TOMSK POLYTECHNIC UNIVERSITY | ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

APPROVED BY

Director of Nuclear Science & Engineering School
_______________ / Oleg Yu. Dolmatov
"25" 06 2020

Course Name: Nuclear Reactor Design Project

Field of Study: Nuclear Physics and Technology

Programme name: Nuclear Science and Technology

Specialization: Nuclear Power Engineering

Level of Study: Master Degree Programme

Year of admission: 2019

Semester, year: semester 3, year 2

ECTS: 4

Total Hours: 144

Contact Hours: 64

- **Lectures:** 32
- **Practical experience:** 32

Self-study: 80

Assessment: Graded credit-test, credit test

Division: Nuclear Fuel Cycle

Director of Programme _______________ / Vera V. Verkhoturova

Instructor _______________ / Sergey N. Timchenko

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Course name: Nuclear Reactor Design Project

Course Overview

Course Objectives	The objective of the course is to develop students' theoretical knowledge and practical skills, which are necessary to conduct professional activity involving the usage of calculation techniques of reactor core and biological shields for nuclear power plants.
Learning Outcomes	**Upon completion of the course, a graduate will obtain the knowledge of:** – fundamentals of nuclear and neutron physics, composition and characteristics of nuclei, the law and characteristics of radioactive decay, theoretical foundations of nuclear reactions and their characteristics; – features of neutron cycle in a nuclear reactor, the concept of the effective neutron multiplication factor, the criticality conditions; processes of fuel burnout and reproduction in various fuel cycles; – physics of transients in nuclear reactors; – existing designs of nuclear reactors in general and their structural elements; – basic types, classes and groups of materials, their compositions and properties (nuclear fuel, coolants, retarders, structural materials, protection materials); – laws of thermodynamics, cycles of steam turbine and gas turbine installations, energy balance of nuclear power plants, efficiency; – thermohydraulic processes in nuclear reactors and power plants, methods of hydraulic profiling of coolant flow, non-stationary processes in transient and emergency modes; – basic laws of natural science disciplines; – sources of ionizing radiation in nuclear power plants; – basic structural decisions for units and elements of the core, reactor and reactor plant as a whole; – security systems and analysis of the reliability of security systems; – behavior of various materials of nuclear reactors and power plants under the influence of ionizing radiation and complex temperature fields; – main characteristics of subcritical, critical and supercritical multiplying systems; – methods for determining the effectiveness of regulatory authorities and management and protection systems; – methods for determining the state of the reactor according to the testimony of instrumentation; – methods for protecting personnel and the public from the possible consequences of accidents, disasters, natural disasters; – power cycles and schematic diagrams of steam turbine and gas turbine nuclear power plants; – main directions of creating fundamentally new nuclear reactors and power plants that meet modern security and environmental requirements;

	– methods for determining the effectiveness of shim rods and control and protection systems; methods of calibration of shim rods; methods of control over shim rods position; methods for determining the state of the reactor according to the testimony of instrumentation; – comparative assessment of the environmental, medical, social and economic aspects of the use of various energy sources; – fundamentals of technology and the environmental consequences of uranium mining, uranium enrichment, fuel fabrication. **Upon completion of the course, graduates are also expected to develop the following skills:** – to calculate the basic physical characteristics of nuclear reactors; – to determine the critical characteristics (position, concentration, etc.) of the regulating bodies at any time during the reactor operation; – to calculate reactor poisoning, slagging, burnout, and accumulation of fuel isotopes; – to apply calculation methods accompanying the process of reactor design; – to apply the acquired knowledge for determining the optimal combinations of core materials depending on the purpose and type of NPP, and to argue the decisions taken; – compose equations characterizing isothermal, isobaric, isochoric, adiabatic and polytropic processes; – to determine the specific volume, enthalpy, internal energy of working bodies used in the thermohydraulic calculation of nuclear reactors; to determine the thermal efficiency of thermodynamic cycles; – to use basic laws of natural science in professional activity; – to apply methods of modeling, calculation and experimental research in the development of new nuclear reactors and power plants; – to apply regularities of the weakening of ionizing radiation in matter; – to classify nuclear reactor safety systems; – to analyze design decisions of the existing power installations and the ones under construction; – to determine the state of the reactor (multiplying system) according to the reactor instrumentation readings; – to determine and use differential and integral characteristics of reactor regulators; – to draw up a schedule for the physical start-up of the reactor and for the reactor output at the required power level; – to assess nuclear and radiation safety, its impact on the environment; – to carry out an approximate or estimated engineering calculation of equipment and station indicators; – to use methods of engineering calculations of processes in nuclear reactors and power plants; – to analyze and interpret the flow of fast and slow neutron-physical processes in the reactor; – to create mathematical models of processes for carrying out complex neutron-physical, thermal-hydraulic, strength calculations, study of safety indicators; – to consider specific characteristics of nuclear power engineering in raising the public awareness of nuclear energy development;

	– to develop plans for calculation and experimental research. **Upon completion of the course, graduates should acquire the practical experience in:** – applying methods for determining neutron effective cross sections; – drawing up regulatory requirements for the physical reactor start-up and for the reactor operating at a required power level; – calculating reactor reactivity change due to poisoning, slagging, burnout, reproduction, temperature effects of nuclear fuel; – using obtained knowledge in the process of design under conditions when general standards cannot be applied; – monitoring and interpreting the thermohydraulic parameters of the core of operating and shut down reactors; – carrying out experiments to perform thermohydraulic calculations of reactors; – combining results of thermal and hydraulic calculations with physical, strength and economical design to justify the parameters of a nuclear installation, its thermal and technical reliability; – assessment of the consequences of using energy-producing technologies – execution of engineering calculations for the main types of professional tasks; – using methods for calculating biological protection and dose rates, radiation safety standards; – making analysis of existing nuclear power safety; – solving direct and inverse problems of reactor control; – calculating efficiency and layout of the reactor control and protection system; – starting-up and controlling the parameters of a research nuclear reactor; – controlling parameters of the neutron field when moving shim rods; – plotting charts, graphs, drawings, diagrams, nomograms, and other engineering visuals; – applying obtained knowledge for solving specific engineering tasks, for comparative assessments in standard and specific situations; – calculating the efficiency and layout of the reactor control and protection system – controlling parameters of the neutron field in conditions of shim rods movement; – implementation of research and development results; – developing computational programmes for calculating parameters and technological processes with the use of computer technologies.
Course Outline	The target course is taught using a variety of teaching forms such as: – 16 lectures; – 16 practical experiences; – 2 colloquiums; – 1 team project. Within the framework of the course, students study the following sections: **Section 1. Neutronic processes** Calculation task is devoted to obtaining practical skills on the following topic:

	– Unit cell of the reactor. – Neutronic properties of the reactor core. – Temperature and power effects of reactivity. **Section 2. Methods of nuclear reactor calculation** Calculation task is devoted to obtaining practical skills on the following topic: – Energy release of reactor core. – Nuclear reactor campaign. – Fuel burnup. Each section includes several lectures and practical experiences. The course ends with a credit-test. *Learners' self-study* involves performance of reports based on calculation tasks, preparation for colloquiums and midterm tests. Students perform 6 calculating tasks during the course of study. Each calculating task ends with a report, which must be presented in paper and formatted according to the TPU guidelines. The number of pages in the report (except for the title page and the list of references) should be at least 3 and not more than 6. The maximum score for a report is 10. The number of points received by a student for each report is determined according to the system of knowledge assessment. *Final assessment* is performed in an oral form using a credit-test paper. Each paper includes three questions or tasks. Time for preparation is 30 minutes. The maximum score is 20; the minimum score is 12. Total score is formed on the basis of three criteria: – Knowledge of professional subject (0-2 scores). – Logical and well-structured answer (0-8 scores). – Correctness and completeness of answers (0-10 scores).
Prerequisites (if available)	1. Nuclear Physics. 2. Special chapters of Advanced Mathematics. 3. Materials of Nuclear Installations. 4. Reactor Physics.
Course Structure	The target course consists of two sections. **Section 1. Neutronic processes** Nuclear reactor. Chain fission reaction. Main parameters of the chain fission reaction. Coefficient of neutron multiplication. Physical features of nuclear reactor. Influence of structural features on the physical parameters of reactor. Role of neutronic calculations in the design of nuclear reactors. Reactor core. Fuel rods. Reflector. Nuclear reactor structure. Features of reactor. Physical design. Choice of the type of reactor design. Fuel cycle. Consumption of natural uranium. Potential dangers of nuclear fuel. Nuclear fission. Neutrons. Delayed neutrons. Energy of fission. Cross sections for the interaction of neutrons with nuclei. Microscopic and macroscopic cross-sections. Density of the neutron flux. Rate of nuclear interactions. Neutrons leakage. Slowing down and diffusion of neutrons. Moderators and neutron reflectors. Chain reaction. Neutron cycle. Critical parameters of the reactor. General scheme for physical calculations of the reactor. Neutrons spectrum. Multigroup theories. Features of the single-group approximation. The single-group equation and its solution. Border conditions. Calculation of the reactor in the single-group approximation in simple cases. Multigroup approximation of the theory of critical parameters. **Section 2. Methods of nuclear reactor calculation**

	Method of separation of variables. Finite cylindrical reactor. Multi-zone cylindrical reactor. Cylindrical reactor with a central shim rod. An example of a single-group reactor calculation. Basic coefficients of the diffusion equation in homogeneous media. Coefficients of the diffusion equation in a heterogeneous reactor. Cell model of a heterogeneous reactor. Distribution of the thermal neutron flux density over the cell of a heterogeneous reactor. Boltzmann equation. Possibilities for its simplification. Finite difference method. Method of spherical harmonics. Method of discrete ordinates. Probabilistic methods. The probability method of the first collisions. The Monte Carlo method. Excess reactivity and operational reactivity margin. Reactivity balance of the reactor. The components of the balance of reactivity. Tasks for physical calculations. Features of physical calculations in reactors of various types. Calculations of elementary cells of reactors. Calculations of the reactor. Calculations of fuel burnup. Calculations of shim rods worth. Main characteristics of the core. Causes of uniformity energy release distribution in the core. Equalization of energy release in the core. Selection and optimization of the initial fuel loading.
Facilities and Equipment	Lecture hall with multimedia equipment: Tomsk, Lenin ave. 2/4, building 11, room 303.
Grading Policy	In accordance with TPU rating system we use: –Current assessment, which is performed on a regular basis during the semester by scoring the quality of mastering of theoretical material and the results of practical activities (calculating task, colloquium). Max score for current assessment is 100, min – 55. Current assessment involves defense of reports based on calculation tasks and colloquiums. Reports on calculation tasks results must be presented in paper and formatted according to the TPU guidelines. The number of pages in the report (except for the title page and the list of references) should be at least 5 and not more than 10. The maximum score for a report is 10. The number of points received by a student for each task is determined according to the system of knowledge assessment. Colloquiums are carried out in a written form using a set of questions or tasks. Each set includes two questions or tasks. Time for preparation is 60 minutes. The maximum score is 10; the minimum score is 4.
Course policy	Attendance at lectures and practical experience is compulsory.
Teaching Aids and Resources	**Compulsory reading:** 1. Oka Y. Nuclear Reactor Design / Y. Oka. – Tokyo : Springer, 2014. – 327 p. – Текст: электронный // SpringerLink. – URL: https://link.springer.com/book/10.1007/978-4-431-54898-0 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ. 2. Hoffelner W. Materials for Nuclear Plants. From Safe Design to Residual Life Assessments / W. Hoffelner. – New York : Springer, 2013. – 477 p. — Текст: электронный // SpringerLink. – URL: https://link.springer.com/book/10.1007/978-1-4471-2915-8 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ 3. Nuclear Thermal Hydraulics / H. Akimoto, Y. Anoda, T. Kazuyuki [and others] – Tokyo : Springer. 2009. – 291p. - Текст: электронный // SpringerLink. – URL: https://link.springer.com/book/10.1007/978-4-431-55603-9 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ.

	4. Fast Reactor System Design / by editor N. Kasahara. – Tokyo : Springer, 2017 – 298 p. Текст: электронный // SpringerLink. – URL: https://link.springer.com/book/10.1007/978-981-10-2821-2 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ. 5. Marguet, S. The Physics of Nuclear Reactors / S. Marguet. — Cham : Springer International Publishing AG, 2017. — 1445 p. – Текст: электронный // SpringerLink. – URL: https://link.springer.com/book/10.1007/978-3-319-59560-3 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ. **Additional reading:** 1. Fast Reactor System Design / by editor N. Kasahara. – Tokyo : Springer, 2017 – 298 p. Текст: электронный // SpringerLink. – URL: https://link.springer.com/book/10.1007/978-981-10-2821-2 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ. 2. Handbook of Nuclear Engineering. With Figures and Tables. V. 1: Nuclear Engineering Fundamentals / by editor D. G. Cacuci. – Karlsruhe : Springer, 2010. – 3701 p. - Текст: электронный // SpringerLink. – URL: https://link.springer.com/referencework/10.1007/978-0-387-98149-9 (дата обращения: 20.09.2020). – Режим доступа: из корпоративной сети ТПУ.
Instructor	Sergey N. Timchenko, Associate professor, Nuclear Fuel Cycle Division, School of Nuclear Science & Engineering, TPU, tel.: +7 (3822) 701-777 (ext. 2368), e-mail: timsn@tpu.ru, personal site: https://portal.tpu.ru/SHARED/t/TIMSN/eng