MEDICAL/RADIOLOGICAL PHYSICS

PAPER 1

1. Radiation Detection and Measurements

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 scintillatior, basic electronic blocks in scintillation detector setup. Radiation detection mechanism of organic and in-organic scintillators, types of scintillators for various applications. Radiation detection by TLD. Photon detection devices - PMT, Photo diodes. Principles of detection mechanism in semiconductor detectors and its application for gamma spectrometry, Diode and MOSFET dosimeters. Neutron detectors: Neutron detection by activation, Nuclear track detectors, Self powered neutron detectors (SPND), BF_3, ^3He, Bubble detectors.

New types of detectors: Radiation detection by direct ion storage (DIS), optically stimulated luminescence detector (OSLD), Diamond, Radiographic and radiochromic films.

Radiation Monitoring Instruments: Dosimeters based on condenser chamber, quartz fibre 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, Densitometer, Digital 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

2. Radiation Dosimetry and Standardization

Absorbed dose - Kerma - Exposure - Air kerma rate constant - Charged particle equilibrium (CPE) – Relationship between Kerma, absorbed dose and exposure under CPE.

Standards - Primary and Secondary Standards, Traceability, Uncertainty in measurement. 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 D_{gas}, Cavity ion chambers, Derivation of an expression for sensitivity of a cavity ion chamber. General definition of calibration factor - N_X, N_K, $N_{D,air}$, $N_{D,W}$. IAEA TRS277: Various steps to arrive at the expression for D_W starting from N_X. TRS398: $N_{D,W,Q}$, $K_{Q,Q0}$. Derivation of an expression for $K_{Q,Q0}$. Calorimetric standards - Intercomparison of standard.

Measurement of Absorbed dose to water (D_W) for External photon and electron beams: Reference conditions for measurement, Type of ion chambers, Phantom, Waterproof sleeve, Determination of different correction factors such as $K_{T,P}$, K_{sat}, K_{pol}, etc. for continuous and pulsed beams, beam quality index and beam quality correction coefficient, Cross calibration.

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.

Neutron dosimetry, Neutron survey meters, calibration, neutron field around medical accelerators. 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.

Chemical dosimeters- Fricke dosimeter - FBX dosimeter - Free radical dosimeter – Ceric sulphate dosimeter Applications of chemical dosimeters in Radiotherapy.

3. Clinical and Biological Aspects

3.1 Clinical Aspects of Medical Imaging and 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.

3.2 Biological Basis of Radiotherapy and Time Dose Fractionation

Physical and biological factors affecting cell survival, tumour re-growth and normal tissue response - Non-conventional fractionation scheme and their effects, Effects of re-oxygenation, repair, redistribution in the cell cycle - High LET radiation therapy.

Time dose fractionation - Basis for dose fractionation in beam and brachytherapy - Concepts for Nominal Standard Dose (NSD), Roentgen equivalent therapy (RET) - Time dose fractionation (TDF) factors and cumulative radiation effects (CRE) - Gap correction, Linear and Linear Quadratic models.

4. Medical Imaging

4.1 Diagnostic Radiology

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, 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 radiodiagnosis, 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, grids.

Intensifying screens: Function of intensifying screens, screen function evaluation parameters, emission spectra and screen film matching, conventional screens vs. rare earth screens.

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

QA of conventional diagnostic X-ray equipment: Purpose of QA, QA protocols, QA test methods for performance evaluation of x-ray diagnostic equipment.

Mammography, Interventional radiology, digital radiography (CR and DR systems), digital subtraction techniques, Conventional tomography, orthopan tomography (OPG), Computed Tomography (CT), QA of CT equipment.

Magnetic Resonance imaging: Proton density, relaxation time T1 & T2 images – Image characteristics - MRI system components - Magnets, Magnetic fields, Gradients, Magnetic field shielding, Radio Frequency systems, computer functions – Imaging process – Image artifacts – MRI .

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

Planning and shielding calculations of diagnostic radiology facilities. Regulatory requirementsfor diagnostic radiology facilities.

4.2 Nuclear Medicine

Unsealed Sources, Production of Radionuclide used in Nuclear Medicine; Reactor based Radionuclides, Accelerator based Radionuclides, Photonuclear activation, Equations for Radionuclide Production, Radionuclide Generators and their operation principles. Various usages of Radiopharmaceuticals.

Imaging Techniques (In-vivo): Basic Principles, 2D Imaging Techniques, 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. NEMA Protocols followed for Quality Assurance / Quality Control of Imaging Instruments.
Physics of PET: Principles of PET, PET Instrumentations, Annihilation Coincidence Detection, PET Detector ad Scanner Design, Data Acquisition for PET, Data corrections and Quantitative Aspect of PET.
Non-imaging Techniques (In-vitro): Radioimmunoassay (RIA), ImmunoRadiometric Analysis (IRMA), Thyroid Uptake, Blood Volume Studies.
Treatment of Thyrotoxicosis, Thyroid cancer with I-131 Concept of Delay and Decay 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 Radiation Dosimetry: Single Compartmental Model and Two Compartmental Models with and without back transference, Beta particle Dosimetry, Beta Dose Calculation, Specifi Gamma Ray Constant, Gamma Ray Dosimetry, Geometrical Factor Calculation, Dosimetry of Low Energy Electromagnetic Radiation. MIRD Technique 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, Limitation of MIRD Technique.

5. Radiotherapy

5.1 Beam Therapy

Description of low kV therapy x-ray units - spectral distribution of kV x-rays and effect of filtration - thoraeus filter - output calibration procedure.
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. Output calibration of ^{60}Co 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. Scatter air ratio (SAR), Scatter maximum ratio (SMR), Off axis ratio and Field factor. Build-up region and surface dose. Tissue equivalent phantoms. Radiation filed analyzer (RFA). 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 and 62 - SSD and SAD set ups - two and three 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. Conventional and conformal radiotherapy. Treatment time and Monitor unit calculations.
Clinical electron beams - energy specification - electron energy selection for patient treatment - depth dose characteristics (D_s, D_x, R_{100}, R_{90}, R_{50}, R_p) - beam flatness and symmetry - penumbra - isodose plots - monitor unit calculations - output factor formalisms - effect of air gap on beam dosimetry - effective SSD. Particulate beam therapy - Relative merits of proton, electron, neutron, x-ray and gamma ray beams - Neutron capture therapy - Heavy ion therapy.
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. Portal and in-vivo dosimetry. Electronic portal imaging devices.

Planning and shielding calculations of beam therapy facilities. Regulatory requirements for beam therapy facilities.

*5.2 **Brachytherapy***

Definition and classification of brachytherapy techniques - surface mould, intracavitary, interstitial and intraluminal techniques. Requirement for brachytherapy sources - Description of radium and radium substitutes - ^{137}Cs, ^{60}Co, ^{192}Ir, ^{125}I 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). ICRU 38 and 58 protocols. Specification and calibration of brachytherapy sources – RAKR/AKS and Absorbed Dose to Water calibration - IAEA TECDOC 1274 and ICRU 72 recommendations – Point and line source dosimetry formalisms - Sievert Integral - AAPM TG-43/43U1 and other dosimetry formalisms.

Afterloading techniques - Advantages and disadvantages of manual and remote afterloading techniques. AAPM and IEC requirements for remote afterloading brachytherapy equipment. Acceptance, commissioning and quality assurance of remote after loading brachytherapy equipment.QA of brachytherapy sources. Integrated brachytherapy unit. Brachytherapy treatment planning - CT/MR based brachytherapy planning - GEC ESTRO recommendations - forward and inverse planning – DICOM image import / export from OT - Record & verification. Brachytherapy treatment for Prostate cancer. Ocular brachytherapy using photon and beta sources. Intravascular brachytherapy - classification - sources - dosimetryprocedures - AAPM TG 60 protocol. Electronic brachytherapy (Axxent, Mammosite, etc.). Planning and shielding calculations of brachytherapy facilities. Regulatory requirements for brachytherapy facilities.

*5.3 **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. Treatment planning calculations for photon beam, electron beam, and brachytherapy - Factors to be incorporated in computational algorithms. Plan optimization - direct aperture optimization - beamlet optimization - simulated annealing - dose volume histograms - Indices used for plan comparisons - Hardware and software requirements - beam & source library generation. Networking, DICOM and PACS. Acceptance, commissioning and quality assurance of radiotherapy treatment planning systems using IAEA TRS 430 and other protocols.

*5.4 **Special and Advanced Techniques***

Special techniques in radiation therapy - Total body irradiation (TBI) - large field dosimetry - total skin electron therapy (TSET) - electron arc treatment and dosimetry – intraoperative radiotherapy.

Stereotactic radiosurgery/radiotherapy (SRS/SRT) - cone and mMLC based X-Knife – Gamma Knife - immobilization devices for SRS/SRT - dosimetry and planning procedures – Evaluation of SRS/SRT treatment plans - QA protocols and procedures for X- and Gamma Knife units - Patient specific QA. Physical, planning, clinical aspects and quality assurance of stereotactic body radiotherapy (SBRT) and Cyber Knife based therapy.

Intensity modulated radiation therapy (IMRT) - principles - MLC based IMRT - step and shoot and sliding window techniques - Compensator based IMRT - planning process – inverse treatment planning - immobilization for IMRT - dose verification phantoms, dosimeters, protocols and procedures - machine and patient specific QA. Concept of Intensity Modulated Arc Therapy (IMAT e.g. Rapid Arc), Image Guided Radiotherapy (IGRT), and Volumetrically Modulated Arc Therapy (VMAT) - Imaging modality, kV cone beam CT (kVCT), MV cone beam CT (MVCT), image registration, plan adaptation, QA protocol.

PAPER 2

1.Radiation Protection Standards

Radiation dose to individuals from natural radioactivity in the environment and man-made sources, basic concepts of radiation protection standards, International Commission on Radiological Protection (ICRP) and its recommendations, categories of exposures, risk factors, international/national radiation protection standards- ICRP, BSS and AERB, overview of UNSCEAR recommendations, factors governing internal exposures, radionuclide concentrations in air and water and contamination levels, dose limits for occupational workers, general public, comforters and trainees.

2. Radiation Hazard Evaluation and Control

Internal and external radiation hazards, evaluation and control of external radiation hazards, individual and workplace monitoring, application of time, distance and shielding; shielding calculations, planning of medical radiation installations, shielding calculation parameters- workload (W), use factor (U), occupancy factor (T); primary and secondary protective barriers, design and shielding requirements for diagnostic X-ray facilities, telecobalt, medical accelerator, brachytherapy installations and medical radioisotope laboratories. Radiation monitoring instruments, calibration check monitoring instruments, radiation monitoring procedures for radiation generating equipment and installations, protective measures to reduce radiation exposures to patients and occupational workers, radiation hazards in radioisotope laboratories, protective equipment.

3. Disposal of Radioactive Waste

Radioactive wastes, sources of radioactive waste, classification of waste, treatment techniques for solid, liquid and gaseous effluents, permissible limits for disposal of waste, sampling techniques for air, water and solid; geological, hydrological, media meteorological and ecological considerations for waste disposal, decontamination procedures. Disposal of radioactive wastes, general methods of disposal, management of radioactive waste in medical, industrial, agricultural and research facilities.

4. Transport of Radioactive Material

Regulatory aspects of transport of radioactive material (RAM), introduction, terms used (e.g. Competent Authority, A1& A2 values, unilateral & multilateral approvals, special form radioactive material, special arrangement, transport index (TI) etc.), transport scenarios (routine, normal and accidental), variety of packages covered under the transport regulations (including designing, testing, transport and storage); general requirements of all packaging, requirements for transport by air mode, test requirements, preparation, marking, labeling of packages, preparation of transport documents (consignors declaration, TREM Card, instructions to the carrier & emergency preparedness in writing), responsibilities of consignor, general instructions and response to off-normal situations during transport.

5. Regulatory Aspects for Medical Radiation Facilities

National legislation, regulatory framework, relevant regulatory documents such as Act, Rules, applicable safety codes, standards, guides and manuals, radiation surveillance procedures, regulatory control-licensing, inspection and enforcement; responsibilities of employer, licensee, Radiological Safety Officer (RSO), technologist, radiation workers and radioisotope supplier. Physical protection of sources, safety and security of sources during storage, use, transport and disposal, regulatory requirements for import/export, procurement, use, handling, transfer and disposal of radioisotopes, inventory control, security provisions: administrative and technical measures, security threat and graded approach in security provision, Radiation Protection Programme (RPP).

6. Radiation Emergencies and Medical Management

Radiation accidents and emergencies in the use of radiation sources and equipment in radiotherapy, nuclear medicine and diagnostic radiology, radiation safety during source transfer operations, source stuck and handling procedures, loss of radiation sources, their tracing and recovery, case studies and lessons learned, Radiation injuries and medical management.

7. Emergency Response Plans and Preparedness

Normal and potential exposures, accident situations involving radioisotopes, elements of emergency planning and preparedness including procedures for notification and line of communication, administrative and technical procedures, emergency response accessories, responsibilities of employer, licensee, RSO, technologist, radiation workers and radioisotope/ equipment supplier in case of emergency.

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