NUCLEAR MEDICINE	
GENERAL INFORMATION	
Course coordinator	Professor Ivica Mihaljević, MD, PhD
Assistant/Associate	Assoc. Prof. Mario Štefanić, MD, PhD Asst. Prof. Tomislav Kizivat, MD, PhD Vlado Wagenhofer, MD, PhD Ivana Marić, MD, PhD Katica Mijatović, MD Hrvoje Delalić, MD Marija Kordić Brandić, MD
Study Programme	Integrated undergraduate and graduate university study of Medicine
Status of the course	Mandatory
Year of study, semester	4th year, 8th semester
ECTS	**2**
Workload (hours)	Lectures (12); Seminars (7); Exercises (11)
Expected number of students	70

COURSE DESCRIPTION

Course objectives

Mandatory course Nuclear medicine is set to provide students with knowledge and skills on the application of nuclear medicine diagnostic methods and therapeutic procedures in the clinical branch of nuclear medicine. The course enables the acquisition of theoretical knowledge of radiopharmaceuticals and the development of the ability to use the acquired knowledge in understanding the scintigraphic tests of functions and diseases of individual organs and organ systems using gamma-camera, single-photon emission tomography (SPECT), positron emission tomography (PET) and PET/CT. Special emphasis is on the scintigraphic tests of the heart, lungs and blood vessels, skeletal system, tests in gastroenterology, neurology, nephrology, urology and hematology, scintigraphic diagnosis of tumors and inflammatory diseases and on familiarizing students with therapeutic applications of radionuclides.

Students will acquire the knowledge of testing the endocrine gland functions using radionuclides, especially of thyroid, parathyroid and adrenal glands, and of determining hormone, antibodies and tumor markers concentrations in serum using radioimmunoassays and other *in vitro* methods.

A specific part of the course is dedicated to the clinical approach to diagnostics, drug, surgical and radioiodine treatment and monitoring of non-tumor and tumor thyroid diseases, which make up a significant part of clinical practice in nuclear medicine. In doing so, the students will acquire knowledge of the ultrasound and cytological tests of the morphology of thyroid and parathyroid diseases.

The course also covers the acquisition of knowledge of biological effects of excessive radiation on the organism, measurement of radioactivity and protection against ionizing radiation.

Enrolment requirements and entry competencies

General competences:
- principles of medical ethics and deontology and obligation to preserve the patient's privacy and dignity
- communication skills (dealing with patients, colleagues and other experts)
- the ability to define and correctly document relevant patient data
- principles of managing practice and career

- understanding the importance of scientific approach to the profession
- preparation of scientific papers for publication
- principles of evidence-based medicine
- fundamental sciences applied in nuclear medicine (anatomy, biochemistry, pathophysiology)

Special competences:

- - fundamental knowledge of radiochemistry (in vitro radioimmunoassay of hormones and other biochemically important substances in serum, plasma and urine)
- - fundamental knowledge of radiopharmacy (preparation and application of radiopharmaceuticals, methods of application, possible reactions to the application of radiopharmaceuticals and procedures in case of possible drug reactions)
- - principles of operation of the radionuclide generator and commercial kits for labeling of pharmaceuticals
- - gamma camera modes, types and parts of gamma cameras, including cameras for single-photon emission tomography and positron emission tomography
- - radionuclides and radiopharmaceuticals for *in vivo* diagnosis of metabolism disorders and functions of individual organs and organ systems
- - specific instrumentation in nuclear medicine
- - application of computer programs for the acquisition and analysis of analogue and digital data

- quality control of gamma cameras and other devices in nuclear medicine

- - handling, use and application of radionuclides in diagnostic and therapeutic procedures in
- ambulatory and hospital conditions

- assessment of indications, the implementation and interpretation of nuclear medicine diagnostic procedures
- treatment of diseases using radionuclides and radiopharmaceuticals according to the protocols of certain procedures in nuclear medicine
- other available imaging methods complementary to nuclear medicine procedures
- diagnostic and therapeutic procedures in benign and malignant thyroid diseases
- application of ^{131}I in the treatment of autonomic and autoimmune forms of hyperthyroidism and thyroid carcinoma
- clinical monitoring of patients treated for thyroid disease
- diagnostic procedures and treatment of thyroid-associated orbitopathy (TAO)
- diagnostics and types of parathyroid diseases
- thyroid ultrasound with a targeted cytological puncture
- bone densitometry
- kinetics of radioactive substances (biological/physical elimination half-life of radioactive substances from the organism, effective half-life)
- biological effects of ionizing radiation on the organism (acute and late effects of excessive radiation)
- patient and staff dosimetry in diagnostics and treatment (“internal dosimetry” X- and gamma rays and factors influencing absorbed doses)
- external and internal decontamination procedures
- establishment and treatment of disorders resulting from nuclear accidents, that is radionuclide contamination
- procedures for disposal of radioactive waste

Learning outcomes at the Programme level

1.2., 2.1., 2.2., 2.3., 3.1., 3.2., 3.3., 3.4., 3.5., 4.1., 4.2.

Learning outcomes (5-10)

Upon successful completion of the course Nuclear medicine, the student will be able to:

1. understand radionuclide generators and commercial kits for labeling pharmaceuticals; specify and explain the application of radionuclides and radiopharmaceuticals in *in vivo* diagnosis of

metabolic disorders and functional disorders of individual organs and organ systems, understand gamma camera modes and types and components of a gamma camera, specify the procedures for quality control of gamma cameras and labeling radiopharmaceuticals.

2. understand indications, performance methods and interpretation of individual nuclear medicine diagnostic procedures, understand and describe nuclear medicine diagnostic procedures for endocrine diseases: thyroid scintigraphy using ^{99m}Tc-pertechnetate and ^{131}I-iodine, whole-body scintigraphy using ^{131}I-iodine, three-phase parathyroid scintigraphy using ^{99m}Tc-MIBI (methoxyisobutylisonitrile) and adrenal medulla scintigraphy using ^{131}I-MIBG (metaiodobenzylguanidine)
3. understand and describe nuclear medicine procedures for diagnosis of heart disease: electrocardiography (including dynamic and pharmacological stress studies) and emergency procedures in cardiological nuclear medicine, apply the practical knowledge necessary for interventions in case of cardiorespiratory arrest (resuscitation procedures, airway access, blood circulation management, defibrillation, etc.), single-photon emission tomography (SPECT) of myocardial perfusion using ^{99m}Tc-tetrofosmin, radionuclide angiocardiography using ^{99m}Tc-pertechnetate, radionuclide ventriculography using ^{99m}Tc-PYP (pyrophosphate) labeled erythrocytes and single-photon emission tomography (SPECT) of sympathetic myocardial innervation using ^{123}I-MIBG (“AdreView”)
4. understand and describe the performance and interpretation of the results of perfuson lung scintigraphy using ^{99m}Tc-MAA (macroaggregated albumin), understand and describe nuclear medicine diagnostic procedures in bone diseases: static bone scintigraphy using ^{99m}Tc-MDP (methylene diphosphate) and three-phase bone scintigraphy, understand and describe nuclear medicine diagnostic procedures in gastrointestinal diseases: dynamic hepatobiliary scintigraphy using ^{99m}Tc-HIDA (dimethyliminodiacetic acid), two-phase single-photon emission tomography (SPECT) of vascular liver structures using ^{99m}Tc-PYP (pyrophosphate) labeled erythrocytes, lower GI tract bleeding scintigraphy using ^{99m}Tc-PYP (pyrophosphate) labeled erythrocytes and Meckel's diverticulum scintigraphy using ^{99m}Tc-pertechnetate, understand and describe nuclear medicine diagnostic procedures in brain diseases: dynamic and static brain scintigraphy using ^{99m}Tc-DTPA (diethylenetriaminepentaacetic acid) and single-photon emission computerized tomography (SPECT) of the brain using ^{123}I-ioflupane (DaTSCAN®), understand and describe nuclear medicine diagnostic procedures in kidney diseases and diseases of genitourinary tract: static renal scintigraphy using ^{99m}Tc-DMSA (dimercaptosuccinic acid), dynamic renal scintigraphy using ^{99m}Tc-MAG3 (mercaptoacetyltriglycine), diuretic dynamic renal scintigraphy using ^{99m}Tc-MAG3, captopril dynamic renal scintigraphy using ^{99m}Tc-MAG3, functional testing of movable kidneys, perfusion renal scintigraphy using ^{99m}Tc-pertechnetate, functional testing of a transplanted kidney using ^{99m}Tc-MAG3, direct radionuclide cystourethrography using ^{99m}Tc-pertechnetate, testicular perfusion scintigraphy using ^{99m}Tc-pertechnetate, understand and describe other nuclear medicine diagnostic procedures: radionuclide dacryocystography using ^{99m}Tc-pertechnetate, dynamic and static scintigraphy of salivary glands using ^{99m}Tc-pertechnetate, sentinel node scintigraphy using ^{99m}Tc-pertechnetate, lymphoscintigraphy of extremities using ^{99m}Tc-nanocoll, whole-body positron emission tomography (PET) using ^{18}FDG (fludeoxyglucose) and scintigraphy of somatostatin receptors (SSTR) in neuroendocrine tumors using ^{99m}Tc-tektrotyd
5. understand the treatment of benign thyroid diseases, understand the application of ^{131}I in treatment of autonomic and autoimmune forms of hyperthyroidism and thyroid carcinoma, understand the treatment of thyroid malignancies, describe the clinical monitoring of patients being treated for thyroid disease, understand the diagnostic procedures and treatment in thyroid orbitopathy (TAO), describe the diagnostic procedures for monitoring and evaluating

the success of radioiodine ablation in the treatment of differentiated thyroid carcinoma, when performing whole-body scintigraphy (WBS) using ^{131}I, and the application of exogenous TSH elevation by injecting recombinant human thyrotropin (rhTSH), understand the synergy between clinical parameters, morphological, functional and molecular methods in the diagnosis of thyroid disease, describe the diagnostics and state types of parathyroid diseases, understand the treatment of parathyroid diseases, describe densitometry and understand complementary techniques for osteoporosis diagnosis, and treatment of patients with metabolic bone disorders, understand indications, diagnostic and therapeutic procedures for clinical treatment of MEN syndrome

6. understand dynamic and static scintigraphic procedures for hyperfunctioning parathyroid tissue imaging and comparison of the use of different radionuclides and radiopharmaceuticals (^{201}Tl, ^{99m}Tc, ^{99m}Tc-MIBI, ^{18}FDG) for imaging of hyperfunctioning parathyroid glands and sensitivity of SPECT, PET and PET/CT diagnostic procedures in the detection of hyperfunctioning parathyroid glands, ectopic parathyroid glands, parathyroid carcinoma, distant metastases and assessment of the stage of the metastatic process, explain the treatment and monitoring of neuroendocrine tumors, especially medullary thyroid carcinoma, by using radiopharmaceutical methylguanidine (^{131}I-MIBG), somatostatin receptor (SSTR) scintigraphy using ^{111}In-DTPA-octreotide and ^{99m}Tc-tektrotyde in the diagnosis of tumors of neuroendocrine origin
7. understand the treatment of different diseases using radionuclides and radiopharmaceuticals, as well as other pharmaceuticals and drugs, and the administration of drugs in nuclear medicine procedures according to protocols of certain procedures
8. link other available diagnostic methods complementary with nuclear medicine procedures
9. understand the measures to protect staff, patients, visitors and the environment (contamination) from radiation, due to specific procedures for the application of open sources of ionizing radiation, understand patient and staff dosimetry, adverse effects of low doses of radiation on individual tissues and organs, risks of genetic damage induced by radiation, describe the measures to protect the population in the event of major nuclear accidents or terroristic attacks involving radioactive substances (e.g. ^{210}Po) and procedures for the care of lightly irradiated people

Course content

Radioactive tracers in biology and medicine: relationship between morphology and function. Nuclear medicine and its specificities. Discovery of radioactivity. Manufacture of artificial radioactive elements in nuclear reactors and cyclotrones. Isotopes in medicine. Nuclear medicine as an *in vivo* application of radioactive tracers. Development of nuclear medicine as a new medical specialty. Application of radionuclides in *in vivo* and *in vitro* diagnostics and treatment. Manufacture of radiolabeled compounds (radiopharmaceuticals). Development of a counter for measuring radioactivity and scintigraphy devices. Development of IT methods. Behavior of radioactive substances in the body. Discovery and George von Hevesy's Nobel Prize. Scintigrams. Simultaneous morphology tests and tests of organ and organ system functions. Definition of radionuclides and radiopharmaceuticals and body biodistribution mechanisms. Molecular nuclear medicine: labeling of complex compounds, receptors, specific monoclonal antibodies, precursors, metabolites and drugs.

Scintigraphy: devices, gamma camera, SPECT, computer processing of scintigrams and PET/CT. Physical basics of nuclear medicine. Basic types of radioactive decay (α-decay, isobaric and isomeric transition), metastable condition, interaction of α, β and γ rays with matter. Detection of radioactivity and detector efficiency. Gamma scintillation counter build. Anger model: scintillation crystals, photocathode and photomultiplier tube. Pulse analyzer, counter and visualization. Collimator: types, role and build. Planar and single-photon emission tomography, single-head and dual-head cameras.

Multi-crystal gamma camera, SPECT (single-photon emission computed tomography) camera and PET/CT (positron emission tomography/computed tomography) camera. Analogue and digital image, reconstruction algorithms and digital data analysis. Concept of parametric image and functional analysis.

Radiopharmaceuticals: manufacture and preparation of radionuclides (radiopharmaceuticals). Biodistribution mechanisms. Definition, classification and selection of radiopharmaceuticals. Properties of the ideal radiopharmaceutical and radionuclide. Quality control of radiopharmaceuticals. Routes of administration of radiopharmaceuticals and distribution mechanisms. Manufacture of radionuclides and radionuclide generator (^{99}Mo/^{99m}Tc): build and elution. Calculation and yield tables. Physical properties of the most commonly used isotopes in nuclear medicine. Radiolabeling, standard operating procedures in the preparation of radiopharmaceuticals. Synthesis of radiopharmaceuticals. ^{99m}Tc-labeled radiopharmaceuticals ^{131}I-labeled radiopharmaceuticals. Radiopharmaceuticals labeled with other radionuclides. Quality control of eluate and radiopharmaceuticals, chromatography. Protective equipment, dose calibrator. Laminar flow hood for the preparation of radiopharmaceuticals. Purchase and use permits, prescribed records, conditions for performing the activity and education required to work with open sources of ionizing radiation. Disposal of radioactive waste. Radiopharmaceuticals in nephrourology: (MAG3, DTPA, OIH, ECD, DMSA), in cardiology (^{201}Tl, MIBI and tetrofosmin), hepatology (IDA-derivatives and colloids), pulmonology (MAA, Technegas, aerosols and noble gases), neurology (HMPAO, ECD, IMP and ioflupane), osteology (diphosphonates), inflammatory diseases (^{67}Ga, monoclonal antibodies and leukocyte markers) and oncology (^{18}FDG). Properties and application of ^{131}I and ^{123}I. PET radionuclides. Therapeutic radionuclides and radioimmunotherapy.

Thyroid disease diagnostics and treatment: measurement of radioiodine accumulation, scintigraphy, ultrasound, cytology and radioiodine treatment. Devices for measuring the accumulation of radiopharmaceuticals: build, selection, radionuclide application and overview of indications. Imaging, radionuclide diagnostic methods: role of ^{99m}Tc and ^{131}I scintigraphy and accumulation measurements in the diagnosis and treatment of benign and malignant thyroid diseases. Thyroid scintigraphy using ^{131}I and ^{99m}Tc-pertechnetate: indications, contraindications, acquisition and dosimetry. Laboratory tests: FT4, FT3, TSH and TRH. Autoantibodies and tumor markers. Rational diagnosis of thyroid diseases and diagnostic algorithms. Thyroid ultrasound with targeted cytological puncture guided by ultrasound: device and examination techniques. B-mode imaging and echo probes. Doppler effect and application. Ultrasound image analysis basics and imaging of neck structures. Echographic imaging of normal thyroid, diffuse diseases, nodules and thyroid malignant tumors. Imaging of enlarged and pathologically altered lymph nodes. Imaging of enlarged parathyroid glands. Cytodiagnostics. Role of ultrasound in rational diagnosis of thyroid disease and parathyroid disease. Classification and etiology of hypothyroidism and hormone replacement therapy. Classification of hyperthyroidism and the most common etiological causes. Overview of indications and treatment selection guidelines. Pharmacological and radical treatment of immunohyperthyroidism. Radioiodine therapy in hyperthyroidism, toxic adenoma and toxic nodular goiter. Calculation methods of therapeutic activity of ^{131}I in benign and malignant thyroid diseases. Application techniques, standard operating procedures in radionuclide therapy, and release conditions for hospital discharge. Diagnosis and treatment of subacute thyroiditis. Diffuse and non-toxic goiter and endemic goiter. Salt iodization. Diagnostic algorithms for evaluation of nodular goiter and indications for radical treatment and PH verification. Principles of thyroid disease surgical treatment and the scope of resection. Principles of management, diagnostic processing and surgical treatment of suppurative thyroiditis.

Immunoassay and nonRIA in determining the concentration of hormones, antibodies and thyroid tumor markers. History, concept and principles of radioimmunoassay. Classification of RIA methods. Competitive and non-competitive RIA with derivatives and comparison with competitive methods. Sources of variability and quality control. Reference ranges and interpretation of results. Thyroid hormones: biosynthesis, serum transport, distribution and hypothalamic-pituitary axis. Free and total T4 and T3. Thyroid antibodies (TPOAt, TRAb, TgAt): epidemiology, functional, clinical and pathological importance, role in the diagnosis and prognosis of thyroid disease. Tumor markers in thyroidology: thyroglobulin, calcitonin and role in patient monitoring. Rational use of laboratory analysis of hormones, antibodies and tumor markers in the diagnosis of thyroid disease.

Nuclear medicine in cardiology and pulmonology: myocardial perfusion scintigraphy, radionuclide ventriculography and shunt detection. Functional aspects of diagnostics in nuclear cardiology with reference to perfusion, metabolism, viability and myocardial kinetics. Radiopharmaceuticals in perfusion scans (^{201}Tl-chloride, ^{99m}Tc-tetrofosmin, MIBI): preparations, activities, applications, dosimetry aspects and mechanisms of accumulation and redistribution of perfusion agents. PET perfusion agents: perfusion and myocardial metabolism in ischemic heart disease and concept of reversible and irreversible defect. Indications for myocardial perfusion scintigraphy, performance and imaging techniques, pharmacological and physical load. Acquisition protocols in the myocardial perfusion scintigraphy and redistribution of radiopharmaceuticals. Pharmacological testing. Planar, SPECT and gated-SPECT scintigraphy and image reconstruction. Importance of perfusion scintigraphy in the diagnosis of ischemic heart disease, prognosis and risk stratification before and after revascularization. Basic analysis of scintigram, reversible and irreversible defect, ischemia, scar and hibernation. Examination of myocardial metabolism. Viability and hibernation, role of ^{201}Tl and ^{18}FDG. Radionuclide ventriculography: methods of labeling and imaging of vascular spaces, principles of functional analysis of ventricular kinetics: analysis of ejection fraction, phase and amplitude images, systolic and diastolic function parameters. Types of shunt and performance. Analysis of P-V curve and segmental composition of the heart. *In-vitro* and *in-vivo* erythrocyte labeling. Planar and tomographic techniques, gated-ECG. Shunt detection using first pass analysis technique. L-R shunt curve analysis, normal result. Quantification of R-L and L-R shunt.

Perfusion and lung ventilation scintigraphy. Perfusion and ventilation lung scintigraphy: indications and importance of pulmonary thromboembolism (PTE). Perfusion and ventilation radiopharmaceuticals. Interpretation of results, concept and importance of matches and mismatches. Preparation of radiopharmaceuticals, activity and instrumentation. Comparison with alternative diagnostic techniques. Lung perfusion scintigraphy using ^{99m}Tc-MAA and microspheres. Radioactive gases (^{133}Xe, ^{81}mKr) and aerosols for lung ventilation scintigraphy. Aerosol generation. ^{99m}Tc-DTPA and ^{99m}Tc-Technegas. Mechanisms of distribution of radiopharmaceuticals and aerosol deposition. Acquisition protocols in lung perfusion and ventilation scintigraphy. Planar and SPECT scintigraphy. Basic scintigram analysis, V/P mismatch. PIOPED criteria. Characteristic features of PTE and COPD.

Nuclear medicine in gastroenterology and hematology: scintigraphy of esophagus, Meckel's diverticulum, liver, spleen, bile ducts, stomach and bleeding. Nuclear medicine diagnosis of infection/inflammation. Scintigraphy in gastroenterology. Esophageal scintigraphy: radiopharmaceuticals, clinical indications, preparation, imaging procedure, visual analysis and quantification. Scintigrams of normal esophageal transit, achalasia and diffuse spasms. Esophageal transit curves. Scintigraphy of gastroesophageal reflux: pathological GER scan in adults and GER scan in children – “milk scan”. Preparation, radiopharmaceutical, imaging procedure and analysis. Scintigraphy of Meckel's diverticulum: symptoms, clinical indications, radiopharmaceutical,

preparation, imaging procedure and description of the results. Problems in the scintigraphy of Meckel's diverticulum using ^{99m}Tc-pertechnetate. Liver scintigraphy using ^{99m}Tc-(S) colloid: clinical indications and site of accumulation. Normal liver scintigrams and "cold areas". Spleen scintigraphy: site of accumulation, radiopharmaceuticals and clinical indications. Hepatobiliary scintigraphy (^{99m}Tc-IDA): preparation, radiopharmaceuticals, site of accumulation, clinical indications, imaging procedure. Hepatocyte function and biliary drainage. Imaging of normal elimination of ^{99m}Tc-HIDA from liver parenchyma, scan of partial and congenital obstruction of d. choledochus, after the cholecystectomy, in obstruction of d. cysticus, determination of the EF of gallbladder and in biliary reflux. Gastric emptying scintigraphy: preparation, radiopharmaceuticals, imaging procedure, clinical indications, meal composition, single vs. dual radionuclide study, correction of attenuation, overlap, motion and analysis. Gastrointestinal bleeding scintigraphy: most frequent localizations of GI tract bleeding, localization of bleeding, symptoms, pathological results criteria, radiopharmaceuticals, imaging procedure and normal results. Characteristics of radiopharmaceuticals: ^{99m}Tc-(S) colloid and ^{99m}Tc-erythrocytes. Pathological findings of the upper and lower GI tract. False positive bleeding. Hepatic hemangioma scintigraphy using ^{99m}Tc-erythrocytes and ^{99m}Tc-HSA: imaging procedure, site of accumulation, sensitivity and specificity of the method, clinical indications, comparison of scintigram with ultrasound and CT results. Infection/inflammation scans: clinical indications, scintigraphy using ^{67}Ga-citrate, leukocytes labeled using ^{99m}Tc-pertechnetate, ^{99m}Tc-HMPAO or ^{111}In-oxide. Monoclonal At labeled using ^{99m}Tc-pertechnetate and ^{18}FDG-PET/CT. Other indicators for infection/inflammation detection: liposomes, nanocolloids, interleukins and radiolabeled antibiotic (^{99m}Tc-ciprofloxacin).

Nuclear medicine in nephrology and urology. Radiopharmaceuticals in nephrourology. Partial renal function: perfusion, plasma flow, GF, endocrine functions, clearance, ERPF and GFR. Pharmacokinetics and pharmacodynamics of tubular (^{99m}Tc-MAG3, OIH), glomerular (^{99m}Tc-DTPA) agents and cortical tubular mass agents (^{99m}Tc-DMSA). Preparations, activities and indications. Preparation of patients, application and acquisition. Dynamic diuretic scintigraphy. Renogram, clearance and intervention. Basic principles of renography: performance, type and analysis of the renogram curves. Static, dynamic and diuretic renal scintigraphy and clinical indications. Diagnosis of renovascular hypertension and captopril test. Rational diagnosis in pediatric nephrourology, significance of renal tubule scintigraphy. Vesicoureteral reflux. Recurrent urotract diseases in children. Active and passive VUR and grading. Direct and indirect radionuclide cystourethrography: radiopharmaceuticals, performance and results. Perfusion scintigraphy of the transplanted kidney. Acute tubular necrosis and transplant rejection. Testicular perfusion scintigraphy. Testicular torsion and acute epididymo-orchitis: characteristics and interpretation of results.

Nuclear medicine in neurology: brain scintigraphy, radionuclide cisternography, SPECT and brain PET/CT. Radionuclide brain tests: tumor diagnostics and inflammation. Static brain scintigraphy. Dynamic brain scintigraphy: radiopharmaceuticals and imaging procedure. Clinical indications: cerebral death, aneurysm, vascular malformations, metastases, abscess, tumors, hematoma and infarction. Representative lipophilic radiopharmaceuticals in regional cerebral blood flow studies (^{99m}Tc-HMPAO) and neuroreceptor analysis (D2R ligands). Diagnosis of cerebral death, extrapyramidal movement disorders (DAT). PET/CT radiopharmaceuticals. Preparations, activities and instrumentation. Brain SPECT studies: tumor viablity (^{201}Tl-chloride, ^{99m}Tc-DMSA), inflammation (^{67}Ga-citrate), perfusion (^{99m}Tc-HMPAO), dopamine and serotonin receptors (^{123}I-iodobenzamide), benzodiazepine receptors (^{123}I-iomazenil) and somatostatin receptors (^{111}In-octreotide). Brain PET/CT: perfusion (^{15}O-H_2O), metabolism (^{18}FDG, ^{11}C-glucose). Clinical indications. Normal brain perfusion scans in epilepsy, Alzheimer's disease, depression, CVI (ischemic), TIA and schizophrenia. Brain tumors: primary (supra and infratentorial) and metastases. Radiopharmaceuticals: ^{99m}Tc-MIBI

(^{201}Tl), HMPAO and ^{18}FDG. Tumor viability. Complementary morphological imaging methods (CT and MR). Radionuclide cisternography: radiopharmaceutical, hydrocephalus, localization of CSF leaks and subarachnoid cysts.

Radiation protection: dosimetry basics, biological effects of ionizing radiation, the effect of excessive radiation on the organism and medical procedures in case of excessive irradiation. Radiation exposure. What is ionizing radiation? Dosimetry and ALARA principle. Irradiation doses and dosimetry units: absorbed, equivalent and effective dose. Effects of equivalent radiation dose on humans. Post-irradiation events in the body (direct and indirect effects theory). Cell parts most susceptible to ionizing radiation. Exposure, internal and external contamination. Determinants of radiation effects. Cytogenetic analysis of chromosomal aberrations. Effects of radiation in biological matter. Interaction of radiation with matter. Tissues and organs most susceptible to ionizing radiation. Genetic mutations and chromosomal aberrations. Factors affecting biological damage caused by ionizing radiation. Effects of low doses of ionizing radiation: somatic, genetic, nonstochastic, stochastic effects and hormesis. Effects of excessive radiation on the organism. Local radiation injuries, acute and chronic radiodermatitis and treatment. Acute radiation syndrome (ARS): components, time dynamics, clinical manifestations, therapy and prognosis. Chronic effects of radiation. Diagnostic and therapeutic procedures in case of excessive irradiation or contamination. Radiation detectors, operating principles and application. Monitoring procedure. Working with monitors, contamination control and surface decontamination. Radiation protection for personnel. Decontamination of a wound and injured persons. Principles and methods of internal dosimetry. Dose assessment. Biological dosimetry methods. Procedures until arrival of the injured person to the hospital and hospital procedures. Procedures with excessively irradiated and contaminated persons in Clinical Department of Nuclear Medicine. Types of radiation injuries, acute local injuries and treatment. Method of treating radiation combined injuries. Organization of radiation protection. Psychological and economic aspects of the accident.

Nuclear medicine in bone tests and oncology: bone, joint and bone marrow scintigraphy. Osteotropic radiopharmaceuticals, biodistribution mechanism and performance procedures. Radiopharmaceuticals: diphosphonate preparations, ^{111}In- and ^{99m}Tc-HMPAO-labeled leukocytes, colloids. Radiolabeling protocols, pharmacokinetics and dynamics, instrumentation and dosimetry. Three-phase bone and joint scintigraphy. Demonstration of representative results: normal results, primary and secondary neoplasms, osteomyelitis and joint endoprosthesis. Skeletal scintigraphy using ^{99m}Tc-MDP, three-phase scintigraphy (early and dynamic scintigrams), normal and pathological findings. Skeletal SPECT. Clinical indications: primary bone tumors (benign and malignant), metastatic bone tumors, aseptic necrosis (Legg-Perthes disease), osteomyelitis (^{99m}Tc-HMPAO, ^{111}In-leukocytes, ^{99m}Tc-nanocolloid, 9^{9m}Tc- ^{111}in-human immunoglobulin – HIG, ^{67}Ga-citrate), fractures (stress fractures), Paget's disease, diffuse metabolic bone diseases (superscan), aseptic bone necrosis and joint diseases (inflammatory and non-inflammatory). ^{18}FDG-PET/CT in inflammations and bone tumors. Bone marrow scintigraphy, radiopharmaceuticals and clinical indications. Scintigraphy using labeled antibodies (immunoscintigraphy) and clinical indications.

Scintigraphy using gallium, labeled antibodies and receptor scintigraphy. Scintigraphy using ^{67}Ga-citrate and monoclonal antibodies (BW250/183), ^{67}Ga in diagnosis of fever of unknown origin, lymphoma and sarcoidosis. Receptor scintigraphy in oncology, neurology and psychiatry.

Compare nuclear medicine and other imaging methods (round table). Comparison of functional and morpho-radiological imaging methods, competitive alternatives, differences and complementarity. Fusion technologies in the rationalization of diagnosis: SPECT/CT, PET/CT, PET/MR and development directions in the area. Rational diagnostics, cost efficiency and effectiveness of

choice. Cooperation, education, division and organization of work in fusion imaging techniques. Role of functional and fusion imaging techniques in individualized medicine, therapy and prognosis.

Mode of teaching

Lectures, Seminars; Exercises

Student obligations

Students are required to attend classes regularly and to actively participate in all forms of instruction. For the successful conduction of seminars and exercises, a prior preparation of the student is required by studying the corresponding chapter in the textbooks. For exercises and laboratory work, the student must wear the prescribed work clothes (white coats). Classes are conducted at the prescribed time and it is not appropriate to enter the classroom after the professor. It is not allowed to bring food and drinks to the class and to enter or exit the classroom without a valid reason. During class as well as during exams, it is not allowed to use cell phones.

Monitoring student work *(alignment of learning outcomes, teaching methods, and grading)*

Teaching activity	ECTS	Learning outcome	Student activity	Assessment methods	Grade points	
					Min.	Max.
Attendance	0.1	1-9	Class attendance	Records	5	10
Practical work (exercises)	0.1	1-9	Studying for practical exam and class attendance	Task completion	5	10
Seminar paper	0.4	1-9	Writing a seminar paper	Presenting a seminar paper	10	20
Written exam	1	1-9	Continuous studying during classes	Written exam	20	30
Oral exam	0.4	1-9	Continuous studying during classes	Oral exam	10	30
Total	**2**				**50**	**100**

Attendance:
Students must attend at least 70% of all classes (lectures, seminars and exercises). A student who has been excused from more than 30% of every class can be referred by the professor to compensate for the absence by sitting for an exam. The exam will be administered by the professor who referred the student to compensate for the absence. The requirement for taking the final exam is the signature in the student's record book (indeks) proving the student's attendance.
Student work will be evaluated during classes and on the final exam. Students are evaluated numerically and descriptively: (insufficient (1), sufficient (2), good (3), very good (4), excellent (5). During classes, a student can earn a maximum of 100 points. Students can achieve a maximum of 40 points during different types of classes (Table 1). A student must pass the written essay in order to be eligible for the oral part of the exam. The final grade represents the sum of the points earned during classes and on the final exam.

Practical work (exercises):
11 clinical exercises will be held during the course, where a student can achieve a maximum of 10 points. A student can achieve 0.9 points during every clinical exercise. The evaluation of practical

work involves participation in individual clinical exercises for which attendance records are being kept.

Seminars:
7 seminars will be held during the course, where a student can achieve a maximum of 20 points through active participation. A student can achieve 2.8 points during every seminar.

Lectures:
By attending the classes, the student can achieve a maximum of 10 points. A student can achieve 0.8 points during every lecture.

Final exam:
A student who has attended classes and achieved a total of a minimum of 20 points from the exercises, seminars and lectures, and a minimum of 12 points on a written essay, is eligible for the oral part of the final exam.

The written part of the final exam comprises 20 five-choice questions having one correct choice. The minimum criteria for earning points is 60% of correctly answered questions. The points achieved on the written part of the final exam are converted into grade points according to the criteria provided in Table 1. Points achieved on the final exam are added to points earned during classes. If a student fails to meet the minimum criteria for the final test on the first exam date, they will retake the final exam on the next exam date, which also applies in the event of failing the oral part of the exam.

Table 1. Valuation of the written part of the exam

Percentages used in the valuation of the written part of the exam (%)	Points
65-69.99	12
70.00-74.99	16
75-79.99	18
80-84.99	20
85-89.99	22
90.00-94.99	24
95-100	30

Valuation of the written part of the final exam:
1 – 10 points: the answer meets minimum criteria
11 – 16 points: average answer with notable mistakes
17 – 24 points: very good answer with minor mistakes
25 – 30 points: exceptional answer

The final exam is mandatory and consists of the written and oral part. During the final exam, the student can achieve a maximum of 60 points – 30 points on the written part and 30 points on the oral part. The points achieved on the written part are converted into grade points according to the criteria provided in Table 1. Points achieved on the final exam are added to points earned during classes. If a student fails to meet the minimum criteria for the final exam on the first exam date, they will retake the final exam on the next exam date.

Formulation of the final grade
Points achieved in class are combined with points achieved on the final exam. The grading in the ECTS system shall be carried out by using absolute distribution, i.e. shall be based on the final

achievement and compared to the numerical system as follows:

A – excellent (5): 80-100 points
B – very good (4): 70-79 points
C – good (3): 60-69 points
D – sufficient (2): 50-59 points
E – insufficient (1): less than 49 points

Required reading (available in the library and through other media)

Title	Number of copies in the library	Availability through other media
1. Dodig D, Kusić Z. Klinička nuklearna medicina [Clinical Nuclear Medicine]. 2nd, revised and supplemented edition. Textbook. Zagreb, Medicinska naklada 2012	12	

Additional reading

1. Kusić Z. et al. Hipertireoza [Hyperthyroidism]. Zagreb: Medicinska naklada; 2016
2. Kusić Z. et al. Hipotireoza [Hypothyroidism]. Zagreb: Medicinska naklada; 2014
3. Dodig D, Huić D, Poropat M, Težak S. Nuklearna medicina u dijagnostici i liječenju bolesti kostiju i zglobova [Nuclear Medicine in Diagnosis and Treatment of Bone and Joint Diseases] Zagreb: Medicinska naklada; 2009
4. Solter M. Bolesti štitnjače - klinička tireoidologija [Thyroid Diseases - Clinical Thyroidology]. Textbook. Zagreb: Medicinska naklada; 2007
5. Biersack H-J, Grünwald F, editors. Thyroid cancer, 2nd ed. Berlin-Heidelberg: Springer-Verlag; 2005
6. Ell PJ, Gambhir SS, editors. Nuclear medicine in clinical diagnosis and treatment. 3rd ed. Edinburgh London New York Oxford Philadelphia San Francisco Sydney: Churchill Livingstone; 2004
7. Težak S, Ivančević D, Dodig D, Čikeš I. Nuklearna kardiologija i pulmologija [Nuclear Cardiology and Pulmonology]. Textbook. Zagreb: Medicinska naklada, 2005
8. Dodig D, Ivančević D, Popović S. Radijacijske ozljede: dijagnostika i liječenje [Radiation Injuries: Diagnostics and Treatment]. Zagreb: Medicinska naklada, 2002

Course evaluation procedures

The quality and success of the realization of the course are monitored through an anonymous student survey, which will include a student assessment of the quality of different classes and of the professors carried out by the Department of Nuclear Medicine and Oncology of the Faculty of Medicine Osijek. Also, competences will be monitored through the students' success at the end of the course. During the classes, records of the attendance of students in lectures, seminars and exercises will be used.

In addition, the quality of the teaching process will also be monitored by the implementation of a unified university student survey for the evaluation of professors established by the Senate of the Josip Juraj Strossmayer University of Osijek.

Note /Other

E-learning does not count towards course contact hours, but is being used in teaching and comprises links to various web pages, as well as video and audio materials available on web pages.