Post MSc DIPLOMA in RADIOLOGICAL PHYSICS (DipRP)

Programme Code: HLTH11

Programme Outcome:

- Apply principles of basic science concepts in understanding, analysis and predication
- To introduce interdisciplinary subjects/concepts/ideas for interdisciplinary application of Medical Physics and ionising radiation safety concepts.
- To introduce advanced ideas and techniques required in emergent area of Medical Physics and radiation safety in cancer care.
- To develop human resources with specialization in theoretical and experimental technique as well as radiation safety required for medical, industrial and research applications of ionizing radiation.
- Understand and apply principles of physics for understanding the medical physics and ionising radiation safety in healthcare.
- Understand and apply mathematical techniques for describing and deeper understanding of medical physics.
- Understand and apply statistical methods for describing the various radiological processes in radiation dosimetry and safety.
- Understand and apply interdisciplinary concepts and computational skills for understanding and describing the medical physics and radiation safety.
- Understanding basic safety standards for protection from the health hazard arising due to ionising radiation exposure.
- Provide in-depth knowledge and skill in various specialty of Radiological/ Medical Physics (radiation oncology physics, diagnostic and interventional radiology physics, nuclear medicine physics, and radiation protection).
- Provide in-depth knowledge and skill in standardization and calibration of medical equipment and for the accuracy of physical methods used in clinical applications and dosimetry, including physical measurements for evaluation of the dose delivered to the patient.
- Engage in research and life-long learning to adapt to changing healthcare practices.

DETAILED COURSE STRUCTURE

CORE COURSE				
Sr. No.	**Course Code**	**Subject Title**	**Lectures (Hours)**	**Credits**
1	01-HLTH11-601-C	Radiation Physics & Radiation Generators	60	4
2	01-HLTH11-602-C	Applied Mathematics	62	4
3	01-HLTH11-603-C	Radiation Dosimetry and Standardization	80	5
4	01-HLTH11-604-C	Radiation Detection, Measurement and Nuclear Instrumentation	62	4
5	01-HLTH11-605-C	Clinical Aspects and Radiation Biology	75	5
6	01-HLTH11-606-C	Medical Imaging and Nuclear Medicine	77	5
7	01-HLTH11-607-C	Radiation Therapy	85	5
8	01-HLTH11-608-C	Radiation Safety	75	5
Total			**576**	**37**

PRACTICALS				
Sr. No.	**Course Code**	**Subject Title**	**Hours**	**Credits**
1	01-HLTH11-601-P	Practical-I	60	2
2	01-HLTH11-602-P	Practical-II	63	2
TOTAL			**123**	**4**
FIELD TRAINING (6 weeks)			**150**	**5**
VIVA-VOCE (1 & 2) + Seminar			**-**	**-**
TOTAL			**846**	**46**

CORE COURSES

Radiation Physics & Radiation Generators [55 Lectures+5 Tutorials (60 hrs); 4 Credits] (01-HLTH11-601-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

- **Nuclear Physics**
  Nucleus-Scattering experiment, properties, Discovery of neutrons, Experimental determination of size of the nucleus etc. Nuclear forces- properties, spin dependence, charge independence etc. Liquid drop model-Binding energy, semi-empirical mass formula, mass parabola, application in stability of neutron star- Radioactivity – α decay - general properties of α particles, spectrum, Gamow's theory, Geiger-Nuttal law- Beta decay- general properties, Fermi theory, spectrum, fall of parity, neutrinos – Positron emission- Electron capture - gamma emission - Internal conversion - Laws of radioactivity - Laws of successive transformations and application in dating - Natural radioactive series - Radioactive equilibrium - Nuclear isomerism – Nuclear reactions - Artificial radioactivity - Elementary ideas of fission and its application in nuclear reactors and nuclear weapons – Fusion-energy production in the sun, production of elements in the universe-big bang and stellar nucleosynthesis.

- **Particle Accelerators**
  Historical development of particle accelerators; basic principles of charged particle acceleration; classification of accelerators as electrostatic, circular, and linear; relativistic effects in accelerator physics; fundamental beam dynamics including transverse and longitudinal motion, emittance, and phase space; principle and operation of the cyclotron and its limitation due to relativistic mass increase; concepts of the synchrocyclotron and the azimuthally varying field (AVF) cyclotron; principle of electron linear acceleration and design of accelerating structures; traveling-wave and standing-wave configurations in electron LINACs; RF cavities as accelerating resonators, and waveguides for RF power transmission and beam acceleration; particle sources including ion sources for protons and heavy ions and electron guns of thermionic and photocathode type with their injection systems and beam characteristics; RF power generation using klystrons, magnetrons, and solid-state amplifiers; principles of synchrotron and synchro-cyclotron acceleration; beam extraction methods such as electrostatic deflectors and magnetic kickers; systems for energy variation and selection; magnet systems in high-energy accelerators including dipoles, quadrupoles, and superconducting magnets; beam optics, transport lines, scanning magnets, and beamline design; and engineering aspects of vacuum systems required for stable accelerator operation.

- **X-ray Generators**
  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 shock proof tubes- Insulation and cooling of X-ray tubes - Mobile and dental units - Faults in X-ray tubes - Limitations on loading. Portable battery-operated X-ray generators.

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 – High frequency generator - 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.

- **Interaction of Radiation with Matter**

  Interaction of electromagnetic radiation with matter Exponential attenuation - Thomson scattering- Rayleigh Scattering- Photoelectric and Compton process and energy absorption - Pair production- Attenuation and mass energy absorption coefficients - Relative importance of various processes. - Concept of linear and mass attenuation coefficient – Energy dependence of coefficient - Build up factors and its dependence on energy.

  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 - Bremsstrahlung - 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- relativistic corrections – Basic concept of proton and other heavy ion therapy. Interaction of neutrons with matter - Sources of neutrons from different interactions- Basic idea of neutron spectra- Compound nucleus theory- Neutron cross-section- theory of elastic scattering- Neutron induced nuclear reactions.

Course Outcomes:

- Refresh the knowledge of nuclear and radiation physics
- Understand the concept of interaction of radiation with matter
- Understand the mechanism and technology of various particle accelerators used in medicine and research
- Understand the mechanism of X-ray generation and technology of X-ray equipment used in medicine, industry and research.

References:

1. K.S. Krane. Introductory Nuclear Physics, 2008.
2. J.S. Lilley, Nuclear Physics: Principles and Applications, 2013.
3. R. Eisberg and R. Resnick. Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles, 2014.
4. J. E. Turner. Atoms, Radiation, and Radiation Protection, 2022.
5. A. Beiser, S. Mahajan, S. Rai Choudhury. Concept of Modern Physics, 2020.
6. Tatjana Jevremovic. Nuclear Principles in Engineering, 2009.
7. J. T. Bushberg, J. A. Seibert, E. M. Leidholdt, J. M. Boone. The Essential Physics of Medical Imaging, 2021.
8. IAEA. Diagnostic Radiology Physics: A Handbook for Teachers and Students, 2014.
9. Rolf Behling. Modern Diagnostic X-ray Sources, 2021.

10. Wangler T.P. RF Linear Accelerators, 2008.
11. C. J. Karzmark, C.S. Nunan, E. Tanabe. Medical Electron Accelerators, 1993.

12. G. David, Williams P. C., Linear Accelerators for Radiation Therapy, 2017.
13. Barker R. J., Schamiloglu Edl. High power microwave sources and Technologies, 2001.

Applied Mathematics and Artificial Intelligence [54 Lectures + 8 Tutorials (62 hrs); 4 Credits] (01-HLTH11-602-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

Course Details:

- **Probability, Statistics and Errors**
  Probability - addition and multiplication laws of probability, conditional probability, population, variates, collection, tabulation and graphical representation of data.

  Basic ideas of statistical distributions frequency distributions, averages or measures of central tendency, arithmetic mean, properties of arithmetic mean, median, mode, geometric mean, harmonic mean, dispersion, standard deviation, root mean square deviation, standard error and variance, moments, skewness and kurtosis.

  Binomial distribution, Poisson distribution, Gaussian distribution, exponential distribution-additive property of normal variates, confidence interval & p-value, Bivariate distribution, Correlation & Regression, Chi- Square distribution, t-distribution, F-distribution, null hypothesis & alternate hypothesis with examples.

- **Numerical Methods**
  Why 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. Taylor series, approximating the derivation, numerical differentiation formulas. Introduction to numerical quadrature, Trapezoidal rule, Simpson's rule, Simpson's Three-Eighth rule, Boole rule, Weddle rule. Initial value problems, Picard's method, Taylor's method, Euler's method, the modified Euler's method, Runge-Kutta method.

- **Monte Carlo Methods**
  Random variables, discrete random variables, continuous random variables, probability density function, discrete probability density function, continuous probability distributions, cumulative distribution function, accuracy and precision, law of large number, central limit theorem, random numbers and their generation, tests for randomness, inversion random sampling technique including worked examples, integration of simple 1-D integrals including worked examples.

- **Basic Computational Programming and Artificial Intelligence**

  - **Python programming**
    Fundamentals of Python; Basic operators in Python; Working with Data - Data Types (Numeric, String, Set, List, Tuple, Dictionary); Operators in python; Python Keywords and Identifiers; Python program flow - If statement, Else statements, Range statement, While loop, For loop, Break, Pass, Continue etc.; Object and class; Python user defined and built-in Functions; Python Modules – Import statement and built-in; File manipulation – Open, close, write, read; Python arrays; Python packages for data science – Numpy and Matplotlib (in depth) - for data analysis and visualization; Handling of excel files using python library.

  - **Artificial Intelligence**

Historical background pertaining to the development of AI;
Logistic regression for predictive modeling -definition and interpretation of the logistic and logit function, Problem, data, model, fit, and evaluation for logistic regression;
Regression, classification and decision boundary definition - difference between regression and classification, converting problem between problem types, interpretation of output of model; Receiver operating characteristic (ROC) analyses - basic concept and interpretation, True positive, true negative, false positive, false negative, Type I and Type II errors, sensitivity and specificity, area under the curve (AUC))

Co-variance, correlation, regression, R2 – definitions, interpretations, analysis;
Machine learning categories - supervised learning, unsupervised learning, reinforcement learning, hybrid learning categories, semi-supervised learning, self-supervised learning);
Machine learning models and data analytics tools - Linear and logistic regression, neural networks, dimensionality reduction, support vector machine, decision trees and random forests, gradient boosting, K-means cluster analysis, metrics of evaluation);

Training and validation of machine learning models - mathematics of training, data augmentation, model selection and regularization, forward and backward stepwise predictor selection, ridge regression, LASSO, training methods, hyper parameter optimization, required sample size, bias-variance trade-off, over fitting, handling co-linearity of predictors (Variance inflation factor, VIF), model validation, cross-validation (K-fold, leave-one-out), bootstrap, generalizability, external validation, calibration;

Deep learning - deep learning and neural networks, convolutional neural networks, recurrent neural networks, long short-term memory (LSTM) networks, transformer networks, transformer networks for text, vision and swin transformer networks for image processing, generative adversarial networks - synthetic images; transfer learning, domain adaptation, augmentation, metrics of evaluation (DICE)

Data management - data collection including data retrieval, data quality assessment, data curation, anonymization and de-identification, labeling and segmentation, harmonization, standardization, robustness, overview of AI-based clinical applications, AI-related ethical issues.

Course Outcomes:

- Understand the theory of probability, counting statistics and errors with special reference to radiological/medical physics
- Application of Numerical methods and Monte Carlo simulation in radiation physics
- To strengthen the knowledge and skill in use of computational techniques and tools for solving the practical problems of radiological sciences

References:

1. J. D. Hoffman, S. Frankel. Numerical Methods for Engineers and Scientists, 2001.
2. M.T. Vaughn. Introduction to Mathematical Physics, 2007.
3. Band W. Introduction to Mathematical Physics, 2010.
4. Abhishek Singh. Essential Python for Machine Learning, 2023.
5. John Whittington. Python from the Very Beginning, 2023.

6. R.Y. Rubinstein and D.P. Kroese. Simulation and the Monte Carlo Method, 2016.

7. Oleg N. Vassiliev, Monte Carlo Methods for Radiation Transport, 2017.
8. W. L. Dunn and J. K. S. Shultis. Exploring Monte Carlo Methods, 2012.
9. M. H. Kalos and P. A. Whitlock. Monte Carlo Methods, 2008.
10. E. B. Podgorsak, Radiation Physics for medical physicists. 2006.
11. Gilmer Valdes, Lei Xing Artificial Intelligence in Radiation Oncology and Biomedical Physics 2023
12. Iori Sumida, Artificial Intelligence in Radiation Therapy, 2022
13. Issam El Naqa, Martin J. Murphy, Machine and Deep Learning in Oncology, Medical Physics and Radiology, 2022

Radiation Dosimetry and Standardization [75 Lectures + 5 tutorials (80 hrs); 5 Credits] (01-HLTH11-603-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

Course Details:

- **Radiation 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).

- **Radiation Sources**
  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 - 125I Sources - Beta ray applicators - Thermal and fast neutron sources - Preparation of tracers and labeled compounds - Preparation of radio colloids.

- **Dosimetry and Standardization of X- and Gamma Ray Beams**
  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 - NX, NK, ND, air, ND, W. Various steps to arrive at the expression for DW starting from NX. IAEA TRS 398 and TRS 483: ND, W, Q: ND, W: KQ, Q0: KQ, Derivation of an expression for KQ, Q0. Calorimetric standards - Intercomparison of standards.

  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 Programs in Reference and Non- Reference conditions.

Standardization of brachytherapy sources - Apparent activity - Reference Air Kerma Rate - Air Kerma Strength - Standards for HDR 192Ir and 60Co sources - Standardization of 125I and beta sources - IAEA TRS 492 - room scatter correction.

Calibration of Radiation Protection Instruments: Fundamental concepts of instrument calibration, Basic requirements for calibration, Various parameters checked during calibration, Selection of radioactive sources and source strength for calibration check.

- **Neutron Standards and Dosimetry**
  Neutron classification, neutron sources, Neutron standards - primary standards, secondary standards, Neutron yield and fluence rate measurements, Manganese sulphate bath system, precision long counter, Tissue Equivalent Proportional Counter (TEPC), Activation method. Neutron spectrometry, threshold detectors, scintillation detectors & multispheres, Neutron dosimetry, Neutron survey meters, calibration, neutron field around medical accelerators.

- **Standardization of Radionuclides**
  Methods of measurement of radioactivity - Defined solid angle and 4π counting - Beta gamma coincidence counting - Standardization of beta emitters and electron capture nuclides with proportional, GM and scintillation counters - Standardization of gamma emitters with scintillation spectrometers - Ionization chamber methods – Extrapolation chamber - Routine sample measurements- Liquid counter – Windowless counting of liquid samples - Scintillation counting methods for alpha, beta and gamma emitter - Reentrant ionization chamber methods - Methods using (n, γ) and (n, p) reactions - Determination of yield of neutron sources - Space integration methods - Solid state detectors.

- **Radiation Chemistry and Chemical Dosimetry**
  Definitions of free radicals and G-value-Kinetics of radiation chemical transformations - LET and dose-rate effects - Radiation Chemistry of water and aqueous solutions, peroxy radicals, pH effects - Radiation Chemistry of gases and reactions of dosimetry interest - Radiation polymerization, effects of radiation on polymers and their applications in dosimetry - Formation of free radicals in solids and their applications in dosimetry - Description of irradiators from dosimetric view point - Dosimetry principles Definitions of optical density, molar absorption coefficient, Beer- Lambert's law, spectrophotometry - Dose calculations - Laboratory techniques - Reagents and procedures - Requirements for an ideal chemical dosimeter - Fricke dosimeter - FBX dosimeter - Free radical dosimeter - Ceric sulphate dosimeter - Other high and low level dosimeters - Applications of chemical dosimeters in Radiotherapy and industrial irradiators.

Course Outcomes:

- Understanding of radiation quantities and units
- Detailed knowledge of various radiation sources including their production process application aspects
- Competency to perform absolute, reference and relative radiation dosimetry with various radiation generators and sources
- Knowledge and skill in dosimetry of neutron and standardization of radionuclides
- Understanding radiation chemistry and use of chemical dosimetry techniques

Reference:

1. Joseph Magill and Jean Galy. Radioactivity Radionuclides and Radiation, 2005.
2. IAEA TRS 374, Calibration of Dosimeters used in Radiation Therapy, 1994.
3. IAEA TRS 398, Absorbed Dose Determination in External Beam Radiotherapy, 2000.
4. IAEA TRS 483, Dosimetry of Small Static Fields Used in External Beam Radiotherapy, 2017.
5. IAEA TRS 492, Dosimetry in Brachytherapy, 2023.
6. P. Andreo, D.T. Burns, A.E. Nahum, J. Seuntjens, F.H. Attix. Fundamentals of Ionizing Radiation Dosimetry, 2017.
7. F. H. Attix. Introduction to Radiological Physics and Radiation Dosimetry, 2004.
8. J. W. T. Spinks, R. J. Woods. An Introduction to Radiation Chemistry, 1990.
9. A. Mozumder. Fundamentals of Radiation Chemistry. 1999.
10. Karl-Heinrich Beckurts, Karl Wirtz, Neutron Physics, 2013.

Radiation Detection, Measurement and Nuclear Instrumentation [57 L + 5 T) (01-HLTH11-604-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

Course Details:

- **Radiation Detection and Measurement**
  Principles of radiation detection and general properties of detectors: Principles of radiation detection, modes of detector operation, Pulse height spectra, Counting curves and plateaus, Energy resolution, Detector efficiency, Dead time, detector window.

  Gas filled radiation detectors: Various regions of operation of gas filled detectors - Ionization chambers, Proportional counters and GM counters - basic detection mechanism, types of radiation detected, mode of operation, different variants of detectors (e.g. sealed, flow type, high pressure, multi- wire, position sensitive), Types of instruments which uses gas filled detectors – radiation

  dosimeters, survey meters, contamination monitors - Cylindrical, plane parallel, spherical and well-type ionization chambers, Extrapolation chamber, Scintillation (organic/inorganic) and semiconductor detectors: Advantages of scintillation detectors, properties of ideal scintillator, basic electronic blocks in scintillation detector setup. Radiation detection mechanism of organic and in-organic scintillators, types of scintillators for various applications. Photon detection devices - PMT, Photo diodes. Principles of detection mechanism in semiconductor detectors and its application for gamma and alpha spectrometry, Diode and MOSFET dosimeters.

  Neutron detectors: Neutron detection by activation, Nuclear track detectors, Self-powered neutron detectors (SPND), BF3, He3, Bubble detectors.

  New types of detectors: Radiation detection by direct ion storage (DIS), OSL, Diamond, Gel dosimeter, Radiation litmus, Radiographic and radiochromic films. Micro dosimeters / Tissue

  Equivalent Proportional Counters (TEPCs), Fast response detectors for used in ultra-high dose rate (FLASH)-Plastic Scintillators & Cherenkov Detectors, Faraday Cup for absolute beam current measurement of electrons, protons, and heavy ions.

- **Nuclear Electronics and Instrumentation**
  Analog electronics: Operational amplifiers (ideal characteristics, different operational circuits - inverting, non-inverting amplifiers, adder, sub-tractor, integrator. Interfacing concepts: Fundamental concepts of interfacing an instrument to PC/Computer, interfacing methods.

  Power Supply: Low voltage and high voltage power supplies for radiation instruments, Generation of low and high voltages and their specifications, Types of batteries and their specifications.
  Basic building blocks used in nuclear measurements: Pre amplifiers, types of preamplifiers and selection of proper preamplifier for specific detector, Types of amplifier - linear, bias amplifier, log amplifier, shaping amplifier, Counters, rate meters - diode pump and IC rate meters, SCA, MCA, Coincidence and anti-coincidence circuit blocks.

Radiation Monitoring Instruments: Dosimeters based on condenser chamber, quartz fiber electrometer, dosimeter based on current measurement, secondary standard dosimeter, Farmer dosimeter, beam therapy dosimeter, clinical dosimeter, isotope calibrator, Radiation field analyzer (RFA).

Instruments for personal monitoring: TLD Reader for medical & research applications, TLD Badge Reader, OSLD badge reader, Image analyser for track counting, Densitometer, Electronic pocket dosimeter.

Area monitoring instruments: Portable and fixed area monitors, fixed area monitors, beta-gamma zone monitor, Survey meters, wide range survey instrument, teletector.
Contamination monitoring instruments: portable contamination monitor, hand &foot surface contamination monitor, portal monitor, laundry monitor, floor monitor.
Neutron monitoring instruments, REM counter.

Method of estimating activity present inside the body - whole body counter. Calibration of Radiation Protection Instruments: Fundamental concepts of instrument calibration, Basic requirements for calibration, Various parameters checked during calibration, Selection of radioactive sources and source strength for calibration check.

- **Counting and Medical Statistics**
  Statistics of nuclear counting - Application of Poisson's statistics - Goodness-of-fit tests - Lexie's divergence coefficients Pearson's chi-square test and its extension - Random fluctuations Evaluation of equipment performance - Signal-to-noise ratio - Selection of operating voltage - Preset of rate meters and recorders - Efficiency and sensitivity of radiation detectors - Statistical aspects of gamma ray and beta ray counting - Special considerations in gas counting and counting with proportional counters - Statistical accuracy in double isotope technique.

  Medical data, descriptive statistics – measure of central tendency - mean, median mode and percentile, Measure of dispersion – range, quartile deviation, standard deviation and coefficient of variation, Sampling techniques and sample size determination, Testing of hypothesis, Test of significance – level of significance, Calculation and interpretation of p value – statistical significance, correlation and regression analysis, sample size calculation, parametric and non-parametric tests.

- **Principles of Personnel Monitoring**
  Design aspects of x-ray, gamma ray and beta TLD personnel monitoring badge used in India – TLD Badge Reader - Occupational dose assessment procedures – audit of personnel monitoring laboratories - national occupational dose registry system. Occupational extremity dosimetry, Eye lens dose measurements. Neutron personnel monitoring in India – CR39 personnel monitoring badge – calibration and dose assessment procedure.

Course Outcomes:

- Understanding the principles of radiation detection and measurement instrumentation
- Working and operational principle of radiation detectors used for various types of radiation
- Electronics involved in various radiation detectors and its instrumentation
- Understanding and use of various radiation monitoring instruments

Reference :

1. P. Horowitz, W. Hill: Art of Electronics. 2015.
2. Serigo Franco. Design with Operational Amplifiers & Analog Integrated Circuits. 2017.
3. Texas Instruments Application Report SBOA092A: Handbook of Operational Amplifier Applications, 2016.
4. N. Widmer, G. Moss, R. Tocci. Digital Systems - Principles and Applications, 2022.
5. M. M. Mano, M. D. Ciletti. Digital Design-With an Introduction to the Verilog HDL, VHDL, and System Verilog, 2018.
6. IAEATECDOC-363. Selected topics in Nuclear Electronics, 1986.
7. Glenn F Knoll. Radiation Detection & Measurement, 2010.
8. A. Martin, S. Harbison, K. Beach, P. Cole. An Introduction to Radiation Protection, 2019.
9. J. E. Turner. Atoms, Radiation, and Radiation Protection, 2007.
10. N. Tsoulfanidis, S. Landsberger. Measurement and Detection of Radiation, 2021.

Clinical Aspects and Radiation Biology [68 L + 7 T) (01-HLTH11-605-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

Course Details:

- **Cell Biology**
  Cell physiology and biochemistry - Structure of the cell - Types of cells and tissue, their structures and functions - Organic constituents of cells - Carbohydrates, fats, proteins and nucleic acids - Enzymes and their functions - Functions of mitochondria, ribosomes, Golgi bodies and lysosomes - Cell metabolism- DNA as concepts of gene and gene action - Mitotic and meiotic cell division - Semi conservative DNA synthesis, Genetic variation ¬Crossing over, mutation, chromosome segregation - Heredity and its mechanisms.

- **Anatomy, Physiology and Pathology**
  Anatomy and physiology as applied to radiodiagnosis and radiotherapy - Structure & function of organs and systems & their common diseases: Skin, Lymphatic system, Bone and muscle, Nervous, Endocrine, Cardiovascular, Respiratory, Digestive (Gastro-Intestinal), Urinary, Reproductive, Eye and ear.

  Anatomy of human body, nomenclature & Surface anatomy, Radiographic Anatomy (including cross sectional anatomy - identify the different organs/ structures on plain x-rays, CT scans and other available imaging modalities. Normal anatomy & deviation for abnormalities.
  Tumour pathology and carcinogenesis, common pathological features of cancers and interpretation of clinico-pathological data.

- **Interaction of Radiation with Cells**
  Action of radiation on living cells - Radiolytic products of water and their interaction with biomolecule- 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 – Cultured cell line and animal experimentation methods for assessing radiation damage – Oxygen enhancement ratio – Dose modifying factors.

- **Biological Effects of Radiation**
  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 – Concept of projection models and risk estimation - 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 characteristics- Genetic burden - Prevalence of hereditary diseases and defects - Spontaneous mutation rate - Concept of doubling dose and genetic risk estimate.

- **Clinical Aspects of Medical Imaging & Radiation Oncology**

  Radiation Therapy, Surgery, Chemotherapy, Hormone Therapy, Immunotherapy & Radionuclide therapy, Benign and malignant disease, Methods of spread of malignant disease, Staging and grading systems, Treatment intent - Curative & Palliative, Cancer prevention and public education and Early detection & Screening.

  Site specific signs, symptoms, diagnosis and management: Head and Neck, Breast, Gynaecological, Gastro-Intestinal tract, Genito-Urinary, Lung & Thorax, Lymphomas & Leukemias & Other cancers including AIDS related cancers.

  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 & cultural issues. Legal aspects - Confidentiality, Informed consent, Health and Safety.

- **Biological Basis of Radiotherapy**

  Tumour growth kinetics, Experimental model systems for studying radiobiology of radiotherapy, Physical and biological factors affecting cell survival, tumour re-growth and normal tissue response - Causes of clinical radioresistance, Hypoxia and reoxygenation in radiotherapy, Non-conventional fractionation scheme and their effect of re-oxygenation, repair, redistribution in the cell cycle, 4 Rs of radiotherapy, Rationales of Multiple fraction daily (MFD) and Continuous hyper accelerated fractionation (CHART) methods, New modalities of radiotherapy, High LET radiation therapy.

- **Time Dose Fractionation**

  Time dose fractionation - Basis for dose fractionation in beam therapy - Concepts for Nominal Standard Dose (NSD), Equivalent Single Dose (ESD), Roentgen equivalent therapy (RET) - Time dose fractionation (TDF) factors and cumulative radiation effects (CRE) - Gap correction, Linear and Linear Quadratic (LQ) models, LQ model for fractionated radiotherapy and concept of Biological Equivalent Dose (BED), BED for fractionated radiotherapy, Estimation of □/□ dose using clinical data, BED correction for gap, BED for brachytherapy, Concept of switching between treatment modalities, BED for MFD and CHART protocols, Concept of incomplete repair, correction for BED and normal tissue complication in MFD and CHART.

Course Outcomes:

- Knowledge of cell biology, human anatomy, physiology and tumour pathology
- Understanding of mechanism and outcome of interaction of radiation with human cells and associated biological effects
- Basic knowledge of clinical aspects of medical imaging and radiation oncology and detailed knowledge of biological basis of radiotherapy
- Thorough knowledge of dose fractionation in radiotherapy and time-dose models

Reference:

1. A. Waugh, A. Grant. Ross and Wilson Anatomy and Physiology in Health and Illness, 2022.
2. E. J. Hall, A.J. Giaccia. Radiobiology for the radiologist, 2018.
3. Edward L Alpen. Radiation Biophysics, 1998.
4. Hollinshead W.H., C. Rosse, P. Gaddum-Rosse. Text Book of Anatomy, 2008.
5. G. Gordon Steel. Basic Clinical Radiobiology, 2002.
6. Irene Harris. Clinical Aspects of Radiation Oncology, 2015.
7. Hasan Murshed. Fundamentals of Radiation Oncology: Physical, Biological and Clinical Aspects, 2019.

Medical Imaging and Nuclear Medicine [67 L+ 10 T); (01-HLTH11-606-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

Course Details:

- **Principles of X-ray Diagnosis and Imaging**

  Physical principle of diagnostic radiology: Interactions of X-rays with human body, differential transmission of x-ray beam, spatial image formation, visualization of spatial image, limitations of projection imaging technique Viz. superimposition of overlying structures and scatter, application of contrast media and projections at different angles to overcome superimposition of overlying structures.

  Radiography techniques: Prime factors (kVp, mAs and SID/SFD), influence of prime factors on image quality, selection criteria of prime factors for different types of imaging, different type of projection and slices selected for imaging, objectives of radio-diagnosis, patient dose Vs image quality.

  Filters: inherent and added filters, purpose of added filters, beryllium filter, filters used for shaping X- ray spectrum (K-edge filters: holmium, gadolinium, molybdenum).
  Scatter reduction: Factors influencing scatter radiation, objectives of scatter reduction, contrast reduction factor, scatter reduction methods; beam restrictors (diaphragms, cones/cylinders & collimators), grids (grid function, different types of stationary grids, grid performance evaluation parameters, moving grids, artifacts caused by grids, grid selection criteria), air gap technique.
  Intensifying screens: Function of intensifying screens, screen function evaluation parameters, emission spectra and screen film matching, conventional screens Vs rare earth screens Radiographic Film: Components of radiographic film, physical principle of image formation on film, double and single emulsion film, sensitometeric parameters of film (density, speed, latitude etc.), QA of film developer.

  Image quality: Image quality parameters; sources of un-sharpness, reduction of un-sharpness, factors influencing radiographic contrast, resolution, factors influencing resolution, evaluation of resolution

  (point spread function (PSF), line spread function (LSF), edge spread function (ESF), modulation transfer function (MTF)), focal spot size evaluation. QA of conventional diagnostic X-ray equipment: Purpose of QA, QA protocols, QA a test method for performance evaluation of x-ray diagnostic equipment. Digital x-ray imaging: Storage phosphor (computed radiography-CR) and DR systems, digital detector technology-indirect conversion digital detectors and direct conversion digital detectors.

  - **Fluoroscopy including interventional procedures**

    Equipments, fluoroscopic imaging chain components, detector systems, automatic exposure rate control, mode of operation, image quality and radiation dose in fluoroscopy.

  - **Mammography**

    Mammography equipment, screen-film mammography, digital mammography detectors, digital detector technology-indirect conversion digital detectors and direct conversion digital

detectors, digital breast tomosynthesis and three-dimensional imaging, QA of mammography equipments.

- **Computed Tomography**

  Principles of X-ray Computed Tomography, CT Generations, Reconstruction Algorithms, CT Equipment and Instrumentation: X-ray tube Design, Filtration, Collimation, Detectors. CT Numbers, Modes of CT Acquisition, Cardiac CT, Dual Energy CT, CT Angiography, CT Dosimetry, Image Quality Assurance tests for CT, CT Image Artefacts.

  Images in the Fourier Domain, Object Segmentation – Thresholding, K-means and Region Growing, Fil-tering: Edge Enhancement and Smoothing Filters, Edge Detection, 2D Morphological Operators. Image Registration: Rigid and Non-Rigid Techniques, Affine And Non-Affine Methods, Applications In Multi-Modality Imaging.

- **Nuclear Medicine & Internal Dosimetry**
  - **Fluoroscopy including interventional procedures**

    Introduction to Nuclear Medicine (NM), Unsealed Sources, Production of Radionuclide used in NM; Reactor based Radionuclides, Accelerator based Radionuclides, Photonuclear activation, Equations for Radionuclide Production, Radionuclide Generators and their operation principles. Production of radiopharmaceuticals from Short lived positron emitters, Various usages of Radiopharmaceuticals.

    In-vivo Non-imaging procedures; Thyroid Uptake Measurements, Blood Volume studies. Life Span of RBC, Blood Volume studies, Life Span of RBC, Renography, etc. General concept of Radionuclide Imaging and Historical developments.

    Radionuclide Imaging: Other techniques and Instruments; The Rectilinear Scanner and its operational principle, Basic Principles and Design of the Anger Camera / Scintillation Camera; System components, Detector System and Electronics, Different types of Collimators, Design and Performance Characteristics of the Converging, Diverging and Pin hole Collimator, Image Display and Recording Systems, Scanning camera, Limitation of the Detector System and Electronics.

    Digital Image Acquisition, Display and Processing Systems. Frame mode acquisition, List mode acquisition. Choice of Matrix size, Image Display systems, Different Imaging Techniques: Basic Principles, Planar / 2D Imaging Techniques. Static, Dynamic, Gated. 3D

    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, Iterative Reconstruction method and their drawbacks. Attenuation Correction, Scatter Correction, Resolution Correction, Artifacts or Sources of Error.

    Image Quality Parameters: Uniformity, Spatial Resolution, Factor affecting Spatial Resolution, Methods of Evaluation of Spatial Resolution, Contrast, Noise, Recovery Coefficient. NEMA Protocols followed for Quality Assurance / Quality Control of Imaging Instruments.

    Physics of PET and Cyclotron: Principles of PET, PET Instrumentations, Annihilation

Coincidence Detection, PET Detector ad Scanner Design, Data Acquisition for PET, 2D/3D, Time of Flight imaging, Data corrections and Quantitative Aspect of PET, Working of Medical Cyclotron, Radioisotopes Produced and their characteristics.
In-vitro Technique: RIA/IRMA techniques and its principles.

Treatment of Thyrotoxicosis, Thyroid cancer with 131I, use of 32P and 90Y for palliative treatment, Radiation Synovectomy and the isotopes used. PRRT, applications of 177Lu & 225Ac. 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.

- **Internal Dosimetry**
  Bio distribution and kinetic analysis of radiotracer concentration, Compartmental Modelling, Single Compartmental Model, Two Compartmental Model with Back Transference, Two Compartmental Model without Back Transference. Catenary & Mammillary models.

  Classical Methods of Dose Evaluation; Beta particle Dosimetry; Equilibrium Dose Rate Equation, Beta Dose Calculation Specific Gamma Ray Constant, Gamma Ray Dosimetry, Geometrical Factor Calculation, Dosimetry of Low Energy Electromagnetic Radiation.

  Internal Radiation Dosimetry, MIRD Schema for Dose calculations; Basic procedure and some practical problems, Cumulative Activity, Equilibrium Dose Constant, Absorbed Fraction, Specific Absorbed Fraction, Dose Reciprocity Theorem, Mean Dose per unit Cumulative Activity and Problems related to the Dose Calculations. Limitation of MIRD Technique. individual dose calculations using Monte Carlo technique, Voxel based dosimetry.

- **Magnetic Resonance Imaging (MRI)**
  Physical principle of diagnostic radiology: Interactions of X-rays with human body, differential transmission of x-ray beam, spatial image formation, visualization of spatial image, limitations of projection imaging technique Viz. superimposition of overlying structures and scatter, application of contrast media and projections at different angles to overcome superimposition of overlying structures.

- **Ultrasound Imaging**
  Interaction of sound waves with body tissues, production of ultrasound - transducers – acoustic coupling- image formation - modes of image display - colour Doppler.

Course Outcomes:

- Understanding the process of X-ray based imaging using both conventional and advanced imaging systems such as digital X-ray imaging systems (radiography and mammography), dental imaging systems and computed tomography (CT) scanners
- Knowledge of working principles and use of open isotope-based imaging systems such as Gamma Camera, Single Photon Emission Tomography (SPECT), Positron Emission Tomography (PET)
- Understanding of the technology and use of medical cyclotron and Internal dosimetry techniques
- Concepts of magnetic resonance imaging (MRI) and ultrasound imaging in diagnosis of various types of cancer

Reference:

1. Carolyn A. MacDonald. An Introduction to X-Ray Physics, Optics, and Applications, 2017.
2. E. Bezak, A.H. Beddoe, L.G. Marcu, M. Ebert and R. Price. Johns and Cunningham's The Physics of Radiology, 2021 (5th Edition).
3. IAEA. Diagnostic Radiology Physics: A Handbook for Teachers and Students, 2014 (http://www-pub.iaea.org/books/IAEABooks/8841/Diagnostic-Radiology-Physics)
4. J. T. Bushberg, J.A. Seibert, E. M. Leidholdt Jr., J. M. Boone. The Essential Physics of Medical Imaging, 2020 (4th Edition).
5. W. R. Hendee, E.R. Ritenour. Medical Imaging Physics, 2002 (4th Edition).
6. S. C. Bushong, and G. Clarke. Magnetic Resonance Imaging, 2014 (4th Edition).
7. R. W. Brown, Y. Chung N. Cheng, E.M. Haacke, M. R. Thompson, R. Venkatesan. Magnetic Resonance Imaging: Physical Principles and Sequence Design, 2014.
8. C. Shah, M. Bradshaw, I. Dalal. Nuclear Medicine: A Core Review, 2021.
9. S. R. Cherry, J. A. Sorenson and M.E. Phelps. Physics in Nuclear Medicine. 2012.
10. H. A. Ziessman, J. P. O'Malley, J. H. Thrall. Nuclear Medicine: The Requisites (Requisites in Radiology), 2013.
11. Henry N. Wagner. A Personal History of Nuclear Medicine, 2006.

Radiation Therapy (75 L + 10 T) (01-HLTH11-607-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

Course Details:

- **Beam Therapy**

  Description of low kV therapy x-ray units. Construction and working of telecobalt units - source design - beam collimation and penumbra - trimmers and breast cones. Design and working of medical electron linear accelerators - beam collimation- asymmetric collimator - multileaf collimator - dose monitoring - electron contamination. Flattening filter free (FFF) beam, Output calibration of 60Co gamma rays, high energy x-rays and electron beams using IAEA TRS 398, AAPM TG 51 and other dosimetry protocols. Relative merits and demerits of kV x-rays, gamma rays, MV X-rays, and electron beams. Radiotherapy simulator and its applications. CT and virtual simulations.

  Central axis dosimetry parameters - Tissue air ratio (TAR) Back scatter/ Peak scatter factor (BSF/PSF)- Percentage depth doses (PDD) - Tissue phantom ratio (TPR) - Tissue maximum ratio (TMR) - Collimator, phantom and total scatter factors. Relation between TAR and PDD and its applications - Relation between TMR and PDD and its applications. SAR, SMR, Off axis ratio and Field factor. Build-up region and surface dose. Tissue equivalent phantoms. Radiation filed analyzer (RFA) and measurement capabilities, commercially available systems. Description and measurement of isodose curves/charts. Dosimetry data resources.

  Beam modifying and shaping devices - wedge filters - universal, motorized and dynamic wedges- shielding blocks and compensators. Treatment planning in teletherapy - target volume definition and dose prescription criteria - ICRU 50 & 62 - SSD & SAD set ups – 2 & 3-dimensional localization techniques - contouring - simulation of treatment techniques - field arrangements - single, parallel opposed and multiple fields - corrections for tissue inhomogeneity, contour shapes and beam obliquity - integral dose. Arc/ rotation therapy and Clarkson technique for irregular fields - mantle and inverted Y fields and extended/ magna fields. Conventional and conformal radiotherapy. Treatment time and Monitor unit calculations.

  Clinical electron beams - energy specification - electron energy selection for patient treatment - depth dose characteristics (Ds, Dx, R100, R90, R50, Rp etc.) - beam flatness and symmetry - penumbra - isodose plots - monitor unit calculations - output factor formalisms - effect of air gap/ virtual source position method on beam dosimetry - effective SSD. Hadron therapy - General concept, specifications of the equipment, beam calibration and dosimetry, immobilization, positioning and alignment systems, acceptance & commissioning, QA/QC, Record & verify, Networking, Oncology information system, Relative merits of proton, electron, neutron, heavy ions, x-ray and gamma ray beams - Neutron capture therapy - Heavy ion therapy, Preview of IMPT.

  Quality assurance in radiation therapy - precision and accuracy in clinical dosimetry - quality assurance protocols for telecobalt, medical linear accelerator and radiotherapy simulators - IEC requirements - acceptance, commissioning and. quality control of telecobalt, medical linear accelerator and radiotherapy simulators. Exit dosimetry/Portal and in-vivo dosimetry. Electronic portal imaging devices.

- **Brachytherapy**

Definition and classification of brachytherapy techniques - surface mould, intracavitary, interstitial and intraluminal techniques. Requirement for brachytherapy sources - Description of radium and radium substitutes - 137Cs, 60Co, 192Ir, 125I and other commonly used brachytherapy sources. Dose rate considerations and classification of brachytherapy techniques - Low dose rate (LDR), high dose rate (HDR) and pulsed dose rate (PDR). Paterson Parker and Manchester Dosage systems. ICRU 38, 58 & 89 protocols. Specification and calibration of brachytherapy sources – RAKR/AKS and Absorbed dose to water calibration - IAEA TRS 492 and ICRU 72 recommendations – Point and line source dosimetry formalisms - Sievert Integral - AAPM TG43/43U1 and other dosimetry formalisms, AAPM TG 186.

Afterloading techniques - Advantages and disadvantages of manual and remote afterloading techniques. AAPM and IEC requirements for remote afterloading brachytherapy equipment. Acceptance, commissioning, quality assurance, safety of remote after loading brachytherapy equipment. ISO requirements and QA of brachytherapy sources. advances in brachytherapy unit.

Brachytherapy treatment planning - CT/MR/USG based brachytherapy planning - GEC ESTRO recommendations - forward and inverse planning, normalization & optimization methods, plan evaluation, DICOM image import / export from OT - Record & verification. Brachytherapy treatment for Prostate cancer. Ocular brachytherapy using photon and beta sources. Intravascular brachytherapy - classification - sources - dosimetry procedures - AAPM TG 60 protocol. Electronic brachytherapy.

- **Radiotherapy Treatment Planning**

Scope of computers in radiation treatment planning - Review of algorithms used for treatment planning computations - Pencil beam, double pencil beam, Clarkson method, convolution superposition, lung interface algorithm, fast Fourier transform, Inverse planning algorithm, Monte Carlo based algorithms and equivalent dose calculation algorithms. Data acquisition & beam modeling, site specific planning.

Treatment planning calculations for photon beam, electron beam, proton and brachytherapy - Factors to be incorporated in computational algorithms. Plan optimization - direct aperture optimization - beamlet optimization - simulated annealing - biological optimization, multi-criterion optimizations, dose volume histograms - (qualitative and quantitative) dosimetry. Indices used for plan comparisons - Hardware and software requirements - beam & source library generation. Networking, DICOM and PACS, archieval and restore, big data management, role of cloud-based solutions. Acceptance, commissioning and quality assurance of radiotherapy treatment planning systems using IAEA TRS 430 and other protocols. Basic concept of AI for radiotherapy treatment planning and dosimetry.

- **Special and Advanced Techniques of Radiotherapy**

Special techniques in radiation therapy - Total body irradiation (TBI) - large field dosimetry - total skin electron therapy (TSET), Total Marrow Lymphoid Irradiation (TMLI) - electron arc treatment and dosimetry - intraoperative radiotherapy, AAPM and IAEA task group reports.

Stereotactic radiosurgery/radiotherapy (SRS/SRT) - cone and mMLC based X-Knife - Gamma Knife immobilization devices for SRS/SRT - including baseplate, masks (open/close), positioning devices and alignment devices -dosimetry and planning procedures - Evaluation of SRS/SRT treatment plans - QA protocols and procedures for X- and Gamma Knife units - Patient specific QA, Film dosimetry for SRS/SRT, various films available for QA, EBT and EBT-XD. Physical, planning, clinical aspects and quality assurance of stereotactic body radiotherapy (SBRT) and Cyber Knife based therapy. Preliminary concepts of ZAP-X solutions for SRS/SRT, IAEA TRS 483.

Intensity modulated radiation therapy (IMRT) - principles - MLC & compensator based IMRT - step

and shoot and sliding window techniques - Compensator based IMRT - planning process - inverse & forward treatment planning-immobilization, patient positioning, setup and alignment devices for IMRT - dose verification phantoms, dosimeters, protocols, ICRU 83, machine and patient specific QA, AAPM TG reports and protocols. Concept of Volumetric Modulated Arc Therapy (VMAT), Image Guided Radiotherapy (IGRT) - concept, definitions, protocols and recommendations, 4DCBCT/4DMVCT, gated CBCT, Hybrid Medical Linac: CBCT-Linac, MR-Linac, PET/CT-Linac for adaptive radiotherapy, Concept of Adaptive Radiotherapy-image registration, dose accumulation and adaptation, QA protocol and procedures - special motion management phantom, 4DCT, Ring gantry accelerators (Radixact, Halcyon, Tomotherapy) - principle - commissioning - imaging - planning and dosimetry - delivery - plan adaptation - QA protocol and procedures. Concepts of radiomics and dosiomics - principles of quantitative feature extraction from imaging and 3D dose distributions.

Surface guided/optically guided RT - concepts, mechanism, hardware, software, imaging techniques, Prospective & retrospective imaging and respiratory waveforms, integration with 4DCT, treatment planning system and treatment machine, phase based and amplitude-based gating, DIBH, DEBH, posture corrections, face recognition & safety, suitability for photons and protons, AAPM TG recommendations.

Course Outcomes:

- Understanding the technology and working principles of various beam therapy equipment such as Telecobalt machine, Medical electron linear accelerators (LINAC), and medical proton accelerator
- Understanding the technology and use of brachytherapy equipment, sources and techniques as well as dosimetry and treatment planning in brachytherapy
- Competence in medical radiation dosimetry, quality assurance of various radiotherapy equipment and use of computers in radiation treatment planning including optimisation and associated radiation safety
- Thorough knowledge and competence in applying special and advanced techniques of radiation therapy such as total body irradiation (TBI), total skin electron therapy (TSET), stereotactic radiosurgery/radiotherapy (SRS/SRT), stereotactic body radiotherapy (SBRT), intensity modulated radiotherapy (IMRT), image guided radiotherapy (IGRT), volumetric modulated radiotherapy (VMAT) and associated patient specific quality assurance

References:

1. E. Bezak, A. H. Beddoe, L.G. Marcu, M. Ebert, R. Price. Johns and Cunningham's the Physics of Radiology, 2021 (5th edition).
2. J. P. Gibbons. Khan’s The Physics of Radiation Therapy, 2019 (6th Edition).
3. T. Pawlicki, D. J. Scanderbeg, G. Starkschall. Hendee's Radiation Therapy Physics, 2016 (4th Edition).
4. Jacob Van Dyk. The Modern Technology of Radiation Oncology, Vol 1, 1999.
5. Jacob Van Dyk. The Modern Technology of Radiation Oncology, Vol 2, 2005.
6. Jacob Van Dyk. The Modern Technology of Radiation Oncology, Vol 3, 2013.
7. Jacob Van Dyk. The Modern Technology of Radiation Oncology, Vol 4, 2020.
8. D. Greene, P.C. Williams. Linear Accelerators for Radiation Therapy, 2017.
9. P.W. Sperduto and J. P. Gibbons. Khan’s Treatment Planning in Radiation Oncology (5th edition), 2021.
10. P. Xia, A. Godley, C. Shah, G. M.M. Videtic, J. Suh (Editors). Strategies for Radiation Therapy

Treatment Planning, 2018.
11. G.M.M. Videtic and N. M. Woody (Editors). Handbook of Treatment Planning in Radiation Oncology, 2014
12. T. Bortfeld, R. Schmidt-Ullrich, W. De Neve, D. E. Wazer. Image Guided IMRT, 2006.
13. D. Baltas, L. Sakelliou and N. Zamboglou. The Physics of Modern Brachytherapy for Oncology, 2006.
14. S. H. Levitt, J. A. Purdy, C. A. Perez and S. Vijayakumar. Technical Basis of Radiation Therapy Practical Clinical Applications, 2012 (4^{th} Revised Edition).
15. IAEA TRS 398, Absorbed Dose Determination in External Beam Radiotherapy, 2000.
16. IAEA TRS 483, Dosimetry of Small Static Fields Used in External Beam Radiotherapy, 2017.
17. IAEA TRS 492, Dosimetry in Brachytherapy, 2023.
18. ICRU Report 97: MRI-Guided Radiation Therapy Using MRI-Linear Accelerators, 2022
19. ICRU Report 93: Prescribing, Recording, and Reporting Light Ion Beam Therapy, 2016
20. ICRU REPORT 89: Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix, 2013.
21. ICRU Report 83: Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT), 2010.
22. ICRU Report 62: Prescribing, Recording and Reporting Photon Beam Therapy (Supplement to ICRU Report 50), 1999.
23. ICRU Report 50, Prescribing, Recording, and Reporting Photon Beam Therapy, 1993.

Radiation Safety [69 L + 6 T) (01-HLTH11-608-C)

Coordinators: Dr S.D Sharma
Email:sdsharma@barc.gov.in

Course Details:

- **Radiation Protection Standards**
  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 – Radiation and tissue weighting factors, equivalent dose, effective dose, committed equivalent dose, committed effective dose – Concepts of collective dose- Potential exposures, dose and dose constraints – Exposure Situations-Planned, Emergency and Existing Categories of exposures – Occupational, Public and Medical Exposures - Factors governing internal exposure - Radionuclide concentrations in air and water - ALI, DAC and contamination levels. Brief introduction to IAEA Safety Standards (Part 1 to7).

- **Principles of Monitoring and Protection**
  Evaluation of external radiation hazards - Effects of time, distance 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.

- **Safety in the Medical Uses of Radiation**
  Planning of medical radiation installations – General considerations – Design of diagnostic, deep therapy, telegamma, standard medical accelerator, Cyberknife, Halcyon, Tomotherapy, Proton Therapy Accelerator installations, brachytherapy facilities, Nuclear medicine (Gamma Camera, SPECT, PET, HDT) facilities, diagnostic radiology (General x-ray, CT, Cathlab, etc.) facilities.
  Evaluation of radiation hazards in medical diagnostic and 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.

- **Applications & Safety in the Industrial, Agricultural and Research uses of Radiation**
  Physical principles of industrial radiography - Comparison of X-¬ray radiography and gamma radiography - Choice of source - Industrial Gamma Radiography Exposure Devices and X-ray equipment for industrial radiography- Photographic film technique - Radiographic contrast Definition of sensitivity - Intensifying screens - Penetrameters.

  Industrial Fluoroscopy - Comparison of fluoroscopy and radiography - Image intensifier. Special techniques - Microradiography, flash radiography_ stereo - radiography - X-ray diffraction - Neutron radiography and electron radiography. Digital Radiography, Computed Radiography, Computed Tomography. Physical principles in the industrial application of radioisotopes - Use of sealed sources - Radioisotope and X-ray based gauges – Use of transmission and scattering gauges for measurement of thickness, density and composition - Level indicators - Bremsstrahlung gauges Beta

and gamma backscattering gauges and their applications - Neutron scattering gauges - Principles and applications of X-ray fluorescence techniques.

Applications in agriculture and research – Radioisotope tracer applications - General principles - Selection of radiotracer Dilution technique - Some examples of applications in agriculture, biology and research areas.Planning of radiation installations and isotope laboratories in industry, agriculture and research - Radiation protection measures and hazards evaluation in industrial and agricultural establishments - X and gamma ray radiography - X-ray diffraction apparatus - Radioisotope gauges - Tracer applications for radioisotopes in agriculture and industry Gamma chamber - Radiation sterilization - Irradiation of food and drugs - Radiation protection in Industrial Radiographic Installations - Enclosed, open top, open field and sky shine. Requirements and design of source storage facilities etc. Planning of gamma and electron irradiator facility.

Scanning facilities, X-ray baggage scanners, portable scanners, container scanners (radioisotope and X-ray based), Drive by and drive through modalities in container scanners, safety systems in container scanners. Planning of container scanner facility. Radiation Safety in Consumer products (Gas mental, lamp starter etc.) manufacturing facilities.Tritium and C-14 monitoring – Monitoring of Spillage - Contamination and control.

- **Radioactive Waste Disposal**
  Radioactive wastes – sources of radioactive wastes - Classification of waste - Treatment techniques for solid, liquid and gaseous effluents – Permissible limits for disposal of waste - Sampling techniques for air, water and solids – Geological, hydrological and meteorological parameters – Ecological considerations.Disposal of radioactive wastes - General methods of disposal - Management of radioactive waste in medical, industrial, agricultural and research establishments. Atomic Energy (radioactive Waste Disposal) Rules, 1987. Environmental impact assessment for discharge of radioactive wastes, interim storage, safe management of disused sources.

- **Transport of Radioisotopes**
  Planning Transportation of radioactive substances - - General packing requirements - Transport documents - Labeling and marking of packages - Regulations applicable for different modes of transport - Transport by post - Transport emergencies - Special requirements for transport of large radioactive sources and fissile materials - Exemptions from regulations – Shipment approval – Shipment under exclusive use – Transport under special arrangement – Consignor's and carrier's responsibilities types of transport package, category of package, TREM card, transport index.

- **Legislation**
  National legislation – Regulatory framework – Atomic Energy Act – Atomic Energy (Radiation Protection) Rules – Applicable Safety Codes, Standards, Guides and Manuals, relevant international standards such as IEC, ISO etc. – Regulatory Control – Licensing, Inspection and Enforcement – Responsibilities of Employer, Licensee, Radiological Safety Officer and Radiation Worker– IAEA Code of conduct-Import & Export of radioactive sources- Graded approach of regulation-Exemption, exclusion and clearance. AERB Safety Directives.

  Physical protection of sources – Categorization of radioactive sources, Safety and security of sources during storage, use, transport and disposal – Security provisions: administrative and technical – Security threat and graded approach in security provision, preparation of security plans for cat-1&2 sources.

- **Radiation Emergencies and their Medical Management**

Radiation accidents and emergencies in the use of radiation sources and equipment in industry and medicine -Industrial radiography devices, GIC, GRAPF etc. and teletherapy, Brachytherapy, Nuclear Medicine- Loading and unloading of sources in teletherapy, brachytherapy, GRAPF etc.- Loss of radiation sources and their tracing - Typical accident cases. Radiation injuries, their treatment and medical management- Case histories. Prophylaxis and decorporating agents.

Orphan and vulnerable sources, emergency handling accessories, emergency preparedness plan and its familiarization, estimation of doses while handling emergency situations, reporting emergency to regulatory body and other relevant authority.

Course Outcomes:

- Comprehensive knowledge of radiation protection standards and recommendations towards occupational and public safety
- Competence in radiation monitoring, evaluation of external/internal radiation hazard, assessment of safety status of a radiation facility and control of contamination
- Thorough knowledge of radiation safety in the medical uses of radiation which involves planning of medical radiation installations, evaluation of hazard and radiation waste disposal
- Understanding of applications and safety aspects of industrial, agricultural and research use of ionizing radiation such as industrial radiography, radio-tracers, planning of radiation installations and isotope laboratory, radiation protection measures and hazards evaluation in tritium monitoring
- Knowledge of the concepts of radioactive waste disposal like sources of waste including classification, treatment techniques of waste and disposal of used radiation sources and radiation generators
- Detailed knowledge in transportation of radioactive substances including packaging, documentation, shipment, emergencies and regulations
- Familiarization with National Legislations (acts, rules, standards, and guides) for the use of radiation in various applications
- Knowhow of radiation emergencies and their medical management

References:

1. H. Cember, T.E. Johnson. Introduction to Health Physics, 2008.
2. Atomic Energy Act 1962.
3. AERB Radiation Protection Rules 2004.
4. ICRP 60 Recommendations, 1990.
5. ICRP 103 Recommendations, 2007.
6. Shapiro J. Radiation Protection: A Guide for Scientists, Regulators and Physicians, 2002.
7. IAEA Safety Standards – General Safety Requirements Part 3:2014
8. Atomic Energy (Radioactive Waste Disposal) Rules, 1987.
9. J. V. Trapp and T. Kron. An Introduction to Radiation Protection in Medicine, 2008.
10. IAEA Safety Standards Series No. SSG-46: Specific Safety Guides - Radiation Protection and Safety in Medical Uses of Ionizing Radiation, 2018.

PRACTICAL

Practical-I (20 Experiments/ 3 h each:60hrs) (01-HLTH11-601-P)

Course Details:

1. Study of production and attenuation of bremsstrahlung radiation.
2. Study of absorption and backscattering of gamma rays in different materials
3. Measurement of range of beta particles by Feather analysis.
4. Study of backscattering of beta particles and its applications.
5. Study of voltage and current characteristics of an ionization chamber.
6. Calibration of survey meters and pocket dosimeters.
7. Familiarization with construction and testing of radiation protection monitors.
8. Calibration and cross calibration of cylindrical and plane parallel ionization chambers used in external beam therapy
9. Calibration of thermoluminescent dosimeter (TLD) and its use in radiation dose measurements.
10. Determination of plateau and resolving time of a G.M. counter and its application in estimating the shelf-ratio and activity of a beta source.
11. Output measurement of a gamma chamber using Fricke dosimeter
12. Calibration of a TLD personnel monitoring badge and evaluation of personnel doses.
13. Calibration of Gamma ray spectrometer [HPGe] and identification of unknown sources using multichannel analyser.
14. Determination of HVT and TVT in different materials for gamma rays.
15. Calibration of neutron personnel monitoring badge and personnel dose evaluation
16. Study of REM counter response with distance and energy of neutron source.
17. Assessing Deep Learning based segmentation in radiotherapy applications.
18. Radiation protection survey around neutron irradiation installation/facility
19. Measurement of reference output of megavoltage x-rays generated by medical electron linear accelerator
20. Measurement of output of high energy electron beams used in radiotherapy

Course Outcomes:

- Understanding radiation physics and mathematical concepts applied to radiological processes
- Construction, characterisation and calibration of various radiation detectors and use of spectrometry techniques in radiological physics
- Preparation, standardisation and uses of chemical dosimeters
- Preparation, standardisation and safety aspects of sealed/unsealed radiation sources

Practical-II (21 experiments/3 h each: 63h) (01-HLTH11-602-P)

Course Details:

1. QA of a medical diagnostic x-ray machine and radiation protection survey of its installation
2. Calibration and study with thyroid uptake probe
3. Radiation protection survey including air contamination measurement of high dose therapy facility
4. Measurement of reference output of a telecobalt machine used in external beam therapy
5. Measurement of total scatter factor of Co-60 gamma rays used in beam therapy
6. Measurement and analysis of PDD curve of high energy photon beams used in radiotherapy
7. Measurement and analysis of PDD curve of high energy electron beams used in radiotherapy
8. Measurement of source strength of HDR brachytherapy source using well chamber
9. Integrity test of a brachytherapy source
10. Study with contaminated surfaces and procedures for decontamination
11. Calibration check of a radiation survey meter
12. Radiation protection survey for an industrial radiography camera
13. Radiation protection survey of teletherapy installations
14. Analysis of patient specific QA plan for IMRT/VMAT
15. Measurement of shift in mechanical isocentre and its coincidence with radiation isocentre of a teletherapy machine
16. Measurement of inter- and intra-leaf transmissions of a multileaf collimator (MLC)
17. Quality assurance (QA) tests of a PET machine
18. Measurement of TG 43 dosimetry parameters of a brachytherapy source
19. 3DRCT/IMRT/VMAT treatment planning using a computerized RTPS
20. Radiation protection survey of a medical cyclotron
21. Imaging and dosimetry quality assurance of a computed tomography scanner.

Course Outcomes:

- Study and evaluation of parameters involved in X-ray diagnostic and associated radiation safety
- Practical knowledge of measuring the strength of open isotopes, thyroid uptake, patient monitoring and safety assessment of nuclear medicine imaging and therapy facilities
- Skill of radiation dose measurement in beam therapy, brachytherapy, and nuclear medicine
- Practical knowledge of architecture and capabilities of radiotherapy treatment planning systems
- Practical competence in radiation protection survey of various medical installations and safety assessment