Ph.D. in RADIOPHYSICS SYLLABUS

Preamble:

The Ph.D. program in Radiophysics is designed to train scholars in the advanced principles of radiological sciences, focusing on the application of physics to medical imaging, radiation therapy, nuclear medicine, and radiation safety. It emphasizes both theoretical foundations and practical expertise to address challenges in healthcare and research domains. The program fosters interdisciplinary collaboration, innovation, and ethical practices in radiological applications.

Goals and Objectives:

Goals

- To develop a deep understanding of radiophysics principles and their applications in medical imaging, therapy, and safety.
- To equip scholars with the skills to conduct high-quality research and contribute to advancements in medical and radiation physics.
- To promote the use of radiation technologies in healthcare while adhering to international safety and ethical standards.

Objectives

- To provide comprehensive knowledge in anatomy, physiology, physics, and mathematics as they relate to radio physics.
- To cultivate expertise in radiation detection, dosimetry, and instrumentation.
- To enhance skills in therapeutic radiation physics and clinical medical imaging.
- To develop professionals capable of ensuring radiation safety in various environments.
- To produce innovative research that addresses contemporary challenges in radiological sciences.

Personality Development and Themes:

The program integrates professional and personal development to nurture communication, ethical reasoning, and collaborative skills, ensuring scholars emerge as leaders in the field. Workshops and activities on effective scientific communication, teamwork, and problem-solving are integral to the program.

Thematic Structure

THEME 1: BASIC ANATOMY & PHYSIOLOGY

Human anatomy: skeletal, muscular, circulatory, and nervous systems. Physiology: cellular functions, organ systems, and physiological mechanisms. Digestive system: Functions of mouth, tongue, teeth, esophagus, stomach, small intestine, large intestine, digestion and assimilation of carbohydrates, fats and proteins, gastric juice, pancreatic juice, function of liver and spleen, blood and circulatory system, blood and its composition, RBC and WBC, blood grouping, coagulation of blood, artery, vein, capillaries and heart structure and functions: Physiological properties of heart muscle, cardiac dynamics: EEG, blood pressure and its regulation. Respiratory, Reproductive and Excretory System: Physical laws of respiration: trachea, lungs and its functions, oxygen transport, nervous regulation of respiration, hormonal control over reproduction, kidney and its functions, water and electrolyte metabolism. Nervous System: Brain and spinal cord: its functions, central nervous system and autonomic nervous system functions, physiology of special senses of hearing, taste vision etc.

THEME 2: BASIC PHYSICS & MATHEMATICS

- Fundamentals of electromagnetism, quantum mechanics, and optics.Review of four-vector and lorentz transformation in four-dimentional space, electromagnetic field tensor in four dimensions and Maxwell's equations: microscopic and macroscopic forms (revision), conservation of the bound charge and current densities, E.M. waveequations in waveguide of the arbitrary cross section: TE and TM modes; Rectangular and circular waveguides, hybrid modes, concept of LP modes. Contravariant and co-variant four-vectors and their products, tensors of rank two and their differentiation, co-variant form of Maxwell's equations: four–potential and four current, E.M. field tensor: its curl and divergence.

Need for Quantum mechanics, revision; inadequacy of classical mechanics; Sequential Stern- Gerlach experiment, analogy with polarization of light, Time evolution and Schrödinger equation; the Schrödinger versus the Heisenberg picture, simple Harmonic oscillation, Schrödinger wave equation, One-dimensional problems, wells and barriers; Harmonic oscillator by Schrödinger equation and by operator method. Uncertainty relation of x and p, states with minimum uncertainty product; General formalism of wave mechanics; Commutation relations

- Mathematical techniques: linear algebra, calculus, and numerical methods.

Need for numerical methods, accuracy and errors on calculations - round-off error, evaluation of formulae, iteration for Solving x = g(x), initial approximation and convergence criteria, Newton-Raphson Method. matrices, inverse, orthogonal and unitary matrices, independent elements of a matrix, eigenvalues and eigenvectors, diagonalization, complete orthonormal sets of functions second order linear ODEs with variable coefficients. , arithmetic mean, properties of arithmetic mean, median, mode, geometric mean, harmonic mean, dispersion, standard deviation, root mean square deviation, standard error and variance.

- Properties of Atom and Nuclei

Nuclear mass, charge, size, binding energy, spin and magnetic moment, Isobars, isotopes and isotones; mass spectrometer (Bainbridge), Spin and parity. Nature of forces between nucleons, nuclear stability and nuclear binding.

Four basic interactions in nature and their relative strengths, examples of different types of interactions. Quantum numbers – mass, charge, spin, isotopic spin, intrinsic parity, hypercharge. Charge conjugation. Conservation laws. Classifications of elementary particles – hadrons and leptons, baryons and mesons, elementary ideas about quark structure of hadrons – octet and decuplet families.

THEME 3: RADIOLOGICAL PHYSICS

- Physics of ionizing and non-ionizing radiation.
- Radiation interactions with matter.

Interaction of electromagnetic radiation with matter, exponential attenuation, Thomson scattering, photoelectric and Compton process and energy absorption, pair production, attenuation and mass energy absorption coefficients, relative importance of various processes. interaction of charged particles with matter, classical theory of inelastic collisions with atomic electrons, energy loss per ion pair by primary and secondary ionization, dependence of collision energy losses on the physical and chemical state of the absorber, Cerenkov radiation, electron absorption process, scattering excitation and ionization, radiative collision, Bremmstrahlung: range energy relation, continuous slowing down approximation (CSDA), straight ahead approximation and detour factors, transmission and depth dependence methods for determination of particle penetration, empirical relations between range and energy, back scattering, passage of heavy charged particles through matter, energy loss by collision, range energy relation, Bragg curve, specific ionization, stopping power, Bethe Bloch Formula, interaction of neutrons with matter, scattering, capture, neutron induced nuclear reactions.

- Principles of X-ray generation, emission, and scattering.

Discovery, production, properties of X-rays, characteristics and continuous spectra, design of hot cathode X-ray tube, basic requirements of medical diagnostic, therapeutic and industrial radiographic tubes, rotating anode tubes, hooded anode tubes, industrial X-ray tubes, X-ray tubes for crystallography, rating of tubes, safety devices in X-ray tubes, ray proof and shockproof tubes, insulation and cooling of X-ray tubes, mobile and dental units, faults in X-ray tubes, limitations on loading, electric accessories for X-ray tubes, filament and high voltage transformers, high voltage circuits, half-wave and full-wave rectifiers, condenser discharge apparatus, three phase apparatus, voltage doubling circuits, currentand voltage stabilizers, automatic exposure control, automatic brightness control, measuring instruments: Measurement of kV and mA, timers, control panels, complete X-ray circuit, image intensifiers and closed circuit TV systems, modern trends.

THEME 4: RADIATION BIOLOGY

- Biological effects of radiation on living tissues.

Action of radiation on living cells, radiolytic products of water and their interaction with biomolecules, Nucleic acids, proteins, enzymes, fats, influence of oxygen, temperature, cellular effects of radiation, Mitotic delay, chromosome aberrations, mutations and recombinations, giant cell formation, cell death recovery from radiation damage-potentially lethal damage and sublethal damage recovery, pathways for repair of radiation damage. Law of Bergonie and Tribondeau. survival curve parameters, model for radiation action, target theory - multihit, multitarget - repair misrepair hypothesis, dual action hypothesis, modification of radiation damage, LET, RBE, dose rate, dose fractionation, oxygen and other chemical sensitizers, anoxic, hypoxic, base analogs, folic acid, and energy metabolism inhibitors, hyperthermic sensitization, radio-protective agents

- DNA damage and repair mechanisms and Radiation carcinogenesis and risk assessment.

Somatic effects of radiation, physical factors influencing somatic effects, dependence on dose, dose rate, type and energy of radiation, temperature, anoxia, Acute radiation sickness -LD 50 dose,effect of radiation on skin and blood forming organs, digestive tract – sterility and cataract formation, effects of chronic exposure to radiation, induction of leukaemia, radiation carcinogenesis, risk of carcinogenesis, animal and human data, shortening of life span, in-utero exposure, genetic effects of radiation, factors affecting frequency of radiation induced mutations, dose-effect relationship, first generation effects, effects due to mutation of recessive characteristic, genetic burden, prevalence of hereditary diseases and defects, spontaneous mutation rate, concept of doubling dose and genetic risk estimate. Side effects related to radiation and dose, acute & Late –monitoring and common management of side effects, information and communication

THEME 5: RADIATION SAFETY

- Radiation protection principles:

Radiation dose to individuals from natural radioactivity in the environment and man-made sources. basic concepts of radiation protection standards - historical background - international commission on radiological protection and its recommendations – The system of radiological protection-justification of practice, optimisation of protection and individual dose limits-adiation and tissue weighting factors, equivalent dose, effective dose, committed equivalent dose, committed effective dose – concepts of collective dose- potential exposures, dose and dose constraints – system of protection for intervention - categories of exposures – occupational, public and medical exposures - permissible levels for neutron flux - factors governing internal exposure - radionuclide concentrations in air and water - ALI, DAC and contamination levels. evaluation of external radiation hazards - effects of distance, time and shielding – shielding calculations - personnel and area monitoring - internal radiation hazards – radio toxicity of different radionuclides and the classification of laboratories – control of contamination – bioassay and air monitoring – chemical protection – radiation accidents – disaster monitoring

- Shielding design and environmental monitoring.

Planning of medical radiation installations – general considerations – design of diagnostic, deep therapy, telegamma and accelerator installations, brachytherapy facilities and medical radioisotope laboratories.Evaluation of radiation hazards in medical diagnostic therapeutic installations – radiation monitoring procedures - protective measures to reduce radiation exposure to staff and patients - radiation hazards in brachytherapy departments and teletherapy departments and radioisotope laboratories - particle accelerators protective equipment - handling of patients waste disposal facilities - radiation safety during source transfer operations special safety features in accelerators, reactors.

- International guidelines and regulatory standards (IAEA, NCRP).

Safety and security of sources during storage, use, transport and disposal – security provisions: administrative and technical – security threat and graded approach in security provision national legislation – regulatory framework – atomic energy act – atomic energy (radiation protection) rules – applicable safety codes, standards, guides and manuals – regulatory control – licensing, inspection and enforcement – responsibilities of employers, licensees, radiological safety officers and radiation

workers – national inventories of radiation sources – import, export procedures Radiation accidents and emergencies in the use of radiation sources and equipment in industry and medicine - radiographic cameras and teletherapy units - loading and unloading of sources - loss of radiation sources and their tracing - typical accident cases. Radiation injuries, their treatment and medical management - case histories.

THEME 6: THERAPEUTIC RADIATION PHYSICS

- Linear accelerators and beam generation.

Radiation sources, natural and artificial radioactive sources, large scale production of isotopes, reactor produced isotopes, cyclotron produced isotopes, fission products, industrial uses, telecobalt and brachy Caesium sources, Gold seeds, tantalum wire, 125 I sources, beta ray applicators, thermal and fast neutron sources, preparation of tracers and labelled compounds, preparation of radio colloids. Particle accelerators for industrial, medical and research applications: the resonant transformer, Cascade generator, Van De Graff Generator, Pelletron, Cyclotron, Betatron, Synchro-Cyclotron linear accelerator, Klystron and magnetron, travelling and standing wave acceleration, Microtron, electron synchrotron, proton synchrotron, details of accelerator facilities in India. Discovery, production, properties of X-rays, characteristics and continuous spectra, design of hot cathode X-ray tube, basic requirements of medical diagnostic, therapeutic and industrial radiographic tubes, rotating anode tubes, hooded anode tubes, industrial X-ray tubes, X-ray tubes for crystallography, rating of tubes, safety devices in X-ray tubes, ray proof and shockproof tubes, insulation and cooling of X-ray tubes, mobile and dental units, faults in X-ray tubes, limitations on loading, electric accessories for X-ray tubes, filament and high voltage transformers, high voltage circuits, half-wave and full-wave rectifiers, condenser discharge apparatus, three phase apparatus, voltage doubling circuits, current and voltage stabilizers, automatic exposure control, automatic brightness control, measuring instruments: Measurement of kV and mA, timers, control panels, complete X-ray circuit, image intensifiers and closed circuit TV systems, modern trends.

- Dosimetry for radiation therapy.

Standards - primary and secondary standards, traceability, uncertainty in measurement. charged particle equilibrium (CPE), free Air Ion Chamber (FAIC), design of parallel plate FAIC, measurement of air kerma/ exposure. limitations of FAIC. bragg-gray

theory, mathematical expression describing bragg-gray principle and its derivation. burlin and spencer attix cavity theories. transient Charged Particle Equilibrium (TCPE), concept of Dgas, Cavity ion chambers, derivation of an expression for sensitivity of a cavity ion chamber. general definition of calibration factor. TRS 398. TRS398: ND, W, Q : ND, W :KQ,Q0 :KQ , Derivation of an expression for KQ,Q0. calorimetric standards – intercomparison of standard measurement of DW for external beams from 60Co teletherapy machines: reference conditions for measurement, type of ion chambers, phantom, waterproof sleeve, derivation of an expression for machine Timing error, procedure for evaluation of temperature and pressure correction: thermometers and pressure gauges. measurement of temperature and pressure. saturation correction: derivation of expression for charge collection efficiency of an ion chamber based on Mie theory. parallel plate, cylindrical and spherical ion chambers, Ksat , Two voltage method for continuous and pulsed beams, polarity correction. measurement of DW for high-energy photon beams from linear accelerators: Beam quality, beam quality index, beam quality correction coefficient, cross calibration. measurement of DW for high energy electron beams from linear accelerators: Beam quality, beam quality index, beam quality correction coefficient, cross calibration using intermediate beam quality. quality audit programmes in reference and non-reference conditions. standardization of brachytherapy sources - apparent activity - reference air kerma rate – air kerma strength - standards for HDR 192 Ir and 60 Co sources - standardization of 125 I and beta sources - IAEA TECDOC 1274 - room scatter correction. calibration of protection level instruments and monitors

- Advanced techniques: IMRT (Intensity-Modulated Radiation Therapy), stereotactic radiotherapy.

Networking in Radiotherapy - Medical image handling and formatting - DICOM - DICOM RT - Radiation Oncology information management system – Electronic record managements - Advanced Treatment techniques and calculations: IMRT, IGRT, VMAT, Adaptive RT – Various dose calculation algorithms - Dose Calculation in Homogeneous and heterogeneous Media – Superposition and Convolution Algorithms - Pencil Beam and Path Length Scaling - Collapsed Cone and Kernel Tilting – Monte Carlo calculations - Inverse plan optimization techniques – Plan Evaluation techniques and parameters for plan evaluation - Biological model based optimization, planning and evaluations - Pretreatment Online/Offline image guidance: Portal films - portal imaging

- Electronic portal imaging devices (EPID) - Type of EPIDs - 2D Image guided radiotherapy - 3D image guided radiotherapy - kV cone beam CT - MV Cone beam CT, In room CT and MRI and other offline/online image guidance techniques.

THEME 7: MEDICAL IMAGING AND NUCLEAR MEDICINE PHYSICS

- Principles of CT, MRI, PET, and SPECT imaging.

Basic principles – spin – processing – relaxation time – free induction decay – T1, T2 proton density weighted image – pulse sequences - basic and advance pulse sequences – MR instrumentation — image formation–localisation of the signal - factors influencing signal intensity- contrast and resolution - types of magnets – super conductors– RF transmitters –RF receivers – gradiant coils – RF shielding -MR spectroscopy – MR artifacts – safety aspects in MRI – QA test . basic principles, two dimensional imaging techniques, three dimensional imaging techniques - basic principles and problem, focal plane tomography, emission computed tomography, single photon emission computed tomography, positron emission tomography. Various image reconstruction techniques during Image formation such as back projection and fourier based techniques, iterativere construction method and their drawbacks. Attenuation correction, scatter correction, resolution correction, other requirements or sources of error

- Nuclear medicine imaging techniques.

In-vivo non-imaging procedures; thyroid uptake measurements, renogram, life span of RBC, blood volume studies, Life Span of RBC etc. general concept of radionuclide imaging and historical developments.

- Image reconstruction and quality assurance.

Spatial resolution, factor affecting spatial resolution, methods of evaluation of spatial Resolution, contrast, noise. NEMA protocols followed for quality assurance / quality control of imaging instruments. in-vitro technique: RIA/IRMA techniques and its principles. Physics of PET and cyclotron: principles of PET, PET instrumentations, annihilation coincidence detection, PET detector ad scanner design, data acquisition for PET, data corrections and quantitative aspect of PET, working of medical cyclotron, radioisotopes produced and their characteristics. treatment of thyrotoxicosis, thyroid cancer with I-131, use of P-32 and Y-90 for palliative treatment, radiation synovectomy

and the isotopes used. concept of delay tank and various waste disposal methods used in nuclear medicine. planning and shielding calculations during the installation of SPECT, PET/CT and medical cyclotron in the nuclear medicine department.

THEME 8: RADIATION DOSIMETRY & STANDARDIZATION

- Dosimetric quantities and units.

Radiation quantities and units, Radiometry, Particle flux and fluence, energy flux and fluence, cross section, linear and mass attenuation coefficients, mass energy transfer and mass energy absorption coefficients, stopping power, LET, radiation chemical yield, W value - dosimetry - energy imparted, absorbed dose, kerma, exposure, air kerma rate constant, charged particle equilibrium (CPE), relationship between Kerma, absorbed dose and exposure under CPE, dose equivalent, ambient and directional dose equivalents [(H*(d) and H'(d)], individual dose equivalent penetrating Hp(d), individual dose equivalent superficial Hs(d)

- Calibration of dosimetry equipment.

Dosimeters: Calorimeters - Ionization chambers: Free Air Chambers - Cylindrical chambers - Plane Parallel chambers - well-type chambers and Extrapolation chambers - Semi-conductor Dosimetry - Luminescence Dosimetry: TLD and OSLD – Film Dosimetry - Chemical dosimetry - Gel dosimetry - Diamond detectors – Scintillation Detectors - Detector arrays - Planar and volumetric dosimetry - Neutron dosimeters and Radiation Protection dosimetry: Pocket Dosimeters - Area Survey meters and Contamination Monitors.

- Dose measurement techniques and uncertainty analysis.

Concepts of description of ionizing radiation fields and its interaction with matter - Energy transferred - Net energy transferred and imparted - Kerma - Absorbed dose - Exposure – Concept of W value - Measure of activity and apparent activity - Air kerma rate constant - Reference air kerma rate – Quantities and units used in Radiation protection such as Equivalent Dose and Effective Dose. Charged particle equilibrium (CPE) - Transient CPE (TCPE) - Stopping power ratios. Cavity theories: Bragg Gray Cavity theory - Spencer Attix Cavity theory - Burlin cavity theory – Measurement of absorbed dose in a medium - General Guidelines on Radiation Dose Measurement - Characteristics of Radiation Dosimeters: Accuracy and precision - Stability - Dose

Linearity and Dose Rate Dependence - Energy dependence - Directional Dependence and Spatial Resolution

THEME 9: RADIATION DETECTORS AND INSTRUMENTATION

- Types of detectors: scintillation, ionization, semiconductor detectors.

Principles of radiation detection and measurement, basic principles of radiation detection, gas filled detectors, ionisation chambers, theory and design, construction of condenser type chambers and thimble chambers, gas multiplication, proportional and GM counters, characteristics of organic and inorganic counters, dead time and recovery time, scintillation detectors, semiconductor detectors, chemical systems, radiographic and radiochromic films, thermoluminescent dosimeters (TLD), optically stimulated luminescence dosimeters (OSLD), radiophotoluminescent dosimeters, neutron detectors, nuclear track emulsions for fast neutrons, solid state nuclear track (SSNTD) detectors, calorimeters, new developments. Dosimeters based on condenser chambers, pocket chambers, dosimeters based on current measurement, different types of electrometers, MOSFET, vibrating condenser andvaractor bridge types, secondary standard therapy level dosimeters, farmer dosimeters radiation field analyser (RFA), radioisotope calibrator, multipurpose dosimeter, water-phantom dosimetry systems, brachytherapy dosimeters, thermoluminescent dosimeter readers for medical applications, calibration and maintenance of dosimeters. instruments for personnel monitoring, TLD badge readers, PM film densitometers, glass dosimeter readers, digital pocket dosimeters using solid state devices and GM counters.

- Other detectors design and their calibration.

Teletector, industrial gamma radiography survey meter, gamma area (Zone) alarm monitors, contamination monitors for alpha, beta and gamma radiation, hand and foot monitors, laundry and portal monitors, scintillation monitors for X and gamma radiations, neutron monitors, tissue equivalent survey meters, flux meter and dose equivalent monitors, pocket neutron monitors, teledose systems. instruments for counting and spectrometry, portable counting systems for alpha and beta radiation, gamma ray spectrometers,multichannel analyser, liquid scintillation counting system, RIA counters, whole body counters, air monitors for radioactive particulates and gases. details of commercially available instruments and systems.

- Advanced instrumentation for radiological physics research.

THEME 10: CLINICAL ASPECTS OF MEDICAL IMAGING, THERAPY & NUCLEAR MEDICINE

- Clinical workflow in diagnostic radiology and radiation therapy.

Patient Registration, Simuation and Counselling. Treatment intent – Curative and Palliative, .Definition of OAR, OAR for different cancers, Immobilisation techniques and patient positions. Cancer prevention and public education and Early detection & Screening

- Patient-specific treatment planning and monitoring.

Patient management on treatment – side effects related to radiation and dose – Acute & Late – monitoring and common management of side effects – information and communication. Professional aspects and role of medical Physicists: General patient care – Principles of professional practice – Medical terminology – Research & Professional writing – patient privacy – Ethical and cultural issues. Legal aspects – Confidentiality, informed consent, Health and fsafety

- Case studies in clinical applications.