

## Abstracts

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### **CTAPT4 — a Program for Complex Calculation of a Nuclear Reactor in *R—Z*-geometry**

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The CTAPT4 program (Calculation Transient Atomic Power and Temperature, version 4) is designed both for modeling the stationary state of a reactor with all major feedbacks, and for conducting computational studies of non-stationary processes of any duration (burnout and fuel reloading, xenon processes, reactor start-up and shutdown several emergency processes) without taking into account the influence of the outer contour equipment. This code was developed specifically for conducting computational studies of reactor characteristics at the stage of developing its concept and selecting basic design solutions: reactor dimensions, fuel element type (flat, cylindrical, spherical), core structure (uniform or cluster-channel) and fuel reloading mode, type of coolant (gas, liquid, liquid metal), etc.

**Key Words:** nuclear reactor, non-stationary processes, computational modeling, feedback, *R—Z*-geometry.

EDN: TDXUOA

UDC 621.039.524.2.034.3

### **Two-temperature Thermal Conductivity Model for Fuel Rods with Heterogeneous Heat Sources in the CTAPT4 code**

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The paper presents a mathematical model for calculating heat transfer in spherical fuel elements with micro-fuel elements featuring heterogeneous heat sources. The model was developed at the I.V. Kurchatov Institute over 30 years ago for the analysis of High Temperature Gas-cooled Reactors (HTGR) and has been used ever since in the CTAPT4 code. The model's key parameter is the so-called "effective thermal resistance of the micro-fuel element shells," which, in this model, is considered constant, although it should not be. The paper provides a detailed assessment of the behavior of this critical parameter, whose precise knowledge significantly determines reactor characteristics during rapid transient (emergency) processes.

**Key Words:** HTGR, micro fuel element, thermal resistance, micro fuel element shell (cladding), heat transfer, transient process, temperature distribution.

EDN: UWIEOX

UDC 621.039.586

### **Research Nuclear Reactor Beyond-Design-Basis Accident Analysis using Various Fuel Failure Models**

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This paper uses a hypothetical accident scenario involving prompt  $>1 \beta_{\text{eff}}$  reactivity insertion in a research nuclear reactor to show that a realistic simulation thereof should account for the reactivity effects caused by the failed portion of fuel elements. This paper considers two basic fuel failure models. The first assumes the fuel element failure to begin with the start of cladding meltdown. The second relies on experimental data on fuel element failure at heat fluxes above the critical one.

**Key Words:** research nuclear facility (RNF), accident, reactivity effect, nuclear fuel, fuel element, critical heat flux (CHF).

EDN: GIWHFP

UDC 621.039

## **Assessment of VVER Core Reactivity Coefficients Uncertainties Based on Xenon Oscillation Experiments Processing**

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This paper describes a procedure based on the Bayesian method using experimental data on the excitation of free xenon oscillations for estimating the uncertainties of neutronic parameters in engineering computing models. This procedure includes: analysis of transients’ sensitivity to model parameters; selection of a priori hypotheses for model parameters; development of simplified polynomial model for some process parameters; and construction of a posteriori probability density for model parameters using Markov Chain Monte Carlo (MCMC). The results of applying this procedure to refine the neutronic parameters using the Nostra code and the data on free xenon oscillation experiments in VVER-1200 reactor are presented. The resulting a posteriori distributions of neutronic parameter uncertainties are compared with a priori hypotheses.

**Key Words:** axial xenon oscillations, Bayesian models, MCMC, uncertainty analysis, sensitivity coefficients, machine learning.

EDN: QQSJNU

UDC 621.039.544.8

## **Combined Application of Gadolinium and Erbium Burnable Absorbers in Extended VVER-1000 Fuel Cycles**

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VVER-1000 fuel cycle can be extended by increasing the initial reactivity margin. Further increase in gadolinium weight content in current gadolinium rod arrangements within fuel assemblies does not increase the reactivity margin compensated by the absorber, but significantly increases power nonuniformity in fuel assemblies. Use of erbium burnable absorbers directly affects the reactivity margin, but causes losses in fuel burnup. This paper analyses the possibility of combined use of gadolinium and erbium burnable absorbers in VVER-1000 reactors, and considers various options for absorber locations. The results demonstrate the possibility of using these burnable absorbers together when shifting to longer fuel operating cycles with higher reactivity margins.

**Key Words:** gadolinium, erbium, multiplication factor, burnup, VVER, polycell, power nonuniformity, reactivity margin, fuel cycle, weight content, Serpent.

EDN: ZIAYTO

UDC 621.039, 51-74

## Modernized Excluded SPND Method

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The article presents the practice of using the existing excluded SPND method in ICIS. The limits of applicability and shortcomings of the existing method are highlighted. A modernized excluded SPND method is described. The results of approbation the new method on operating NPPs are presented.

**Key Words:** self-powered neutron detector (SPND), in-core instrumentation system (ICIS), VVER, failure detection.

EDN: CRNRXU

UDC 621.3.002

## Experimental Study of Background Currents in SPND Two-Wire Signal Cable

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The article describes the results of an experimental study of the formation of background currents in SPND two-wire signal cable in the field of gamma radiation. The designs of the experimental installations used, as well as two samples of cables used for signal lines, are briefly described. The results of measurements of the core-wires currents in various series of experiments are presented. The analysis of the obtained results is carried out. In some experiments, a change in the polarity of the core-wires currents was detected.

**Key Words:** two-wire signal cable, background current, self-powered neutron detector (SPND), in-core instrumentation system (ICIS), gamma-sensitivity of the signal cable, VVER.

EDN: HZVYKY

UDC 539.1.08

## Noble Radioactive Gases Volumetric Activity Measurement Method in NPP Accident Conditions

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Ensuring the safety at modern NPPs requires reliable wide-ranging measurements of the volumetric activity of noble radioactive gases during anticipated operational occurrences and accidents. Existing emergency instrumentation mainly implements indirect measurements that lead to high measuring errors. The available instrumentation tools based on direct measurement methods have a number of fundamental engineering limitations, which make them unusable in emergency situations. To ensure the design-basis measuring accuracy in the entire range of volumetric activity values, this paper suggests a new method allowing direct measurements in conditions of high external gamma background and other factors.

The article also analyzes possible volumetric activity values of noble radioactive gases for modern NPP projects, reviews the existing measurement methods and detectors, and defines their limitations for activities of up to  $10^{17}$  Bq/m<sup>3</sup>.

**Key words:** volumetric activity, noble radioactive gases, nuclear power plant emissions, radiation environment monitoring, ionization chamber, semiconductor detector, scintillation detector, direct measurement method, beta radiation, detector sensitivity, emergency conditions.

EDN: XGAALS

UDC 621.039.587

## **Preliminary Startup Mode Analysis Results for Single-Circuit VVER-SKD Nuclear Power Plant**

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Based on preliminary estimates, this paper suggests an algorithm for single-circuit VVER-SKD nuclear power plant startup at constant pressure. Coolant flow stability studies were performed for VVER-SKD double-inlet core peripheral part where the coolant flows from top to bottom. Using the KORSAR system code, the coolant flow stability loss boundary was determined, and normal operation modes were shown to lie within the stable flow region. Thermohydraulic analysis of peripheral fuel assemblies performed by the TEMPA-SC subchannel code confirms the coolant flow within fuel assemblies to be stable. This paper also reviews startup patterns for foreign reactor designs with supercritical water coolant parameters in two operating modes with sliding and constant pressure.

**Key Words:** VVER-SKD, supercritical pressure, start-up regime, stability of the coolant flow, KORSAR, TEMPA-SC.

EDN: ZZXS MR

UDC 536.2

## **Simulated Nuclear Power Facility Cooldown Using Lunar Regolith**

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This paper describes a theoretical study of possible heat transfer from the secondary circuit of a nuclear power facility into lunar regolith available at anomalously low initial temperature of 73 K in craters on the shadowed side of the Moon. The paper reviews thermophysical properties of the regolith and provides numerical simulation of heat transfer in channels that contain hot fluid when adding suspended regolith granules and when the outer channel walls come into contact with the granular layer. It is shown that polar regolith can be additionally used for reactor facility cooldown with simultaneous water production.

**Key Words:** nuclear power facility, polar regolith, convective heat exchange.

EDN: XGIARX

UDC 621.039

## **Methods to Improve Dynamic Stability of VVER-1200 Power Units**

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The results of commissioning tests and operating experience of VVER-1200 units at Novovoronezh, Leningrad, and Belarusian NPPs confirm the need to adjust the protections and optimize the power setback algorithms involved with the main equipment shutdown. Improving the dynamic stability during shutdown of the key units — such as feedwater pumps, condensate pumps, circulation pumps, and reactor coolant pumps — can be achieved by:

- optimized settings of process protections and interlocks to prevent excessive activation of safety systems that may lead to load reduction or unit cutoff from the grid;
- optimized power setback methods to smoothen the transients associated with the shutdown of non-redundant equipment such as condensate, feedwater and circulation pumps;
- equipment modernization to minimize the steam generator level variation effects during transients.

This article presents specific proposals for adjusting design algorithms to improve the dynamic stability of VVER-1200 power units in basic normal operation modes, which will increase their in-service reliability and safety.

**Key Words:** dynamic stability of the power unit, process protections and interlocks, accelerated preventive protection, reactor power controller, automatic power controller, feedwater pumps, condensate pumps, circulation pumps, reactor coolant pumps.

EDN: XBUXNL

UDC 621.039.546

## **Temperature Dependences of Hydrides Dissolution and Precipitation in Unirradiated E110 Alloy Cladding under Different Temperature Scenarios**

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This paper describes hydride dissolution and precipitation temperature measurements in unirradiated E110 alloy containing 20—180 wppm of hydrogen performed by differential scanning calorimetry (DSC) in the standard dry storage temperature range. Dependences of hydride solubility limit in E110 alloy were identified for dissolution (TSSD) and precipitation (TSSP). Hydride precipitation temperatures were shown to depend on the thermal history of samples. Hydride precipitation temperatures were also measured in partial dissolution mode. Partial dissolution experiments show that hydride dissolution rate at temperatures of 250—340 °C is higher than at 380—425 °C.

**Key Words:** zirconium alloys, E110 alloy, fuel cladding, dry storage, zirconium hydrides, hydrogen solubility, differential scanning calorimetry.

EDN: TWNEQU

UDC 621.039.564.3:004.032.26

## **Application of Machine Learning Methods for VVER Equipment Stress Calculation Based on External Thermocouples**

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This article considers application of neural network to calculate stresses at control points in VVER reactor plant equipment and pipelines, and presents the main development aspects and possible modifications of computational models. Respective test calculations are shown to provide highly accurate solutions. It is also shown that converting the neural network model to a recurrent form positively affects its stability relative to input signal disturbances. This approach can be used both to assess the reactor equipment service life and to determine the actual stress factors for equipment strength assessment.

**Key Words:** VVER, equipment, stress, inverse thermoelastic problem, neural network.

EDN: UJTMEI

**Assessment Options for Preliminary Estimates of Maximum Permissible  
Radioactive Releases to Comply  
with Sanitary Protection Zone Size Requirements in NPP Design**

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The main objective of designed NPP safety analysis is to assess the radiation impact on the population during normal operation. This article presents estimated maximum permissible releases (MPR) and possible options for establishing values thereof at the NPP design stage with account of the required sanitary protection zone size. Options to determine MPR numerical values for a design-basis release source compliant with the effective sanitary rules, as well as with Rostekhnadzor safety guidelines, methods and rules are considered. The article also provides a preliminary list of radionuclides to be taken into account at the design stage, if the technical documentation contains no information on the expected estimated release.

It is shown that an assessment and/or analysis of NPP radiation impact in normal operation mode is sufficient at the early design stage.

**Key Words:** sanitary protection zone, nuclear power plants, radioactive substances, radioactive releases, maximum permissible releases, radiation safety.

EDN: IYDGNL