

SUMMARIES

A.V. Vorontsov, R.A. Ivanov, V.P. Struev, V.G. Khoroshev. **Perspective trends in development of the power plants for passenger vessels and marine structures.** Pp. 5–16.

The paper covers the problems regarding modern power plants of commercial vessels and offshore structures (above all, oil-drilling platforms) operating on the continental shelf and in the deep-water areas. The paper mainly focuses on the perspectives of installing air-independent units on the submarines performing underwater geologic explorations, as well as development and exploitation of oil fields. Such units are nuclear power systems, heat engines of closed and semi-closed cycle, electric storage battery systems and the units with electrochemical and chemical fuel elements.

Key words: *offshore structures, power plants, airindependent unit, continental shelf, mineral product.*

V.G. Khoroshev, N.P. Pogodin. **Biological pollution control technology for ballast waters of transport ships.** Pp. 17–38.

The paper describes control and management aspects of transport ship ballast water system.

The paper analyses biological species of invasive marine organisms and microbiological pollution transported in the ballast water of ships. It also analyses ships routes and most troublesome areals of invasive sea organisms.

The authors examine ship systems which can potentially be used to extinguish biological and microbiological pollution of ballast water.

The authors cover the methods of ballast water treatment – replacement, mechanical, physical, chemical and other methods of ballast waters treatment and assess their efficiency.

Key words: *ship ballast, invasive marine organisms, water treatment.*

A.Z. Bagerman. **Ensuring the lifetime of sea gas-turbine engines.** Pp. 39–42.

The paper covers current Russian situation with the production of ionites used in the technological loops of ship power units. The authors give some recommendations on how to solve the problem.

Key words: *ship power units, turbine blade, degradation.*

B.I. Dobrin, V.G. Khoroshev. **Problems of ion-exchange materials production and delivery for the Navy purposes.** Pp. 43–48.

The paper covers current Russian situation with the production of ionites used in the technological loops of ship power installations. The authors give some recommendations on how to solve the problem.

Key words: *marine power plant, ionites, ion-exchange material.*

Yu.M. Dlugoborsky, V.A. Frisk, M.Sh. Denisova, Yu.V. Kopytov, V.G. Khoroshev. **High-temperature fuel cells with solid oxide electrolyte: current foreign developments.** Pp. 49–54.

The paper covers the current developments in the area of high-temperature solid oxide fuel cells (SOFC).

The SOFC fueled by synthetic gas (mixture of oxygen and carbon oxide) can be used for powering electronics and transport systems, and can also be used as a backup power supply for information systems. These circumstances allow expecting SOFC-based power sources to be applied for both civil and military purposes.

Key words: *ship power installations, fuel cell, electrolyte, synthetic gas.*

R.A. Ivanov, I.Yu. Leikin. **Generalized mathematical model of non-stationary operation modes for ship power plants with hydrogen-oxygen electrochemical generators.** Pp. 55–70.

The paper presents the developed principal layout of the ship power installation with hydrogen-oxygen electrochemical generator.

Basing on conservation laws, the authors give (in closed form) non-stationary equations for the main processes taking place in the whole ship power plant and in its individual elements. In particular, the authors present the equations of heat propagation in the moving substance, diffusion equations, hydrodynamic equations for non-compressible liquid and gas, equations of solid bodies movement, general electrodynamic equations, equations of chemical kinetics and volt-ampere parameter equations for the fuel cell.

These equations can be used for mathematical modeling of standard and emergency operation modes of ship power units with electrochemical generators.

Key words: *ship power installation, hydrogen-oxygen electrochemical generator, equations of heat propagation, equations of diffusion, general electrodynamic equation, equations of chemical kinetics.*

R.A. Ivanov, Yu.A. Kurilov, L.F. Chevguz. **Design assessments of mass-size characteristics for hydrogen storage systems in underwater engineering.** Pp. 71–88.

The paper gives the analysis of the following possible ways to store hydrogen fuel aboard the submersibles, in the balloons with high gas pressure, at the cryogenic level of temperatures in liquid state, in chemically combined state (hydroreactive and intermetallic compounds and other hydrogen-containing substances), as well as new perspective methods.

The article gives quantitative and qualitative comparison of the above mentioned storage systems (for specific objects – submersibles and submarines) whose analysis allows selecting a realistic storage system at the FEED stage.

Key words: *hydrogen store, chemical generator, hydrogen-containing substances, storage system.*

Yu.N. Myasnikov. **System analysis and its application for ship power plant reliability assessment.** Pp. 89–110.

Basing on the system approach, the author formulates the concept of initial statements for ship power plant reliability assessment. The paper analyses the factors having impact on ship equipment reliability and shows that failure modes and the laws of failures distribution in time can be brought to an exponential law which satisfactorily characterizes the reliability of equipment in the process of its normal operation. In this case failure rate λ becomes not only the main value to be determined, but also the constant one, and the author's experience in standard ship equipment reliability tests allows solving comparative analysis problems already at the stage of ship power plant design.

Key words: *power plant reliability, failure, technical diagnosis.*

S.P. Bolgarov, V.M. Vorobyev, A.V. Vorontsov, R.A. Ivanov. **Analysis of accident reports regarding operation of nuclear ice-breakers and transport ships.** Pp. 111–128.

The paper gives the results of the analysis of accident reports on nuclear ice-breakers and transport ships. The goal of the paper is to prepare input data for the generation of data base on the emergencies caused by natural and technogeneous factors. This information can further be used for preparing the report confirming nuclear ice-breaker operation safety.

As input material, the author mainly used monthly and yearly reports on the operation of Russian nuclear ice-breakers and Sevmorput LASH-ship, global fleet operation experience, as well as CNIIMF materials published in special bulletins.

Key words: *nuclear ice-breaker, accident, safety, radiation safety, nuclear safety, accident, grounding, flood.*

A.V. Vorontsov, I.V. Kudinovich, A.Zh. Suteeva, M.G. Khorkov. **Trends in development of water-cooled ship reactor of integral type with steam-condensate cycle in the primary loop.** Pp. 129–134.

One of the possible ways to improve nuclear steam-generating units (SGU) with water-cooled reactors is to change over to the steam-condensate cycle (SCC) in the primary loop so that the core directly generates saturated or moist steam with high dryness factor (core with direct steam generation), whereas steam generator serves to condense and recool coolant condensate.

To implement SCC in the ship reactor of integral type it is required to develop the core with direct generation of saturated steam and high energy intensity (about 100 MW/m³). The main problem in the development of such core is to ensure sub-critical heat exchange at high heat flows (over 1 MW/m²) and high steam content (at the output of the core balance steam content $x = 1$).

This problem can be solved through spinning coolant flow. Centrifugal forces caused by this spinning lead to the fluid phase separation at the inner surface of the fuel elements which ensures high heat flows in subcritical heat exchange mode at high steam content.

Heat-generating channel (HGC) for direct generation of steam (with high dryness factor) in the core is a three-way channel with circular fuel element and central non-heat-generating tube. The HGC can produce heat flow spinning in the circular slot between non-heat-generating tube and inner surface of heat element, as well as on its outer surface. Joining of the third way of all HGCs in the general space of heat-generating system ensures coolant mixing which leads to averaging possible deviations of coolant parameters at the output of the second way of separate HGCs and also improves HGC hydrodynamic stability.

Experimental studies performed at electrically heated channels at the KSRI confirmed HGC thermotechnical operability.

The paper gives main technical characteristics and describes specific design features of the ship SGU based on integral reactor with SGC in the primary contour and condensate cycle of the heat carrier with heat power of 150 MW.

Key words: *steam-generating unit, steam-condensate cycle, heat-generating channel.*

I.V. Kudinovich. **Thermal state of fuel element under impulse heating.** Pp. 135–144.

Nuclear reactors accidents related to unauthorized introduction of excessive reactivity are characterized by rapid production of great heat amount in the core. Despite the following sharp decrease of the reactor power because of negative reactivity feedback links (density effect of inhibitor, Doppler effect of the fuel), the amount of the energy stored in fuel elements can be sufficient to fully or partially melting of the core.

The goal of this paper was to develop the procedure to calculate thermal state of the fuel element placed in the still water under condition of impulse heat production increase.

The calculation procedure developed is based on one-dimensional heat conductivity equation describing heat transfer inside the fuel element which is solved through numerical finite-difference method and closing relationships defining heat exchange conditions on the outer surface of the fuel element. The closing relationships selected consider all heat exchange modes on the outer surface of the fuel element under impulse warming in cold water, heat release to the one-phase coolant, bubble boiling on the fuel element surface, transitory and film boiling on the fuel element surface after the starting of heat exchange crisis and emission-caused heat removal. The calculation procedure also considers film boiling instability after inner heat production decrease in the fuel element and transition to the film boiling in this case.

This procedure served as basis for TIMP software development.

To verify thermal state calculation procedure the fuel element dummy (electrically heated stainless steel rod with diameter of 6 mm, length of 0,22 m located in cold (20 °C) water at the pressure of 0,1–7,8 MPa, power density of the inner heat production in the element being 3–7,2 kW/cm, power impulse duration 0,5–2 s) was subjected to the experimental study. The experiment included the measurement of electric power brought to the dummy, temperature of rod surface (as well as the average rod temperature defined by electric resistance) and pressure deviation from the initial value. These parameters were measured both during dummy warming and 10 seconds after the power was switched off.

The paper compares experimental data to the calculation results of the dummy thermal state obtained using TIMP software and RELAP5/MOD3 program that is widely used to analyze emergency modes of water-cooled reactors. The results obtained using TIMP software show better agreement with the experimental data than those obtained using RELAP5/MOD3. It is related to the fact that TIMP software correctly defines critical density of the heat flow on the surface of the fuel element located in still water with the temperature significantly lower than saturation temperature, and also to the fact that TIMP, unlike other programs, considers the instability of film boiling along the warmed rod after inner heat production is ceased.

Key words: *thermal state, fuel element, heat exchange, computing technique*

R.S. Kolevatov, I.V. Kudinovich. **Calculating targets for electronuclear units using GEANT-4 software package.** Pp. 145–152.

Powerful electronuclear sources of neutrons generated by a beam of accelerated charged particles in the target made of heavy elements can be used in nuclear engineering to transmutate long-living radioactive waste, produce new fissionable materials and obtain energy. In the electronuclear units fission reaction takes place in the subcritical reactor, and the required density of neutron flux is ensured using an extra electronuclear source of neutrons.

Based on the calculation results obtained using GEANT-4 software package, this paper presents the data on the neutron outcome from various metal targets (*Fe, Cu, Ta, W, Pb*) under effect of the neutron beam with the energy from 100 MeV to 1 GeV and spatial distribution of energy release in the target.

The article gives the data on neutrons generation in large models, dependency between neutron outcome and target size and spatial distribution of energy release in the target.

Based on the results of the work done, it is possible to make the following conclusions:

1. Comparison of GEANT-4 calculations to the experimental data confirms the possibility of practical use of GEANT-4 for electronuclear unit targets calculation.

2. In the electronuclear unit with subcritical reactor having the power of 200 MW at $k_{\text{эф}} = 0,98$ and the accelerated particles flow of 5 mA the density of neutrons outcome in the target must be not less than 13 neutrons/proton, which can be achieved for metal targets if the protons energy is not less than 400 MeV.

3. For the cylindrical target optimal size for the neutrons outcome is as follows: diameter $D = 2..3 \lambda_{\text{in}}$, length $L \approx D$, penetration depth of the beam inlet point $z_0 \approx 0,3 \lambda_{\text{in}}$.

4. Comparison of the calculation results obtained using GEANT-4 for the heat release in the target under effect of the proton beam with the experimental data makes it possible to conclude that they coincide satisfactorily.

Key words: *nuclear engineering, metal target, proton beam, neutron.*

V.P. Balabin, V.A. Barinov, A.V. Davidovich, N.L. Kuchin, V.M. Prostitenko. **Integral approach to qualitative assessment of the marine vessel nuclear safety based on radiation risk criterion.** Pp. 153–162.

The paper suggests an approach to the safety assessment of designed nuclear marine vessels (NMV) purposed for performing safety level qualitative assessments of the designed platforms basing on the radiation risk criterion. This criterion must be applied as a safety measure because it is required to consider (at the design stage) potential radiation which is normally assessed not only by its dose but also by long-term consequences risk.

The paper gives recommendations on the guidelines of the radiation risk quantitative assessment in the course of NMV design for normal operation conditions and for possible emergencies. These recommendations can be used while making comparative assessments of safety levels for various NMV basing on radiation risk criterion.

Key words: *nuclear marine vessels, safety, radiation risk.*

M.N. Ganul, N.L. Kuchin, I.V. Sergeev. **Analytical evaluation of pollution-induced radiation level effects on humans at sea.** Pp 163–170.

Planning and implementing various projects concerning possible radioactive pollution of sea requires predicting radiation impact on people. Radiation pollution of water areas with operating and repaired floating A-plants, nuclear ships and vessels, stored fragments of nuclear submarines designed for recycling and decommissioned submarines as well as radiation pollution of the open sea influence people in different ways.

The main way of the radiation impact if the open sea is polluted is that people consume sea food coming from the polluted areas. On the contrary, radiation pollution of the water areas with military and industrial nuclear objects

has direct effect on humans, even if these water areas are at considerable distances. In the latter case the main way of radiation impact is external radiation coming from water and inhaling radionuclides.

To perform quantitative assessment the authors have analytically modeled each of the above mentioned radiation ways and recommended the assessment method for the radiation impact concerning radiation impact of the sea. The peculiarity of this method is that it uses dose coefficient transforming volumetric activity of the sea water in the polluted area into efficient radiation dose for population including fishing as well as various industrial activities at the places where nuclear facilities are located and repaired.

The paper gives calculated dose coefficients and formulas to define efficient radiation dose for each of the above mentioned sea areas subjected to radiation pollution.

Key words: *radioactive pollution, radiation impact, radionuclides, dose coefficient.*

M.N. Ganul, N.L. Kuchin, I.V. Sergeev. **Radiation risk due to sea pollution related to afloat storage of recycled nuclear submarines reactor blocks.** Pp. 171–180.

The paper contains analytical assessment of sea radiation pollution consequences related to the emergency sinking of afloat stored recycled nuclear submarines reactor blocks with unloaded spent nuclear fuel.

The main ways of storage personnel exposure to radiation in case of emergency resulting of radionuclide leakages into the water area are inhaling of these radionuclides and external radiation from water. Normal working time in such areas throughout the year is different for various professional groups characterized by the combinations of the above mentioned irradiation ways. According to these ways the following groups have been identified:

Group No 1, which mainly is exposed to radiation through inhaling radionuclides. This group consists of people working in the open industrial sites near water surface.

Group No 2 is characterized by the combination of the two main ways of radiation exposure. This group consists of people working at piers, floating quays and waterborne vehicles directly contacting with the water of the polluted area.

Group No 3 consists of the divers which, apart from the two ways above, become exposed to external radiation from water and sea bed in the process of underwater activities.

To assess radiation impact caused by radioactive pollution of sea water, the doses have been calculated for various radiation exposure cases and for each of the professional groups. Two variants were selected for the calculations, depending on the equilibrium volumetric activity of radionuclides in the water of the area in question.

Most *conservative* variant: the nuclear submarine is laid up for 5 years prior to its recycling, post-recycling time is equal to zero. This variant corresponds to the maximum volumetric activity.

Typical variant: submarine lay-up period prior to recycling is 10 years, post-recycling time is 10 years.

Calculation results analysis showed that in the first case efficient radiation doses for all professional groups are approximately 20 $\mu\text{Sv}/\text{year}$. This dose is mainly acquired through inhaling radionuclides. In the second case the most radiation-exposed group is Group № 3 (efficient dose approximately 1 $\mu\text{Sv}/\text{year}$, mainly acquired through the radiation from water).

In case of the emergency at question individual radiation risk caused by working at the storage site throughout a year is not higher than $1 \cdot 10^{-5}$, i. e. the level of negligible risk, according to Radiation Safety Regulations (RSR-99). Individual yearly damage (in lost years of life expectancy) is not higher than $2 \cdot 10^{-5}$ years if the nuclear submarine is laid up for 5 years prior to recycling and not stored after that (i. e., sunk immediately after the block is formed) and not higher than $1 \cdot 10^{-6}$ years for more realistic variant – 10 year lay-up period prior to recycling and 10 years after that.

Key words: *nuclear submarines, reactor, nuclear fuel, environmental pollution, efficient radiation dose.*

O.B. Chistyakov, A.I. Laikin. **General-purpose submersible system for identifying explosive, poisonous and radioactive substances in potentially dangerous objects.** Pp. 181–188.

One of the most challenging tasks of ecological sea monitoring is to identify the content of potentially dangerous objects on the sea bottom using non-destructive methods.

Most of the modern non-destructive control methods for potentially dangerous objects on the sea bottom do not allow obtaining the information about the elements of their content. Neutron radiation method is practically the only technique that allows obtaining such data, and exactly this method is laid at the basis of the system operation.

High penetration power of neutrons and their ability to start nuclear reactions with the substance with practically immediate (reaction time is about 10^{-10} – 10^{-9} seconds) generation of characteristic gamma radiation by the neutron capturing nucleus supplies the data about the element structure of the objects in question.

Explosive and poisonous substances are found by the analysis of characteristic gamma radiation produced by the nuclei of phosphorus or sulfur under effect of irradiation by slow neutrons.

Special decision-making algorithms compiled in the process of the system development, allow automatic identification and do not require a qualified operator.

The paper gives characteristic gamma spectra obtained during the full-scale tests of the prototype system at sea in 2007 year. Conclusions concerning operability limits of this complex are made.

Key words: *neutron radiation method, neutron generator, safety, ecological monitoring.*

D.S. Grishin, N.L. Kuchin, A.I. Laikin, Yu.A. Platovskih. **Specifics of radioecological situation definition in bays and gulfs of the Arctic and the Far East regions basing on full-scale radioactive pollution measurements.** Pp. 189–200.

In the recent years numerous data have been published concerning radiation pollution sources in the seas around Russian coasts. The most interesting are the Arctic and the Far East regions where various radioactive waste of military and civil nuclear fleet was dumped since 1959 till 1993 year.

This paper establishes certain specific features of sea bottom sediment pollution processes in the gulfs of the Novaya Zemlya islands. In particular, it is assumed that radioactive particles defining the areas with high concentration come from their sources without interacting with water, which sets absolutely new problems in the framework of radionuclides transport theory.

The paper gives preliminary assessment of the radioecological situation in the Arctic and in the Far East and, along with it, draws the conclusion that at present there are no control values for radioactive pollution concentration and no procedure to calculate these for local water areas, including the cases when such pollutions are heterogeneous which impedes more precise assessment of radioecological situation.

The article sets the requirements regarding the scope of information required to assess radioecological situation in the water areas with increased level of pollution caused by technogenic radionuclides, including not only direct radioactivity measurement in water and on sea bed, but also the measurements of various geophysical and hydrological values, such as velocities of the currents, the concentration of suspended materials, etc.

The paper is concluded with the recommendations regarding the development of the procedure for radionuclides transport calculation in bays, considering the possibility of radionuclides presence in hot particles and the specifics of non-stationary field of flows in the bays. There are also recommendations concerning the development of the assessment criteria for the water area radioecological state, continuation of radionuclides concentration measurements in those bays and gulfs where their level is found to be considerable.

Key words: *radiation pollution, radioactive waste, radionuclides, radio-ecological situation.*

D.V. Bykov, A.S. Kapinos, V.A. Lebedev. **Using water-jet ejector to remove ground during ship salvaging operations.** Pp. 201–204.

The ground is removed in three different ways: using excavators, water-jet machines or water-jet ejectors. A water-jet ejector is the most universal device for ground removal, since this method allows efficient pumpage of heterogeneous mixtures, namely pulp (mixture of water and ground).

The paper examines mode and geometric characteristics of the water-jet ejector flow section, which are used to derive a system of equations for the developed mathematical model. To examine mode and geometric characteristics of the water-jet ejector flow section a test rig was constructed. The paper describes the test rig and the results of the tests performed on this rig.

Key words: *ship-raising, ground removal, heterogeneous mixture, water-jet ejector.*

A.V. Gladilin. **Small diameter cable hydroacoustic antennas based on elastic piezomaterials.** Pp. 205–213.

The analysis of possibility of creation of the small diameter cable hydroacoustic antennas by use of elastic piezomaterials is presented. The fragment of cable antenna with elastic piezocomposite elements is described.

Key words: *hydroacoustical antenna, cable antenna, piezomaterial, piezocomposite.*

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