

ELECTROPULSE METHOD OF DECONTAMINATION OF NUCLEAR POWER PLANT EQUIPMENT

Petr Konstantinovich Nagula, Denis Leonidovich Tretinnikov, Olga Valentinovna Kalenchukova

The Joint Institute for Power and Nuclear Research – SOSNY, 99 Academician A.K.Krasin Str.,
Minsk BY-220109, Belarus

Abstract

A review of existing methods of decontamination of nuclear power plant equipment; it describes the advantages and disadvantages of the existing methods. A new promising method for decontamination of removable NPP equipment with a complex surface configuration. The technology and the advantages of the proposed method. Presented physical-mathematical model that calculates non-steady field electrolyte concentration, temperature and electric field in the electrolyte during electro surface treatment.

Key words: corrosion, radioactive contamination, decontamination, equipment, nuclear power plant

1. DECONTAMINATION IN NUCLEAR ENERGY

The development of nuclear – power engineering and the need for repair long maintained nuclear installations put a number of problems before researchers: the organization of the water regime and its means of maintaining, decontamination of equipment, predicting the radiation situation. The corrosion products are carried and put off on a path of 1 contour in reactors cooled by water under pressure, and in boiling reactors – throughout the system, including turbine.

The presence of corrosion products within the system and its subsequent deposition on the surfaces of the coolant path, and in particular on the heat transfer surfaces can lead to a breach heat exchange. The deposition of insoluble corrosion products on the surfaces of friction mechanisms setting often causes violation of their work, such as sticking valves, control rods drive and so on. The corrosion products formed on the surfaces of structural materials in the core and deposited on these surfaces from the coolant, and the coolant circulated through the core, when irradiated with neutrons become radioactive. The subsequent transition of corrosion products in the coolant, and deposits on the surface of the core is lead to the radioactive contamination of all the routes and the equipment of 1 contour.

As a result, after a few years of the work of reactor radiation environment around equipment circuit is so deteriorating, that significantly limited access to it, and the service and repair of equipment determines the possibility of further use of the installation.

Therefore, decontamination equipment – removal of radioactive contamination – as a means of normalization of radiation environment is an essential component of chemical technology coolants of nuclear power plants. Used methods of decontamination must be highly effective (for sanitary-hygienic reasons and due to the problem of recycling resulting from the decontamination of liquid radioactive waste), corrosion-safe and the most mechanized.

The expansion of construction of nuclear power plant (and in particular for the Republic of Belarus, the construction of the Belarusian nuclear power plant) and increasing their power make the problem of decontamination of equipment and premises even more urgent and acute in our country and abroad, and require further improvement of the methods and means of decontamination.

1.1. Types of radiation contamination

Radioactive contamination in the form of solid, liquid or gaseous substances, after contact with the object surface are fixed on the surface. Between radioactive substances and the surface occurs the connection, which determines the retention of radioactive substances, contaminated sites, and then the

conditions of deactivation. Depending on conditions of fastening of radioactive substances it is necessary to distinguish superficial, deep and volumetric (for the gas and liquid environment) pollution [1].

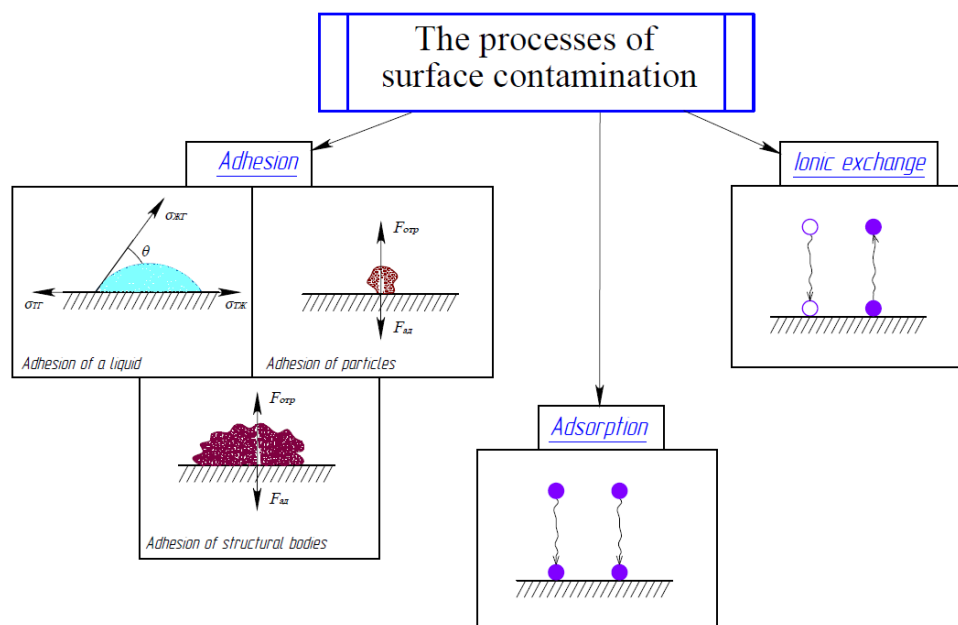


Fig. 1 – The processes of surface contamination

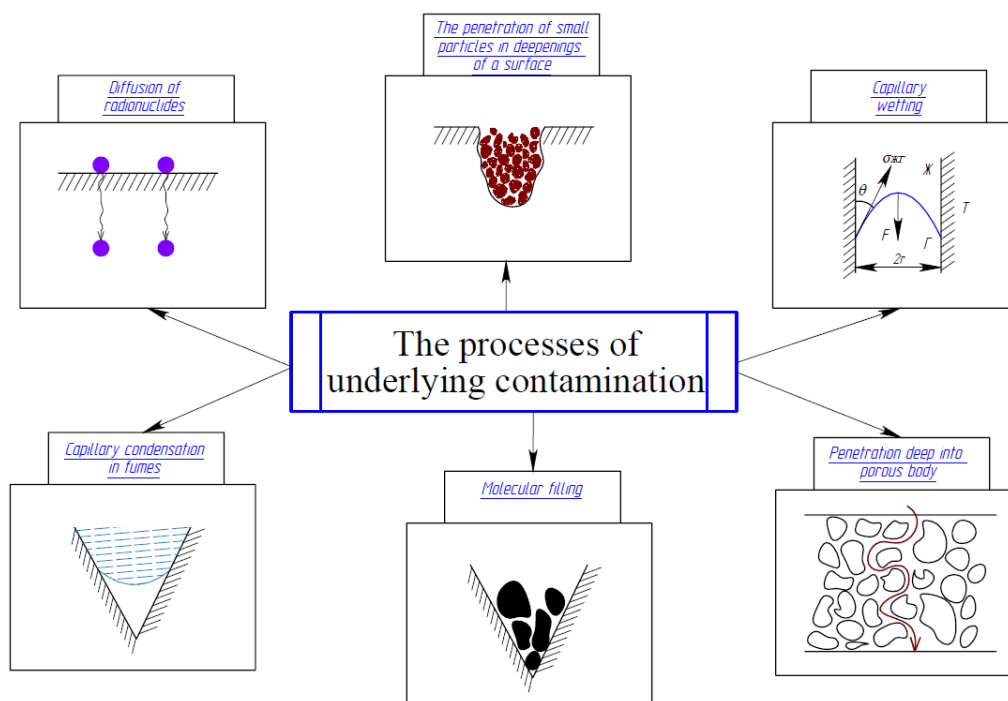


Fig. 2 – The processes underlying contamination

In conditions of superficial pollution radionuclides are found only in the outer part of the surface of various objects. Decontamination is the removal of active substances attached on the outside surface of objects. Depending on physical and chemical interaction between a polluted surface and carriers of activity takes place adhesive, adsorption and ion exchange processes of radioactive contamination (Fig. 1).

In case of deep contamination active substances penetrate deep into the material, and the deactivation process is not limited to the removal of radioactive substances from the outside surface, and is also associated with removing them from the bottom. Types of deep radioactive contamination are presented in Fig. 2.

1.2. Ways of deactivation

Ways of deactivation must meet following requirements [3]:

- 1) to ensure the effective disposal of radioactive contamination; the effectiveness is optimized, if residual contamination does not exceed the maximum. The purpose of the process can be the removal of some or all types of radioactive contamination. The choice of decontamination is determined by the nature of the surface and radioactive contamination as well as the type and dimensions decontaminated equipment;
- 2) do not cause significant corrosion and destruction of a deactivated material;
- 3) the quantity of radioactive waste should be minimal, their structure should conform to a way of processing;
- 4) the way of deactivation should be economic, safe, does not lead to the spread of radioactive contamination, allow for the possibility of mechanization.

The classification of methods of decontamination can be based on two basic principles: the physical state of the medium and deactivating features of the actual decontamination. Depending on a modular condition of the deactivating environment all the methods of decontaminating can be divided into liquid, aneroid and combined (Fig. 3).

Aneroid ways are applied basically to deactivation of areas, the roads, the painted products, building designs, etc. At deactivation of the equipment of the NPP the given ways possess low efficiency: at deactivation by a jet of gas or dust using suction decontamination factor DF (the ratio of the initial radioactive contamination to the final [2]) reaches only 5-10; adding a gas jet abrasives – 150-200.

1.2.1. Liquid ways of deactivation

Deactivation by a jet of water is applied to removal of radioactive pollution from surfaces of walls of buildings, a tank of a reactor, internal and outer surfaces of tanks, containers, etc. Washing by a stream of hot water under pressure is used for deactivation of steam generators, heat exchangers, etc. At deactivation of walls of a building from aerosol contamination DF varies (depending on water flow) 17 to 67. Water-jet processing of inner surfaces of capacity for storage of liquid radioactive waste is less effective, DF 2.5-3.3. Disadvantages of water-jet method – low efficiency of removal of durably fixed pollution, high consumption of water and a large amount of liquid radioactive waste.

Decontamination solutions based surfactants are widely used for decontamination of clothing, buildings, vehicles, paved roads and other facilities. The use of deactivating solutions in comparison with processing by a jet of water allows to reduce expense per unit area of the treated surface. Depending on expense of solution DF of the given method can reach 200. The main disadvantages of this method are the low efficiency relative to the depth of contamination and a large amount of liquid radioactive waste. *Decontamination foam* is used to create sufficient deactivating medium in the case of deactivation of larger containers, thus strongly reducing the flow of solution and the volume of liquid radioactive waste compared with decontamination solutions.

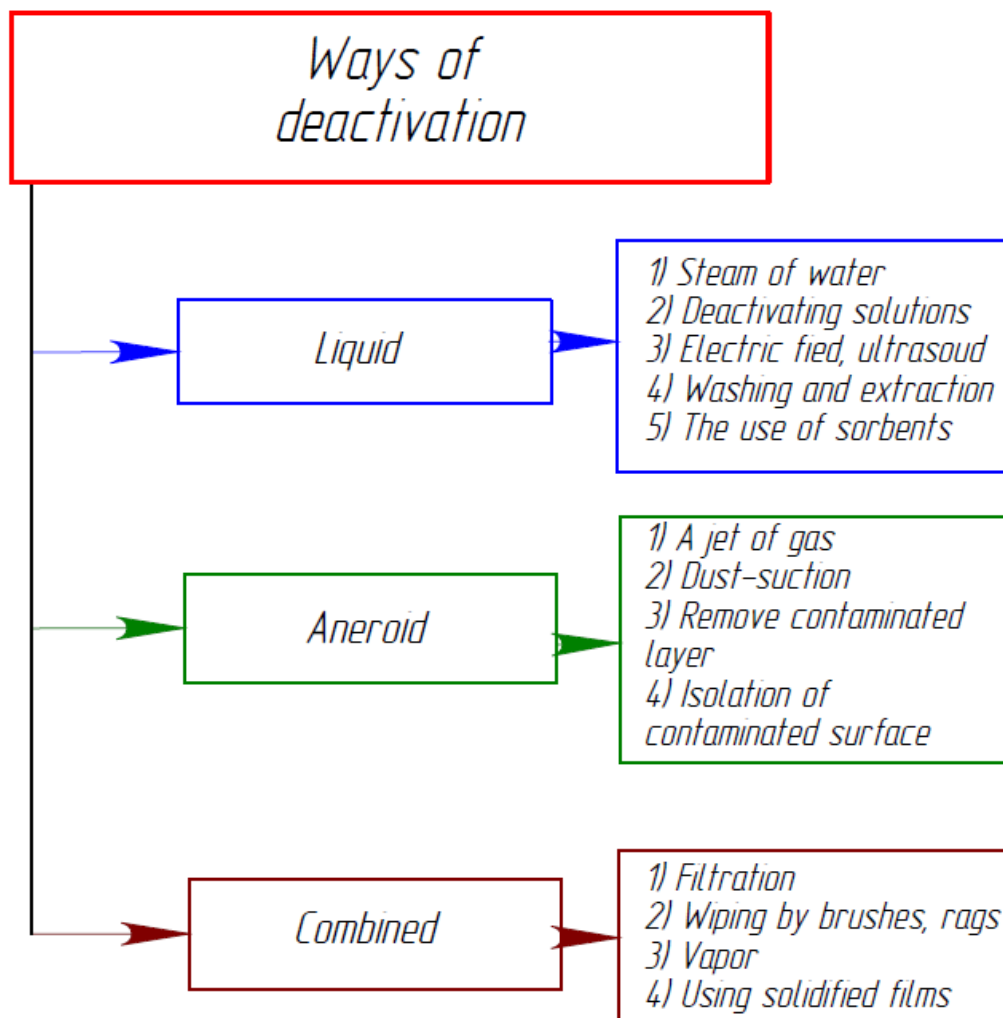


Fig. 3 – Ways of deactivation

Nowadays the way of deactivation is widely applied *using sorbents*. This way consists in processing the polluted surface by a small amount of a sprayed solution with the subsequent covering its layer using an absorbent powder sorbent. Gathering of the sorbent is carried out by vacuumization. The deactivating solution together with stripped radioactive pollution is absorbed by a sorbent and acts in firm waste. Efficiency of sorbate deactivations essentially depends on deactivating properties of a solution, as well as from stability of a sorbent in the deactivating environment. Disadvantages of the method - low efficiency of removal of durably fixed pollution; the possibility of using method only on flat horizontal surfaces.

Deactivation by demountable polymeric coverings consists in the application of the contaminated surface composition, containing the polymer, surfactants - active substances and complexing agents. Applied covering dries out after a certain period of time and hardens, turning to the elastic film easily removed together with pollution. This method is also used to protect surfaces equipment and premises before carrying out of operations, where it is possible radioactive contamination. At deactivation by polymeric coverings leaves more than 90 % of activity.

Nowadays the most common and highly liquid method of decontamination is *decontamination electric field (electro-chemical decontamination)*. The electrochemical decontamination is based on the removal of radioactive contamination as a result of the combined action of the electric field and chemicals forming decontamination solution. When an electric current there is a transition of a superficial layer together with radioactive pollution in a solution (the first stage of process of

deactivation). Then (the second stage of the process) radioactive contaminants are removed along with the spent solution. The role of the decontamination solution in the decontamination process performs the electrolyte [1].

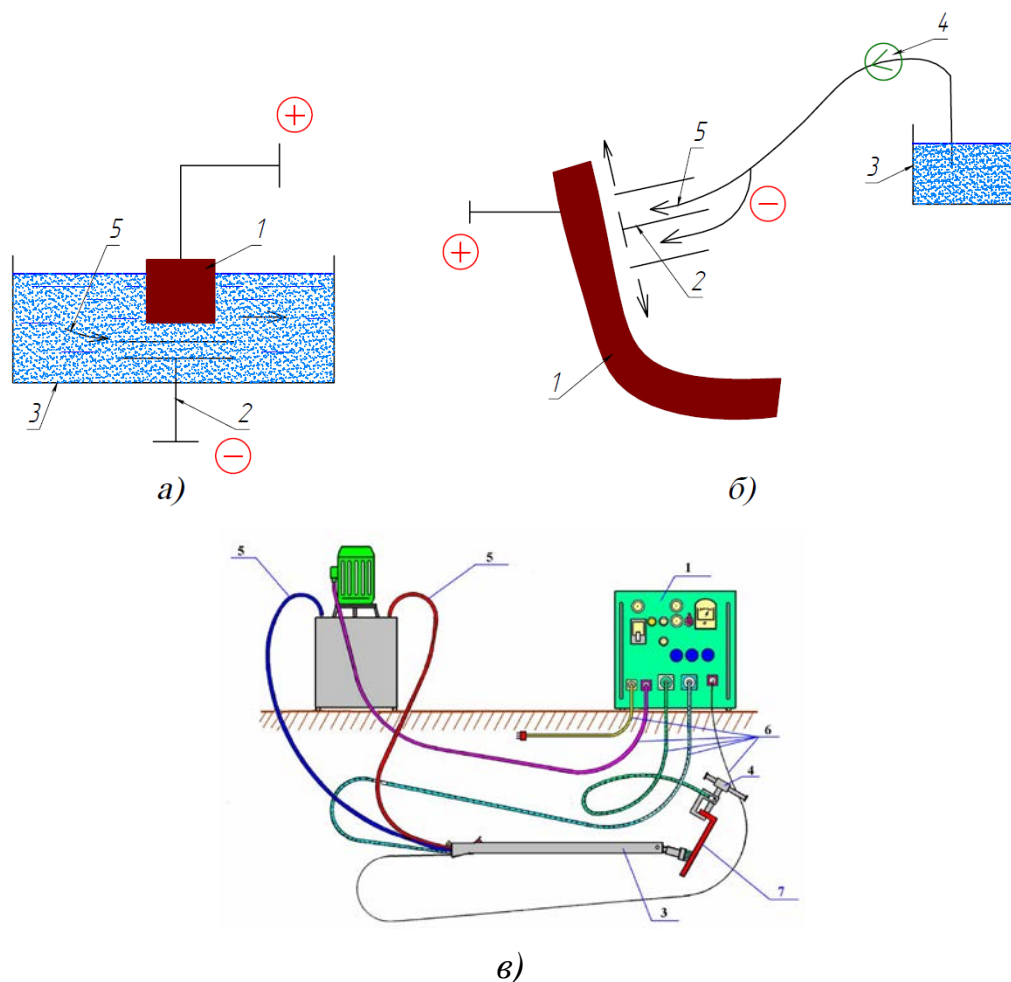


Fig. 4 – Scheme and equipment for electrochemical decontamination:

- a) Scheme of submerged electrochemical method; б) Scheme of the electrochemical method with an external electrode: 1 – processed products (anode); 2 – cathode; 3 – working bath; 4 – pump; 5 – the direction of flow of the electrolyte. б) Setting of the electrochemical decontamination with external electrode 1 – control panel; 2 – the pump unit; 3 – tools; 4 – clip; 5 – a hose; 6 – cable; 7 – decontaminated surface

Electrochemical decontamination is carried out in two different versions. Deactivation of the small-sized demountable equipment of the NPP is made by means of submerged method: by means of the stationary installations having (fig. 4a) an electrolytic bath 3 (cathode) for immersing processable details 1 (anode). For deactivation of large-sized objects or units the scheme with a remote electrode (fig. 4 б and в) is used: the deactivating solution moves the pump 4 of a working bath 3 in space between the cathode and a processable product 1.

The effectiveness of electrochemical decontamination of steel surfaces contaminated with radionuclides ^{204}Tl , depending on the current density in Table 1 [1]. These data demonstrate the advantages of electrochemical deactivation, especially in solutions on the basis of oxidizers. Electrochemical deactivation is not effective in an alkaline environment. The main advantages of the electrochemical method of decontamination are a possibility of removal of superficial and deep

contamination from surfaces of any complexity, significant efficiency; the main disadvantage is the need to use as electrolyte chemically active solutions and compositions often comprising aggressive corrosion – hazardous, volatile, toxic, flammable components, including mixtures based on the strong acids.

Table 1 - Decontamination factor (DF) of decontamination at different current densities

Decontamination solution	Current density, A/m ²			
	0	500	1000	2000
1	2	3	4	5
0.2H.HNO ₃	9	112	278	330
0.1H.KOH	9	1.4	1.7	3.0
37.2% HClO ₄	11	165	200	350

2. THE ELECTROPULSE METHOD OF DEACTIVATION

Alternatively the electrochemical way of deactivation is offered to use an electropulse method, it is still called «electrolytic-plasma» [4-7].

This method is suitable for clearing a surface of the demountable equipment of the NPP of the complex shape made from stainless and black steel, of the fixed superficial and deep radioactive contamination.

The principle of an electropulse method is similar to submerged electrochemical method, schematically it is possible to present it as follows:

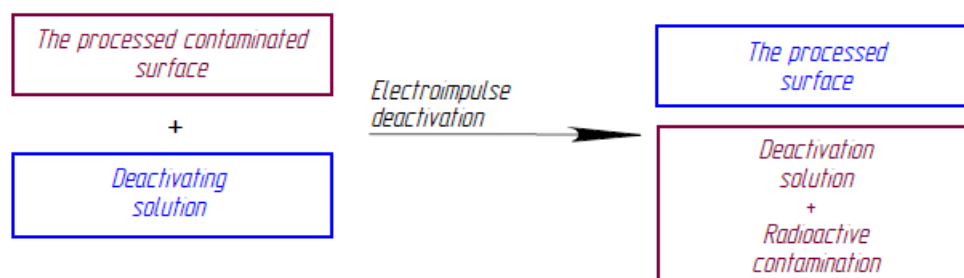


Fig. 5 – The principle of an electropulse method of deactivation

For realization of process of deactivation the positive pole of a source of a current of the raised pressure is connected to the polluted product, and the negative pole is put to a metal bath in which there is an electrolyte (fig. 6). At immersing a product in electrolyte around the product the steam – gas thin pillow is formed (fig. 7), and intensity of an electric field rises sharply up to a level when chemical, covalent, metal and other communications collapse, there are sign – variable oxidation – reduction processes which transfer the elements that are in the superficial layer, in the connections easily separated from a surface. The contamination removed from a surface are transferred to non-soluble connections (hydroxide), dropping out in a deposit. Processing is carried out at an electrolyte temperature of 70 - 85 °C and voltage 250 V - 350 V for 1 - 6 minutes at a current density of 0.1 - 0.2 A/cm². The process is completely automated. The effectiveness ratio for this method of decontamination reaches 500.

As electrolyte weak solutions of neutral salts are used at electropulse deactivation. For example, for the treatment of austenitic steels of type X18H10T (analog AISI 321 – which are used as the main structural material of nuclear facilities), the electrolyte is an aqueous solution of 3-4% ammonium sulfate [4-7]. This is a substantial advantage over the electrochemical decontamination methods. At processing there is a dissolution of a superficial layer of metal on sites of structural inhomogeneities and smoothing of micro-roughness. The electropulse way of deactivation favorably influences on metal, reduces deterioration and corrosion, reduces a susceptibility to radioactive pollution. Thus, the given method is very perspective for deactivation of the equipment of the NPP as, besides fast removal of pollution, improves a condition of a surface.

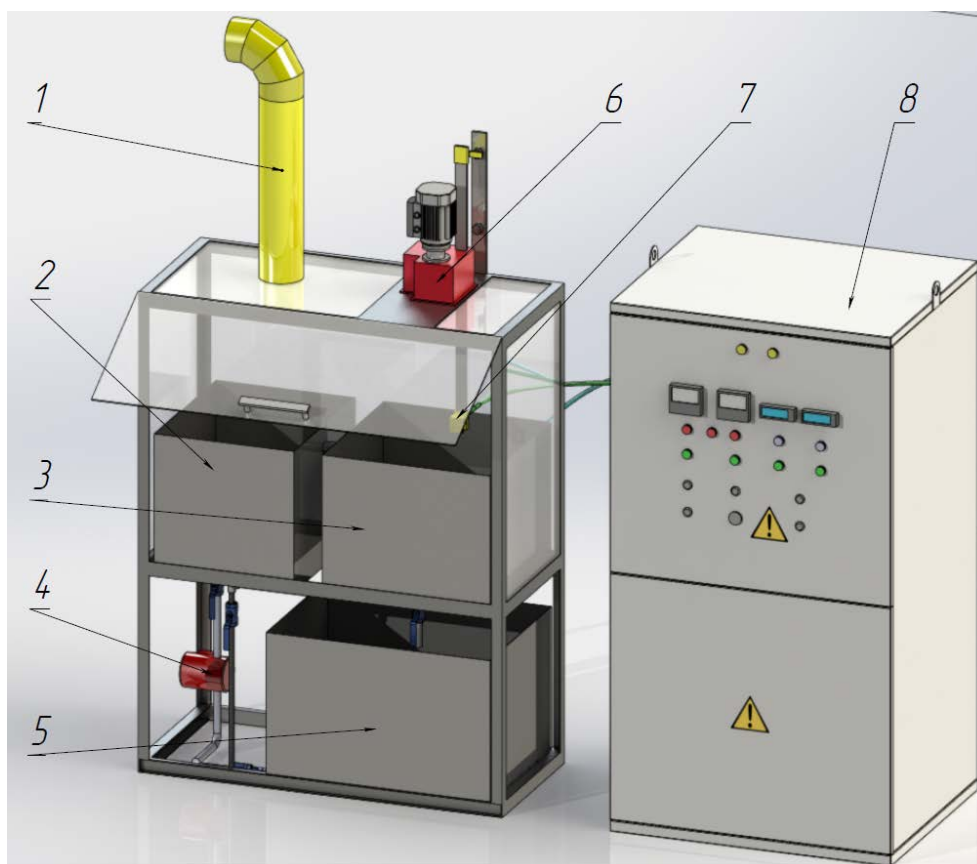


Fig. 6 – Installation for electropulse processing ЭИИИ-15: 1 - tube of extraction system, 2 – capacity for cooling the electrolyte; 3 – a metal bath (working capacity, the cathode); 4 – the circulating pump; 5 – capacity to drain the electrolyte; 6 – lifting mechanism; 7 – attaching point of the polished detail (anode); 8 – control panel (power unit)

The electropulse method of deactivation conforms to all the requirements for methods of decontamination of NPP equipment:

- 1) provides effective removal of radioactive contamination;
- 2) does not cause essential corrosion and destruction of a deactivated material;
- 3) deactivation of the liquid radioactive waste formed as a result of processing of polluted surfaces, does not require any special methods, and it is made by the regular ways used on the NPP;
- 4) a method of decontamination is economical, safe, does not lead to the spread of radioactive contamination, allows for the possibility of mechanization;

5) process is completely automated, it means that the impact of radiation impact is minimized on the staff.

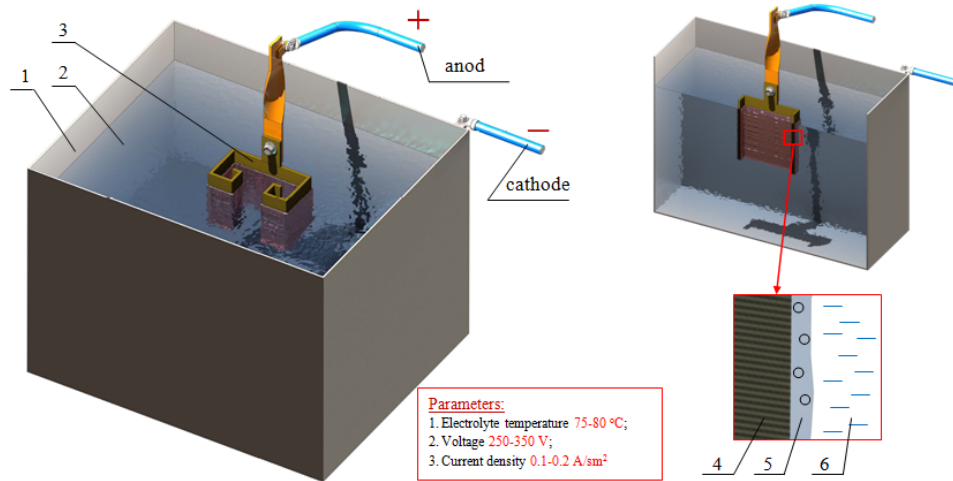


Fig. 7 – The scheme of electropulse processing: 1 – a metal bath (working capacity); 2, 6 – the electrolyte; 3, 4 – a processable detail; 5 – steam-gas pillow

2.1. Theoretical laws of electropulse processing

The mechanism of electropulse processing of metals is complex and now it is not found out yet up to the end. Thus, the question of the physical and mathematical description of the processes proceeding at electropulse processing, is studied by far not completely and now is very actual.

For modeling the processes proceeding in electrolyte at electropulse processing of surfaces of complex shape, the following system of the differential equations is offered:

1) For the description of hydrodynamic movement of electrolyte we use known Navier-Stokes' equation in the Boussinesq approximation:

$$\rho_0 \left(\frac{\partial \vec{v}}{\partial t} + (\vec{v} \Delta) \vec{v} \right) = -\nabla p + \mu \nabla^2 \vec{v} + \rho_0 [\alpha(n - n_0) - \theta(T - T_0)] \vec{g}, \quad (1)$$

where p – pressure; α and θ – coefficient of expansion due to changes in concentration and temperature, accordingly, g – gravitational acceleration.

$$\nabla \vec{v} = 0 - \text{the condition of incompressibility of the liquid electrolyte} \quad (2)$$

Boundary conditions for the field speed have the form (3) on all surfaces, limiting the electrolyte:

$$\vec{v} = 0 \quad (3)$$

The initial condition corresponds to the resting electrolyte:

$$\vec{v} = 0; \quad t = 0 \quad (4)$$

2) The equation of intensity of an electric field:

$$\frac{\varepsilon}{c^2} \left(\frac{\partial^2 \vec{E}}{\partial t^2} - 2(\vec{v}, \nabla) \frac{\partial \vec{E}}{\partial t} - (\vec{v}, \nabla)(\vec{v}, \nabla) \vec{E} + \left(\frac{\partial \vec{v}}{\partial t}, \nabla \right) \vec{E} \right) + \mu_0 \left(\frac{\partial \vec{J}_q}{\partial t} + \vec{v} \nabla \vec{J}_q \right) = \frac{1}{\mu} (\Delta E - \text{grad div} \vec{E}) \quad (5)$$

where $\vec{E}$ – intensity of an electric field; $\vec{J}_q$ – charge density:

$$\vec{J}_q = \lambda(\vec{E} - \lambda_A^* \nabla n) \quad (6)$$

For the task of boundary conditions will consider interface S of two environments with various electro-physical properties.

On contact under action of an external electric field there are superficial charges σ and superficial currents i (the vectors laying in a tangent of a plane to surface S).

The boundary condition for intensity of an electric field [8]:

$$E_{\tau 1} - E_{\tau 2} = 0 \quad (7)$$

Where the index τ designates tangents components of vectors to surface S , indexes 1 and 2 – adjacent environments with various electric properties.

3) The diffusion equation:

$$\frac{\partial n}{\partial t} + \vec{v} \nabla n = -\nabla q_i \quad (8)$$

$$q_i = -D_A \nabla n + D_A^* \lambda \vec{E} \quad (9)$$

Where D_A - normal coefficient of molecular diffusion of the impurity or solute as a whole; λ – specific electric conductivity of the electrolyte; D_A^* , λ_A^* – the coefficients of ambipolar diffusion and specific electric ambipolar conductivity accordingly; n – electrolyte concentration.

4) The heat equation:

$$C_p \rho \left(\frac{\partial T}{\partial \tau} + \vec{v} \nabla T \right) = -\nabla \vec{J}_\tau + \vec{J}_q \vec{E} \quad (10)$$

$$\vec{J}_\tau = -k \nabla T \quad (11)$$

where C_p – the specific heat at constant pressure; $\vec{J}_\tau$ – the density of heat flow; k – coefficient of heat conductivity.

As a boundary condition of the diffusion equation and heat conductivity are supplemented with expression [8, 9]:

$$\text{div } i + J_{qn1} - J_{qn2} = -\frac{\partial \sigma}{\partial t} \quad (12)$$

where the index n designates normal components of vectors to surface S , indexes 1 and 2 – adjacent environments with various electric properties.

As a result of the decision of system of the equations (1) – (12) it is possible to establish non-stationary fields of concentration of electrolyte, temperatures and an electric field in electrolyte at electropulse processing surfaces.

The system of equations (1) – (12) is solved numerically using the software package Wolfram Mathematica.

3. CONCLUSION

Electropulse method of processing is a perspective way of deactivation of the demountable equipment of the NPP of a configuration of any complexity.

Besides the rapid removal of surface radiation contamination of equipment, the use of this method of decontamination dissolves the surface layer of the metal in the areas of structural inhomogeneities and smoothing micro roughness; decrease in wear and corrosion of processable surfaces; reduction of a susceptibility to radioactive pollution; improvement of a condition of a surface. Unlike electrochemical ways of deactivation at which chemically active solutions and compositions are used, at an electropulse method as electrolyte weak solutions of neutral salts are applied, that apparently is essential advantage of the given method.

The electropulse method of deactivation meets all the requirements for methods of decontamination of NPP equipment.

The question of the physical and mathematical description of the processes proceeding at electropulse processing, is studied far not completely and now is very actual. Authors offer the physical and mathematical model, allowing to establish non-stationary fields of concentration of electrolyte, temperatures and an electric field in electrolyte at electropulse processing surfaces.

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