Abstracts
Journal "Problems of Nuclear Science and Engineering. Series: Physics of Nuclear Reactors", issue No.2, 2023

UDC 621.039.51

Research of the High-Sensitivity Self-Powered Neutron Detector Properties

V.F. Shikalov, L.V. Kozlova, L.O. Kapitanova,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

The paper presents the results of a study of the properties of high-sensitivity self-powered neutron detectors (SPND) in order to determine their sensitivity to the conditional neutron flux density and absorbed dose rate of ^{60}C gamma-ray in metrologically certified zones at the research reactors of the Kurchatov Institute Research Center OR, IR-8, critical nuclear stand "KVANT" and the gamma radiation installation GUT-200M.

Key Words: self-powered neutron detector (SPND, characteristics, sensitivity, certified neutron and gamma radiation fields.

UDC 621.3.002

Experimental Study of the Gamma Component in the Rhodium SPD Signal

V.N. Kochkin, A.Yu. Kurchenkov, E.N. Poznyrev, Yu.M. Semchenkov,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

A primary comprehensive experimental study of the contribution of reactor gamma radiation to the total signal of an SPD with a rhodium emitter was performed. This contribution was assessed by comparing the signals of a rhodium SPD and the same SPD with a palladium emitter, since palladium has similar electron-photonic properties to rhodium, but it lacks the beta decay of neutron activation products, which is the main component of the useful signal of a rhodium SPD. Primary tests comparing the signals of two SPD were carried out at the IR-8 research reactor. To confirm the assumption that the electron-photon properties of rhodium and palladium SPD are similar, special measurements were performed on the GUT200m gamma installation.

Key Words: self-powered neutron detector (SPND), rhodium, palladium, in-core noise diagnostic systems (ICND).

UDC 621.3.002

Self Powered Neutron Detector with Hafnium Metal Emitter in VVER Reactors

A.E. Kalinushkin, A.Yu. Kurchenkov, D.S. Markov, I.A. Sergeev,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

A Self Powered Neutron Detector (SPND) with a neutron-sensitive emitter made of metallic hafnium is investigated. The SPND was manufactured by the Research Center "KI" and irradiated at the IR-8 reactor together with rhodium SPNDs. It is shown that, in contrast to the common SPND with a hafnium oxide emitter, this SPND produces an inertia-free signal that is only an order of magnitude smaller than the rhodium SPND.

Key Words: direct charge detector (SPND), hafnium metal emitter, In-core instrument system (ICIS), neutron flux monitoring system (NFMC).

UDC 621.039

Statistical Component of Calibration Error of VVER In-Reactor Thermal Sensors

A.S. Timonin,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

The results of the analysis of the random error of calibration of in-reactor thermocouples installed in VVER are presented. It is shown that from the point of view of metrological reliability, one of the promising variants of the calibration technique is an option based on comparing the readings of the calibrated thermocouple with the temperature, which is determined using the sum of the readings of loop resistance thermometers weighted with the coefficients of influence of each loop on the calibrated thermocouple. The coefficients of influence can be determined on the basis of correlations due to the thermohydraulic features of the circulation of the coolant in the main circulation circuit.

Key Words: VVER, thermocouple, resistance thermometer, calibration.

UDC 621.039.51

Results of Numerical Simulation of Measurements of Scram Worth Performed during the Start-Up Phase of the 2-nd and 3-rd Fuel Loads of the Novovoronezh NPP unit 6

N.M. Zhylmaganbetov, A.I. Popykin, A.A. Smirnova, N.A. Starova,
Scientific and Engineering Centre for Nuclear and Radiation Safety (SEC NRS),
2/8, bld. 5, Malaya Krasnoselskaya st., Moscow, 107140,
L.V. Kryakvin, M.O. Denisova,
All-Russian Research Institute for Nuclear Power Plants Operation JSC (VNIIAES JSC),
25, Ferganskaya st., Moscow, 109507

The paper presents the results of numerical simulation of measurements of scram worth during the start-up phase of the 2-nd and 3-rd fuel loads of the Novovoronezh NPP (NVNPP) unit 6. Numerical simulation of measurements of scram worth for partially burned core was performed according to the method, which was previously developed in SEC NRS and successfully applied to the physical start-up tests of units of NPP with VVER reactors. The paper presents comparisons of calculated and measured currents of ionization chambers and reactimeter readings when measuring scram worth at the start-up phase of the 2-nd and 3-rd fuel loads.

Key Words: VVER, burn-up, reactivity, measurement of reactivity, numerical simulation of measurements, unit. 6 of NVNPP.

UDC 621.039

Method of Homogenization of Group Neutron-Physical Constants Taking into Account Heterogeneous and Kinetic Effects

V.N. Vasekin, P.A. Fomichenko,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

A method of accounting for heterogeneous and kinetic effects in the preparation of homogeneous group neutron-physical constants for the diffusion model is described. The results of the application of the proposed technique in the preparation of homogenized group neutron-physical constants for a fast reactor BREST-OD-300 type are presented. It is shown that taking into account heterogeneous and kinetic effects during homogenization increases the accuracy of calculating integral parameters and distributed characteristics that are important for safety.

Key Words: homogenization technique, heterogeneous effects, kinetic effects, neutron-physical constants

UDC 621.039.52

Procedure of the Evaluation of the Neutron Field Influence on the Reactivity Effects in Engineering Calculations

D.G. Kresov, E.V. Olenskaya,
JSC "Afrikantov OKBM", 15, Burnakovsky passage, Nizhny Novgorod, 603074

In order to improve the accuracy of engineering calculations of ship reactor installations with an increased energy resource, which are characterized by significant values of the reactivity coefficients for the coolant and axial offsets, a preliminary study of the method for refining the dependence of the reactivity density effect on the nature of the distribution of neutron fields was carried out. The necessity of method validation based on comparison of calculated and experimental natural temperature dependences is noted.

Key Words: engineering calculations, reactivity effect, axial offset, perturbation theory, natural temperature dependence.

UDC 539.125.525

Influence of Thermalization Effects on Neutron-Physical Characteristics of the VVER-SKD Fuel Assemblies

V.V. Kolesov, V.V. Sinitsa, Ya.A. Kotov
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

When performing neutron-physical calculations of water-cooled reactors at supercritical pressure VVER-SKD the question arises of taking into account the effect of thermalization during scattering of neutrons by hydrogen atoms in the composition of high-density water vapor. Since the scattering of thermal neutrons is significantly affected by the presence of bonds of scattering atoms, an attempt was made to evaluate the influence of the scattering model on the neutron-physical characteristics of fuel assemblies of these reactors. Two models were considered — a free gas model and a model using the scattering law $S(\alpha, \beta)$, which relates the energy and momentum of a neutron scattered on hydrogen in the composition of a water molecule. The data necessary for the calculations were obtained on the basis of the JEFF-3.3 и JEFF-3.1.1 libraries using the NJOY and GRUCON processing systems. The calculations of the VVER-SKD cell and fuel assembly were carried out by the Monte Carlo method using the MCNP 5.3.120 code. The K_∞ values obtained as a result of calculations using different scattering models showed that hydrogen bonds begin to affect the neutron spectrum starting from a density of 0.5—0.6 g/cm^3 and higher, while the influence of scattering model on the thermalization effect did not exceed 0.2%.

Key Words: VVER-SKD, cell, fuel assembly, thermal neutron scattering, free gas model, scattering at bound nuclei, neutron thermalization.

UDC 621.039

PRIM-AES Software Package for Simulation of Transient Modes at Power Units with VVER Reactors.

D.A. Gornostaev, A.V. Budnikov, E.D. Sokurenko, A.V. Fomin, A.S. Kolokol
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182.

A description of the PRIM-AES software package (NPP simulator program) for modeling neutron-physical and thermal-hydraulic processes in transient modes at power units with VVER reactors is presented. The complex includes a dynamic simulation environment for the implementation of complex algorithms for automatic control systems based on SimInTech CAD systems and the TIGR-M program for coupled neutron-physical and thermal-hydraulic calculation of normal operation and emergency modes, which is a development of the TIGR-1 software package.

The article describes the modernization of the thermal-hydraulic module of the TIGR-1 software package, carried out in order to expand the scope of the code in the volume of the power unit. The structure of a new software-computing complex with a description of its constituent modules, as well as an interface for data exchange between them, has been developed and presented.

The goals and objectives of the application of the developed software package are determined, which allow assessing the relevant criteria of dynamic stability for stationary modes of normal operation, transient modes of normal operation, including power maneuvering modes, operation limitation modes in case of violation of safe operation conditions and emergency modes of the second category with failures of the main equipment.

Key Words: power unit, stationary and dynamic transients, automated process control system, modernization of the calculation code, integration of models, graphic editor, adaptation and analysis of data from the archives of the Top-level Control System of NPP and In-core instrumentation, GET-R1 computer-aided design system.

UDC 621.039

Numerical Simulation of Fluid Flow and Heat Transfer at Supercritical Pressures of a Water Coolant for a Wire-Wrapped Rod Bundle

V.Yu. Kukanov, A.A. Sedov, P.S. Polyakov,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

In this paper, to evaluate the effectiveness of the ANSYS CFX 14.0 code and obtain the properties of the fluid flow, one heat transfer experiment using water as a coolant at supercritical pressures was selected: a bundle of 2 × 2 rods with wire spacing along the entire length. A 3D CFD study of fluid flow and heat transfer at supercritical pressures was carried out for the geometry of the rod bundle, the key parameter of which was the temperature of the inner wall of the rod. The influence of turbulence models SST, k—ω, BSL, as well as various types of meshes on the results to ensure the reliability of the assumed wall temperature is investigated. After the above study, the obtained data on CFD models were verified on experimental data. It was found that the CFD model is able to qualitatively describe the temperatures of the inner surfaces of the rods, which were reported in experiments.

Key Words: pressurized water reactor, supercritical parameters of water, fuel assembly, wire spacing.

UDC 621.039.54

Verification of the Mathematical Model of Thermo-Viscous-Elastic Behavior of Cylindrical Bodies

A.S. Stepanov, A.A. Sedov,
НИЦ "Курчатовский институт", 123182, Москва, пл. Академика Курчатова, д. 1

The article presents the verification of a mathematical model of thermo-viscous-elastic behavior on analytical tests for a hollow cylinder with and without bottoms, as well as a solid cylinder for an elastic state and a state of steady creep.

Key Words: verification, thermo-viscous-elastic model, solid and hollow cylinder.

UDC 621.039.531

Application of Miniature Eccentric Tension Specimens for Determination of Crack Resistance of VVER-1000 Reactor Pressure Vessel Steels in the Ductile to Brittle Transition Range

A.P. Bandura, D.Yu. Erak, D.A. Zhurko, M.E. Korshunov, S.A. Bubiakin,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182

The paper presents results of testing miniature CT-0,16 specimens of VVER-1000 reactor pressure vessel materials in the initial and irradiated states and after holding at high temperatures, processed by the master curve method (ASTM E1921). A comparative analysis between the obtained transition temperatures T_0 and previously obtained results for standard three-point bending test PCV specimens was carried out and showed the closeness of these results.

The metal inhomogeneity was assessed according to the SINTAP procedure based on the performed tests, indicating the need to increase the number of specimens in the test series in order to correctly determine the T_0 parameter.

It has been concluded that CT-0,16 type specimens are promising for use in studies of brittle fracture resistance of vessel steels when the volume of metal is limited.

Key Words: CT-0,16, mini-CT, fracture toughness, VVER-1000.

UDC 621.039.53

Calculation-Experimental Preliminary Possibility Assessment of High-Nickel Steel Application for the VVER-TYPE Reactor Pressure Vessels of Future Generations

E.A. Kuleshova,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182, National Research Nuclear University "MEPhI", 31, Kashirskoe highway, Moscow, 115409,
I.V. Fedotov, S.P. Kuznetsov,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182.

The current work presents experimental-calculated assessment of application of high-nickel pressure vessel steels developed by JSC "NPO CNIITMASh" as materials for pressure vessels of advanced reactors. Structure-phase state and mechanical characteristics of these steels were considered as well as the possibility to manufacture a reactor shell with industrially developed wall thickness. Increasing the service characteristics required the use of the set of following measures: complex steel alloying modification, removing of metallurgical impurities (first of all, phosphorus) and formation of the optimal grain size in the casting. The calculation considered: suspected working temperature, coolant pressure, strength category of the candidate steels and their thermal and radiation resistance.

Key words: reactor pressure vessel steels, Ni concentration, mechanical properties, preliminary calculation of steels applicability.

UDC 541.15

Radiation-Chemical Fixation of Nitrogen in an Aqueous Solution H_2 and N_2 under the Accelerated Protons Irradiation. Mathematical Model and its Verification

S.A. Kabakchi,
NRC "Kurchatov Institute", 1, Academika Kurchatova sq., Moscow, 123182,
O.P. Arkhipov,
JSC "N.A. Dollezhal Research and Development Institute of Power Engineering",
2/8, M. Krasnoselskaya st., Moscow, 107140,
A.O. Verkhovskay, M.L. Lukashenko,
JSC "All-Russian Research Institute for Nuclear Power Plants Operation", 25, Ferganskaya st.,
Moscow, 109507

A mathematical model of the radiation-chemical synthesis of ammonia in an aqueous solution of nitrogen and hydrogen is presented. We used our own, previously unpublished data obtained at the "Protoka" facility [1] to verify the model. Protons with an energy of 30 MeV of the Kurchatov Institute cyclotron were used as a simulator of a nuclear reactor radiation. The irradiation conditions — temperature, pressure, absorbed dose rate, as well as the composition of the solutions corresponded to those characteristics of primary coolant system of a pressurized water reactor.

Statistical correlation theory was used to substantiate the adequacy of the developed mathematical model. Calculations showed that the correlation coefficient between the calculated and experimental values of the concentrations of synthesized ammonia is 0.90, which indicates the presence of a strong positive correlation between the calculated and experimental data. The maximum deviation of the experimentally obtained values of the concentrations of synthesized ammonia from the calculated values was ±80% of the calculated value. Taking into account the complexity of the experiment on "Protoka" facility, which affects the error of experimental data, the proposed mathematical model should be considered adequate taking into account the error obtained.

Key Words: mathematical model, experimental stand, model verification, synthesis of ammonia.

UDC 629.039.58

Volatility of Iodine Molecular Forms and their Transfer Between Liquid and Gas-Vapor Phases Inside the VVER Containment

C.D. Khoroshilova, A.B. Sazonov, O.S. Bystrova, V.A. Grachev, S.K. Belus, K.V. Tsarkova,
NRC "Kurchatov Institute", 1, Akademika Kurchatova sq., Moscow, 123182.

The experiments on distillation of iodine solutions with different contents of boric acid and pH values have been done to determine and refine some properties of inorganic iodine volatile forms, i.e. I_2 and HOI. Use of these results to calculate the iodine partition coefficient (PC) showed its dependence not only on temperature and pH, but also on time, initial concentration of total iodine, and one of each iodine form in solution. In acidic solutions and at low temperature volatility of iodine is controlled by the properties of I_2, whereas in basic solutions and at high temperatures it is controlled by ones of HOI. Equilibrium achieved between liquid and gas-vapor phases is controlled by kinetics of I_2 and HOI hydrolysis in liquid. Thus, use of equilibrium PC may result in significant error when gaseous releases of radioactive iodine during a VVER primary coolant loss accident are to be estimated. Alternative numeric model describing iodine interphase transfer and taking into account both chemical kinetics of the iodine-containing species and current VVER accident sump solution composition and temperature is proposed for calculations.

Key Words*:* VVER, primary coolant, radioactive isotopes, iodine, hypoiodous acid, hydrolysis, potential of hydrogen, partition coefficient, Henry's constant.