. Test and research (at 1000^{0}C)	-	-	
3.1. The test	1	1000	Change Ir-Pt couple
3.2. Research of CP after test	14	1000	
4. Test and research (at 1200^{0}C)	-	-	-
4.1. The test	1	1000	Change Ir-Pt couple
4.2. Research of CP after test	14	1000	
5. Test and research (at 1400^{0}C)	-	-	-
5.1. The test	1	1000	Change Ir-Pt couple
5.2. Research of CP after test	14	1000	
6. Test and research (at 1600^{0}C)	-	-	-
6.1. The test	1	1000	Change Ir-Pt couple
6.2. Research of CP after test	14	1000	
7.Report	30	1000	
8.Total	120	10500	

Table 10. Programme and cost for high temperature steam test and research

Name	Time, day	Cost, $ US
1. Steam stand tuning	14	1000
2. Research of CP before test	7	500 (weigh)
3. The test at 550^0C	10	1000
3.1. Research of CP after test	7	500
3.2.Control water-chemical mode	-	500
4. The test at 650^0C	10	1000
4.1. Research of CP after test	7	500
4.2.Control water-chemical mode	-	500
5. The test at 750^0C	10	1000
5.1. Research of CP after test	7	500
5.2.Control water-chemical mode	-	500
6. The test at 850^0C	10	1000
6.1. Research of CP after test	7	500
6.2.Control water-chemical mode	-	500
7. The test at 950^0C	10	1000
7.1. Research of CP after test	7	500
7.2.Control water-chemical mode	-	500
8. Report	30	500
9. Total	-	12000