PhD COMPREHENSIVE EXAMINATION
NUCLEAR TECHNIQUES SYLLABUS

FUSION PLASMA PHYSICS

1. Concepts of fusion power generation

Nuclear physics basics for fusion power: reactions, cross sections, fuel cycle, concept of thermonuclear fusion. Comparison of the concepts of peaceful thermonuclear power (inertial and magnetic confinement).

Main types of plasma diagnostics, related physical phenomena: plasma waves, plasma radiation, rate equations. Prominent fusion devices.

2. Magnetic confinement fusion technology

Magnetic confinement, motion of charged particles in a magnetic field. Geometry of the magnetic field in the various designs: linear device, stellarator, tokamak, RFP. Installation and main components of fusion devices. Plasma production, refueling, heating, plasma-wall relationship, current drive, course of an experiment.

Particle and heat transport in fusion plasmas. Instabilities important from the perspective of operation.

3. Theoretical fusion plasma physics

Definition and primary physical properties of a plasma. Formulation, properties and limit of applicability of the kinetic theory, the multi-fluid plasma model and magnetohydrodynamics; examples through applications.

MHD equilibrium, MHD stability, prominent plasma waves and their applications in magnetic confinement fusion devices.

MEDICAL PHYSICS

4. Teletherapy – photon and electron therapy

Principles of operation, design and characteristic parameters of radiotherapy treatment machines. Photon and electron beam calibration, dosimetry of small radiation fields. Devices and methods of metrology used in radiotherapy. Radiation design, the role of imaging, assessment of radiation treatment plans, plan quality indices, patient dosimetry. Equipment of image-guided radiotherapy, correction methods. Radiation protection of teletherapy treatment machines. Radiobiological characteristics of acute and late side effects induced by radiation, LQ model. Prevention of radiation accidents, quality assurance measurements and risk assessment.

5. HDR and LDR brachytherapy

Brachytherapy radiation techniques, properties of radiation sources, characteristics of afterloading treatments. Design, quality assurance and radiation protection of HDR devices, use of applicators. Characteristics, tools and radiation protection of LDR brachytherapy treatments. Role of imaging equipment in therapy. Radiobiology characteristics of HDR és LDR brachytherapy, acute and late side effects. Determination of the organs at risk and the planning target volume, radiation treatment planning techniques, dose prescription, methods of dose calculation. Prevention of radiation accidents, quality assurance measurements and risk assessment.

6. Medical imaging by ionizing radiation

Mathematics and algorithms of tomographic and planar image reconstruction: Radon and inverse Radon transform, ML-EM method, planar imaging procedures and image quality features. Diagnostic x-ray: sources, detectors, CT. Isotope diagnostics: radiation sources, design and detectors of the gamma camera, PET and SPECT, Anger principle, collimators. Parameters affecting image quality. Propagation of ionizing electromagnetic radiation in tissue, Monte Carlo methods with medical applications.

7. Medical imaging by non-ionizing radiation

Magnetic resonance imaging: basic concepts, ordering and relaxation of spins in an external magnetic field, T1 and T2 relaxation, Bloch equations, design and operation of an MRI machine, FID, pulse-echo and IR sequences, 3D MR imaging, effect and correction of chemical shift. EPI sequence, artifacts and their possible correction, dependence of the signal-to-noise ratio on the imaging parameters, noise statistics in real and k-space, contrasts. Parallel imaging techniques. Simultaneous multi-slice imaging, controlled aliasing, phase-constrained imaging, compressed sensing MRI, modern diffusion MRI. Diagnostic ultrasonography: sources and detectors, interaction of ultrasound with matter, tissue models, A-, B- and M-mode imaging, Doppler mode.

NUCLEAR METROLOGY AND RADIOANALYTICS

8. Radiation and particle sources

Phenomena of nuclear and atomic physics. Ion sources, particle acceleration by electrostatic and resonance methods, design and operation principles of linear and circular accelerators, beam handling, ion optics, storage rings, special accelerators for nuclear and atomic physical investigations, high-energy accelerators built for particle physics applications, synchrotrons and free-electron lasers for atomic physics and material structure investigations. Accelerators of prominent particle physics laboratories.

9. Detection of electromagnetic radiation and particles

Principles of detection and the corresponding interactions between electromagnetic radiation and matter, particles and matter. Physical options and technical implementations of the detection of neutrinos and neutrons. Gaseous ionization detectors, scintillators and semiconductor detectors, devices and their applications. Design and primary structural elements of electromagnetic radiation and particle spectrometers. Methods and possible applications of gamma, X-ray, beta and alpha spectrometry, pulse-shaping concepts (pulse shape discrimination, time of flight, coincidence, position sensitive detection, etc.) and electronic methods. Special semiconductor, superconductor and dosimetric detectors.

10. Radioanalytical methods

Principles of radioanalytics, its primary technical procedures, and its applications for the investigation of the chemical properties, composition and structure of materials and analysis of radioactive isotopes. Isotope effect, dating methods, chemical separation of isotopes. Analysis of naturally occurring and artificially produced radioactive isotopes. Application of radioanalytical and nuclear spectroscopic procedures in the nuclear industry and in nuclear plant operations: radioanalysis of coolants, sipping, investigation of fuel unit inhermeticity, control of radioactive waste and emissions.

Radiation protection

11. Radiation protection and its legislation

Biological effects of radiation. Interpretation of dose and dose rate from the standpoints of physics, metrology and biology, base and derived quantities, elements of the regulation of doses, measuring procedures of dose and dose rate. Types and methods of identification of radioactive substances leading to committed dose when incorporated inside the human body. Sources of natural and artificial radiation. Domestic and international legislation of radiation protection. Handling radiation sources. Radiation accidents. International legislation of the transportation of radioactive substances.

12. Pollution propagation and radioactive waste management

Components and sources of environmental radiation, sources of radioactive substances released into the environment. Propagation of radioactive substances in homogeneous and inhomogeneous environmental systems. Determination of the radioactivity of environmental samples by laboratory and *in situ* methods, radiation protection monitoring. Production and handling of radioactive waste, volume reduction, conditioning solutions, temporary and permanent storage of radioactive waste, investigation methods for the characterization of radioactive waste. Nuclear decommissioning.

NUCLEAR REACTOR PHYSICS

13. Nuclear physics

Properties of nuclei (nuclear radius, density, nuclear spin, quadropole and magnetic dipole moment, binding energy). Stability of nuclei, types of decay and their theoretical description, decay chains, interactions of radiation and matter. Description of nuclear models: Fermi gas model, liquid drop model, collective model. Yukawa model of nuclear forces, isospin. General properties of nuclear reactions, direct and compound nuclear reactions, resonances. Nuclear fission and fusion.

14. Reactor physics

Boltzmann transport equation and its analytical solution (Case method), diffusion approximation, basics of reactor kinetics, reactivity feedback, neutron noise methods, methods of reactivity measurement, theory of slowing down. S_n and P_l methods, finite difference and finite element discretization, process of reactor physics calculations (resonance self-shielding, cell homogenization). Reactor physics codes.

15. Thermal hydraulics

Materials used in reactors (structural materials, fuels, coolants) and their physical properties. Heat diffusion in reactor materials. Heat transfer in case of various coolants. Equations of hydraulics. Stationary description of the coolant channel in case of single- and two-phase flow. Boiling heat transfer, boiling crisis. Distribution of power and temperature in the active zone, operational limits. Thermal hydraulic system codes for nuclear reactors. Equations describing three-dimensional heat and fluid flow problems and their numerical solutions; CFD codes.

16. Monte Carlo particle transport methods

Fundamentals of Monte Carlo methods (pseudorandom numbers, sampling reactions, directions and free path lengths), their theory (solving integral equations using Monte Carlo methods, collision and path length estimators, reduction of standard deviation, adjoint Monte-Carlo) and practice (prevalent codes, typical applications).

17. Nuclear reactors and fuel cycle

Facilities of the fuel cycle (uranium mining, enrichment, fuel fabrication, spent fuel handling, reprocessing, permanent storage). Types and generations of nuclear power plants, thermal and fast reactors. Components of nuclear plants (containment system, power generation system, heat transfer circuit, safety systems, cooling, ventilation, controls). Behaviour of fuel throughout the burning cycle. Fast reactors in advanced nuclear fuel cycles (breeding, transmutation). Burnup calculations and fuel cycle simulations.

18. Operation and maintenance of nuclear reactors

Moderation and reactivity factors. Self-controlling properties of nuclear reactors. Changes in operational parameters during the campaign. Xe and Sm poisoning. Behaviour and monitoring of fuel units and the reactor vessel. Processes and detection of nuclear fuel damage. Nuclear reactor and its technological environment as a radiation source. Active zone monitoring, in-core and ex-core detectors. Instrumentation, diagnostics and operational measurements of nuclear reactors. Design of the control room.

19. Nuclear reactor safety

Domestic and international regulations of the safety of nuclear reactors. Basic safety principles for nuclear power plants. Design requirements, licensing. Design basis and its extension. Considerations and requirements for choosing the site. External and internal initial events. Deterministic and probabilistic safety assessments and their methods, tools. Risk-based or risk-informed design, principle of differentiation by safety in design. Considerations for the safe storage of spent fuel. Nuclear reactor accidents and their lessons, their effect on the progress of nuclear power.