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International Atomic Energy Agency

Postgraduate Medical Physics Academic Programmes

Endorsed by the International Organization for Medical Physics (IOMP)

VIENNA, 2013

TRAINING COURSE SERIES

56

POSTGRADUATE MEDICAL PHYSICS ACADEMIC PROGRAMMES

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2013

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Printed by the IAEA in Austria
December 2013

POSTGRADUATE MEDICAL PHYSICS ACADEMIC PROGRAMMES
IAEA, VIENNA, 2013
IAEA-TCS-56
ISSN 1018–5518
© IAEA, 2013
Printed by the IAEA in Austria
December 2013

FOREWORD

The safe and effective implementation of technology in radiation medicine requires expert medical physics support. In order to fulfil their duties, medical physicists working as health professionals should demonstrate competency in their area of specialization by obtaining the appropriate educational qualification and clinical competency training in one or more aspects of medical physics.

At the international level, there are very few established, accredited academic education programmes for medical physics students, and no international guidelines exist which provide the recommended requirements, outline and structure of such a programme. An increasing number of Member States with a ‘critical mass’ of medical physicists are seeking support to initiate their own national postgraduate education programmes. This publication, therefore, seeks to provide guidelines for the establishment of a postgraduate academic education programme in medical physics, which could also be used to achieve harmonized standards of competence worldwide. This publication was developed in support of the internationally harmonized guidelines given in IAEA Human Health Series No. 25 on the requirements for academic education and clinical training of clinically qualified medical physicists.

In addition to academic education, medical physicists should obtain specialized clinical training. The IAEA has published three Training Course Series publications with accompanying handbooks, which provide guidelines and references to training material for clinical training programmes for medical physicists specializing in radiation oncology (TCS-37), diagnostic radiology (TCS-47) and nuclear medicine (TCS-50).

Endorsement of this publication has been granted by the International Organization for Medical Physics (IOMP). The IAEA officer responsible for this publication was D. van der Merwe of the Division of Human Health.

CONTENTS

1. INTRODUCTION

Medical physics was classified as a profession by the International Labor Organization in 2011 [1]. The International Atomic Energy Agency (IAEA) International Basic Safety Standards Interim edition [2] specifically refers to the roles and responsibilities of the medical physicist in respect of medical exposure, patient protection and safety. In addition, specialized education, training and competencies are a requirement. The recognition of medical physicists remains however, a challenge in many regions [3].

An international survey of existing medical physics education programmes has shown that often physicists with little or no background in medical physics are working in the hospital environment as clinically qualified medical physicists [4]. The results of this survey and the recommended requirements for the academic education, clinical training and on-going re-certification of medical physicists are represented in Fig. 1, as published in recent International Atomic Energy Agency (IAEA) publications [4]. Several possible modes of faculty organization and content delivery are also presented in the publication from the International Organization for Medical Physics (IOMP) model curriculum project [5].

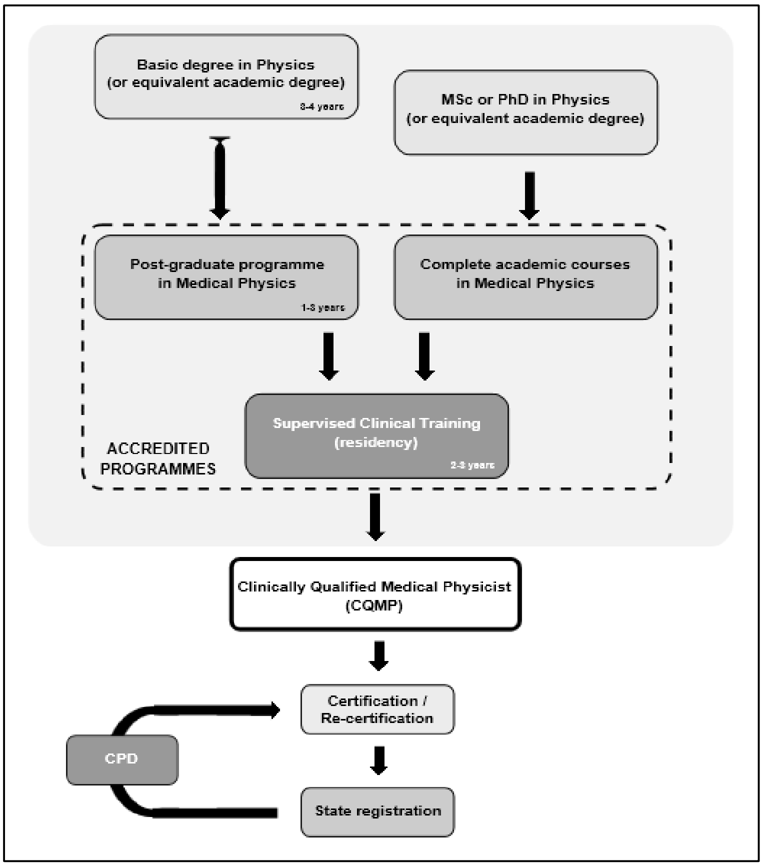

FIG. 1. The recommendations on minimum requirements for the academic education and clinical training of clinically qualified medical physicists [4]. Successful completion of accredited programmes as shown within the dashed line in the figure, equips a medical physicist with the necessary knowledge, skills and competence to provide a safe and effective medical physics clinical service.

The academic education programme in medical physics fundamentally prepares a student to enter a formal clinical medical physics residency [6-10]. It will also provide the student with the basic knowledge needed to embark on a career in the regulatory, industry, metrology, research and development or innovation through research sectors, for instance. On these broad foundations students are then able to build more advanced specialist studies in particular branches of medical physics depending on their aptitude and inclination. Further post-graduate studies would be necessary to pursue a purely academic career in medical physics.

An alternative route to enter the medical physics clinical training process for individuals already holding a post-graduate qualification (e.g. Masters or PhD) in physics, engineering or the equivalent, should ensure that the incumbent in addition take appropriate academic courses covering all the relevant specialties of medical physics. This could be arranged prior to or during the period of clinical training. It should also consist of full-time equivalent years, meaning that if the clinical training programme includes academic courses, the allocated time for the clinical training should be extended accordingly [4].

The major outcome therefore of the academic programme would be to provide students with a thorough grounding in the physiological basis, analytical methods and fundamental aspects of medical physics and instill an attitude of integrity, professionalism, critical-thinking and scientific rigor.

The programme should be hosted by an academic institution capable of awarding a Master's level and PhD post-graduate research degree in order to remain sustainable by offering academic career development pathways. This institution should however, be linked to a university teaching hospital complex, to ensure proper access to equipment for laboratory purposes and for the essential exchange with the clinical use of medical physics.

2. ADMISSION CRITERIA

The 3–4 year undergraduate degree of students entering a post-graduate medical physics academic programme should be in Physics or an equivalent relevant physical or engineering science. Because there are significant differences in the level and composition of tertiary education worldwide, it is often necessary for qualifications authorities to determine the local degree equivalence prior to student registration. For admission to the medical physics programme, it will in addition be necessary to interrogate the academic transcript of the degree and it is recommended that:

- At least 2 years of undergraduate level mathematics were completed successfully including:
    - Applied Linear Algebra
    - Advanced Calculus
    - Complex Variables
    - Differential Equations
    - Numerical methods

- The following physics topics should be covered during undergraduate study. If not, they should be completed prior to entry into the medical physics program:
    - Electricity and Magnetism
    - Atomic Physics/Nuclear Physics

- Quantum Mechanics
- Classical Mechanics
- Solid State Physics
- Modern Physics and Relativity
- Thermodynamics / Statistical Physics
- Signal Processing
- Physics of Fluids and Gases
- Optics
- Computational Physics/Computer Programming

The admission requirements for other individuals, who have already completed a graduate or post-graduate degree in any other field, should be the same. Generally universities have well-established autonomous criteria to recognize prior learning. If credit can be obtained for 67% of the medical physics core modules outlined in this document for instance, the award of a post-graduate certificate in medical physics may be appropriate. Likewise 33% credit may result in the award of a post-graduate diploma. It is recommended that completion of 100% of the core modules results in the award of a post-graduate medical physics degree.

3. INFRASTRUCTURE

3.1. ACADEMIC FACULTY

The academic faculty should include at least one instructor holding a PhD in the medical physics field. The lack of faculty with a PhD will most likely limit the ability of the institution to offer the course at a post-graduate level. Teaching is usually provided both by full time academic staff and by medical physicists and other health care professionals working in the health care sector. The structure should therefore include a formal link with a clinical medical physics department in a hospital setting with a teaching mandate. Ideally, an appropriate number of hospital-based, clinically qualified medical physicists should hold formal faculty appointments in the university department hosting the programme. Radiobiologists, clinicians and regulators may also assist in providing instruction of appropriate modules. In turn, the clinical staff could also hold reciprocal honorary academic contracts.

To attain sufficient depth and breadth of competencies the clinical department(s) supporting the programme should comply with the minimum staffing levels of medical physics in accordance with IAEA recommendations [11], national or international staffing guidelines.

3.2. FACILITIES

As part of the formal link between the academic institution or university and the hospital(s), there should be an agreement or Memorandum of Understanding (MOU) providing students with supervised access to clinical equipment. The clinical radiation oncology, radiology and nuclear medicine services that support the academic programme should be equipped with at least the basic resources required to commence a medical physics clinical training programme [7-9]:

- Radiation oncology services should have:
    - A teletherapy unit
    - A treatment planning system

    - A simulator (conventional and/or computed tomography (CT))
    - Dosimetry equipment, including a water phantom
    - Brachytherapy, and
    - Medical imaging services
- Radiology services should have:
    - General X ray units
    - Fluoroscopy X ray units
    - CT
    - Mammography unit, and
    - Dental units.
    - In addition it would be advantageous to have access to ultrasound units, a dual energy X ray absorptiometry (DXA) unit, a thermo luminescent dosimetry (TLD) system and a magnetic resonance imaging (MRI) unit.
- Nuclear medicine services should have:
    - A gamma camera, single photon emission computed tomography (SPECT) or SPECT/CT system
    - Dose calibrator, probes and counters
    - Phantoms and calibration sources
    - Survey meters and contamination probes
    - Nuclear medicine therapy services
    - In addition it would be advantageous to have access to positron emission tomography (PET) or PET/CT.

Because students will be exposed to the clinical environment, all local liability issues concerning equipment, health and safety, radiation safety and protection, professional, research and education ethics, and patient confidentiality issues need to be clarified in the MOU. In some countries, students will in addition need to register with a professional body in order to participate in any clinical activities.

Internet connectivity and access to computer workstations with basic computational software is important. Library access including electronic journal access, and the relevant reports and publications from the major medical physics international reference organizations is important (e.g. ICRU, ICRP, NCRP, AAPM, IAEA, NCS, IPEM, IOMP, etc.). The list of core reference textbooks associated with the recommended medical physics modules is given in the next section.

4. MEDICAL PHYSICS MODULES

The academic modules contained within the medical physics programme should aim at preparing a student to conduct research and to apply critical and innovative thinking to problem solving. At least a small research project should be included.

4.1. CORE MODULES

The core modules are provided below, including an outline of their content:

- Anatomy and Physiology as applied to Medical Physics
    - Anatomical nomenclature

        - Origin of anatomical names
        - Prefixes and suffixes
        - Anatomical position and body plane terminology
    - Structure, Physiology, Pathology, and Radiographic appearance (X ray, CT, MRI and nuclear medicine imaging) of:
        - Bones and bone marrow
        - Brain and Central nervous system (CNS)
        - Thorax
        - Abdomen
        - Pelvis
        - Respiratory, digestive, urinary, reproductive, circulatory, lymphatic, endocrine systems

- Radiobiology
    - Classification of radiation in radiobiology
    - Cell-cycle and cell death
    - Effect of cellular radiation, oxygen effect
    - Type of radiation damage (tissue, organ and whole body)
    - Cell survival curve
    - Dose-response curve
    - Early and late effects of radiation (deterministic, stochastic and teratogenic); effects on the developing embryo
    - Modelling, linear quadratic (LQ) model, α/β ratio
    - Fractionation, 2 Gy per fraction equivalent total dose (EQD_{2Gy})
    - Dose rate effect
    - Tumour Control Probability (TCP), Normal Tissue Complication Probability (NTCP), Equivalent Uniform Dose (EUD)
    - Tolerance doses and volumes, Quantitative Analysis of Normal Tissue Effects in the Clinic (QUANTEC) [12]
    - Normal and tumour cell therapeutic ratio
    - Radio-sensitizers, protectors

- Radiation Physics
    - Overview of Modern Physics
        - Historical overview
        - Atomic and nuclear Structure
        - Radioactive decay
        - Elementary quantum mechanics
    - Photon interactions
    - Neutron interactions
    - Charged particle interactions
    - Multiple scattering theories
    - Stopping power
        - Restricted, unrestricted

        - Linear energy transfer (LET)
    - Transport Equation
        - Charged particle slowing down
        - Continuous slowing down approximation (CSDA)
    - Introduction to Monte Carlo Techniques
    - Overview of Non-ionizing radiation physics

- Radiation Protection
    - Introduction, historical perspective and sources of radiation
    - Radiation protection detection and measurement (Geiger-Mueller (GM), proportional counters, scintillators, TLDs, ionization chambers, neutron detectors)
    - Exponential attenuation, half-value layer (HVL), inverse square law, tenth-value layer (TVL)
    - Shielding calculations
    - Operational dosimetry, e.g. equivalent dose, effective dose, etc. [12]
    - Legal framework for radiation protection [2]
    - Occupational, public exposure and annual limits
    - Emergency procedures
    - As low as reasonably achievable (ALARA) concept
    - Justification
    - Radioactive transport and waste management
    - Risk assessment and communication of risk

- Professional and Scientific Development
    - Ethics
        - Helsinki Agreement
        - Basis of clinical trials
        - Ethics review/committees
    - Professionalism
        - Clinical governance
        - Quality management
        - Code of conduct
        - Management of medical equipment
    - Statistical methods in research
    - Computational tools and analysis
    - Peer review/Journal club
    - Presentation skills
        - Scientific communication
        - Techniques of instruction

- Research Project
    - Research planning
    - Literature review

- Data gathering and processing
- Critical analysis
- Scientific writing
- Authorship, integrity, plagiarism

- Medical Imaging Fundamentals
  - Mathematical methods
  - Tomographic reconstruction techniques
  - Linear systems
  - Introduction to image acquisition and processing
  - Perception
  - Registration, segmentation and fusion
  - Evaluation of image quality, concepts and quantities

- Radiation Dosimetry
  - Quantities and units
  - Charged particle equilibrium
  - Fano theorem
  - Cavity theory
  - Radiation standards
  - Calibration traceability
  - Calibration coefficients e.g. absorbed dose to air ($N_{D,air}$) and water ($N_{D,w}$), etc.
  - Radiation dosimeters
  - Reference dosimetry protocols and codes of practice [14-22]
  - Small field dosimetry (fundamental aspects, recommendations [23,24])

- Physics of Radiation Oncology
  - Overview of clinical radiotherapy and radiobiological basis
  - Radiation therapy equipment (accelerators, ^{60}Co teletherapy, cyclotrons, kV generators)
  - Basic photon radiation therapy
  - Patient setup, including positioning and immobilization
  - Simulation, virtual simulation, digitally reconstructed radiographs (DRRs), image registration
  - Dosimetric functions and basic treatment planning
  - Dose calculation algorithms and heterogeneity corrections
  - Prescribing, recording and reporting according to the ICRU Reports 50, 62 and 83 [25-27]
  - Basic electron radiation therapy, ICRU Report 71 [28]
  - Brachytherapy including the ICRU Report 38 [29] and the AAPM TG 43 [21] formalism
    - High dose rate (HDR) and low dose rate (LDR)
    - Equipment and sources
    - Treatment planning

    - Inverse Planning and optimization for intensity modulated radiation therapy (IMRT)
    - Small-field radiotherapy equipment and techniques (stereotactic radiotherapy (SRT) and radiosurgery (SRS), stereotactic body radiotherapy (SBRT), IMRT, Tomotherapy™, Cyberknife™, Gammaknife™, VERO™, etc.)
    - Image guidance and verification in radiotherapy (Cone beam CT (CBCT), ultrasound (US), portal imaging, in-vivo dosimetry (IVD), image registration)
    - Radiation therapy information systems
    - Principles of quality management in radiation oncology

- Physics of Nuclear Medicine
    - Production of radionuclides and radiopharmaceuticals
    - Detectors and electronics
    - Non-imaging instrumentation
        - Dose calibrators, Well counters
        - Probes
    - Imaging Instrumentation
        - Planar, whole-body
        - SPECT
        - PET
        - Hybrid imaging
    - Internal dosimetry (Medical Internal Radiation Dose (MIRD) formalism, biokinetic modelling and compartmental analysis)
    - Quantitative imaging
    - Radionuclide therapy
    - Image quality and noise
    - Principles of quality management in nuclear medicine

- Physics of Diagnostic and Interventional Radiology
    - X ray production including spectra
    - Exposure parameters and influence on image quality
    - X ray Imaging
        - Radiography
        - Mammography
        - CT
        - Fluoroscopy and interventional radiology
        - DXA, dental and tomography
        - Patient dose and system optimization
    - Ultrasound Imaging
        - Acoustic properties of biological tissues
        - Wave, motion and propagation, acoustic power
        - Modes of scanning
        - Transducers
        - Doppler

        - Safety
    - MRI
        - Physics of MRI
        - MR image formation
        - MR instrumentation
        - MRI methods
        - MR contrast and image quality
        - Safety
    - Clinical applications and artefacts
    - Dual and multi-modality imaging
    - Principles of quality management in radiology

Appendix I lists all the above core modules and suggests the contact hours recommended to cover The material in each topic. This will assist institutions to allocate human resources appropriately in support of such a programme, which requires more than 300 hours.

Appendix II provides a sample programme based on the recommended core modules and the IOMP model curriculum model curriculum [5]. Included are the suggested contact and laboratory hours as well as the allocation of grades to each module towards the final mark. This programme consists of 7 modules that are mainly classroom based and 1 research module. This particular programme would require students to be registered for 2 years of fulltime study.

4.2. PRACTICAL SESSIONS

Practical sessions or laboratory work is possible in all modules, however one laboratory module could cover multiple courses. Examples of laboratory exercises are given below and the academic modules to which they apply are provided:

- Anatomy and Physiology as applied to Medical Physics
    - Anatomy and function using different imaging modalities
- Radiation Physics and Radiation Dosimetry:
    - Measurements with ionization chambers in Co-60, X ray, and accelerator beams
    - Water Tank Scanning
    - Measurements with solid state dosimeters (TLD, metal-oxide semiconductor field-effect transistors (MOSFET), optically stimulated luminescent dosimeters (OSLD), film)
- Radiation Physics:
    - Monte Carlo Transport Calculations
- Radiation Protection
    - Radiation Survey of a clinical installation and shielding calculation
- Medical Imaging Fundamentals
    - Digital Imaging and Communications in Medicine (DICOM) practical
    - Experiments in perception
- Radiation Dosimetry

    - Reference dosimetry calibration of clinical beams using an International protocol, e.g. IAEA TRS 398
- Physics of Radiation Oncology
    - A basic treatment planning exercise
- Physics of Nuclear Medicine
    - Calibration of the sensitivity of a Gamma Camera
    - Gamma ray spectroscopy
- Physics of Interventional and Diagnostic Radiology
    - X ray tube output dependence on HVL, tube voltage, tube current, exposure time, beam filtration and distance
    - Image quality assessment (contrast, resolution, modulation transfer function)
- Radiobiology
    - Measurement of a Survival Curve

4.3. CORE RESOURCES

A list of core knowledge sources that could be used to develop the programme is provided below, noting that many are examples of the current major textbooks in the field. Some are available electronically. A fully developed programme should ideally make use of a far more extensive list of textbooks and software, e.g. EMITEL e-Encyclopedia of Medical Physics and Multilingual Dictionary of Terms (http://www.emitel2.eu/emitwwwsql/index-login.aspx). It should be noted that all IAEA material is available on line and most of the syllabus is covered in the three IAEA handbooks [30-32]. In addition the Human Health Web site (http://humanhealth.iaea.org) contains a substantial range of texts and downloadable teaching aids.

- Anatomy and Physiology as applied to Medical Physics:

[1] TORTORA, G.J., DERRICKSON, B.H., Principles of Anatomy and Physiology. John Wiley & Sons, Inc., New Jersey, USA (2011).
[2] WEIR, J., ABRAHAMS, P.H., SPRATT J.D., SALKOWSKIET L.R., Imaging Atlas of Human Anatomy, 4th Edition. Mosby, Maryland, USA (2010).

- Radiobiology

[1] HALL, E.J., AND GIACCIA, A. Radiobiology for the Radiologist, Lippincott Williams & Wilkins, Philadelphia, USA (2011).
[2] STEEL, G. G., Basic Clinical Radiobiology, Hodder Arnold Publishers, London (2002).
[3] LEHNERT, S., Biomolecular Action of Ionizing Radiation (Series in Medical Physics and Biomedical Engineering), Taylor and Francis, USA (2007).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Biology: A Handbook for Teachers and Students, Training Course Series, No. 42, IAEA, Vienna (2010).
[5] NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES, Health Risks from Exposure to Low Levels of Ionizing Radiation, BEIR VII PHASE 2, The National Academies Press, Washington, D.C. (2006).

- Radiation Physics

[1] PODGORSAK, E. B., Radiation Physics for Medical Physicists (Biological and Medical Physics, Biomedical Engineering), Springer, New York, USA (2010).
[2] CARRON, N.J., An Introduction to the Passage of Energetic Particles through Matter, Taylor and Francis, USA (2006).
[3] EVANS, R. D., The Atomic Nucleus. Krieger, Florida, USA (1982).

- Radiation Protection

[1] CEMBER, HERMAN, AND JOHNSON, THOMAS, Introduction to Health Physics. McGraw-Hill Medical, New York, USA (2008).
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards - Interim Edition General Safety Requirements Part 3, IAEA, Vienna (2011).
[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, ICRP, Ottawa (2007).

- Professional and Scientific Development

[1] JURAN, J. M and DE FEO, J., Juran's quality handbook: The complete guide to performance excellence, McGraw-Hill, New York (2010)

- Medical Imaging Fundamentals

[1] GONZALEZ, RAFAEL, AND WOODS, RICHARD, Digital Image Processing. Prentice Hall, New Jersey, USA (2007).
[2] BUSHBERG, JERROLD T., ET AL, The Essential Physics of Medical Imaging, Lippincott Williams & Wilkins, Philadelphia (2011).

- Radiation Dosimetry

[1] ATTIX, FRANK H., Introduction to Radiological Physics and Radiation Dosimetry. Wiley, USA (1986).
[2] ROGERS, D.W.O., AND CYGLER, JOANNA, Clinical Dosimetry Measurements in Radiotherapy: AAPM 2009 Summer School, Medical Physics Pub Corp, Madison, USA (2009).
[3[KNOLL, GLENN F., Radiation Detection and Measurement. Wiley, USA (2010).

- Physics of Radiation Oncology

[1] PODGORSAK, ERVIN, Radiation Oncology Physics: A Handbook for Teachers and Students, IAEA, Vienna (2005).
[2] KHAN, FAIZ M., The Physics of Radiation Therapy, Lippincott Williams & Wilkins, Philadelphia (2009).
[3] MAYLES, P., NAHUM, A., AND ROSENWALD, J.C., Handbook of Radiotherapy Physics, Theory and Practice, Taylor & Francis, USA (2007).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Applying Radiation Safety Standards in Radiotherapy, Safety Report Series No. 38. IAEA, Vienna (2006).
[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection in the Design of Radiotherapy Facilities, Safety Report Series No. 47. IAEA, Vienna (2006).

- Physics of Nuclear Medicine
[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Medicine Physics: A Handbook for Teachers and Students, IAEA, Vienna (under preparation) (2013)
[2] BUSHBERG, JERROLD T., ET AL, The Essential Physics of Medical Imaging, Lippincott Williams & Wilkins, Philadelphia (2011).
[3] CHERRY, S.R., SORENSEN, J.A., AND PHELPS, M.E., Physics in Nuclear Medicine, Saunders, Philadelphia (2003).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Applying Radiation Safety Standards in Nuclear Medicine, Safety Report Series No. 40, IAEA, Vienna (2005).
[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection in Newer Medical Imaging Techniques: PET/CT, Safety Report Series No. 58, IAEA, Vienna (2008).

- Physics of Interventional and Diagnostic Radiology
[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Diagnostic Radiology Physics: A Handbook for Teachers and Students, IAEA, Vienna (under preparation) (2013)
[2] BUSHBERG, JERROLD T., ET AL, The Essential Physics of Medical Imaging, Lippincott Williams & Wilkins, Philadelphia (2011).
[3] DENDY, P.P., AND HEATON, BRIAN, Physics for Diagnostic Radiology, Third Edition (Series in Medical Physics and Biomedical Engineering), CRC Press, USA (2011).
[4] HENDEE, W.R., AND RITENOUR, E.R., Medical Imaging Physics, Wiley-Liss, New York (2002).
[5] SPRAWLS, PERRY, Physical Principles of Medical Imaging, Medical Physics Pub Corp, Madison (2009).
[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Applying Radiation Safety Standards in Diagnostic Radiology and Interventional Procedures Using X Ray, Safety Report Series No. 39, IAEA, Vienna (2006).

4.4. ADDITIONAL TOPICS

The following additional topics are recommended and are likely to be offered in countries with the relevant specialist expertise and resources:

- Health Technology Assessment
- Information and Communications Technology
- Particle Therapy or Special Techniques
- Accuracy requirements and uncertainties in radiation medicine
- Electronics
- Optical Imaging
- Microdosimetry
- Biological models in treatment planning
- Monte Carlo techniques in treatment planning
- Targeted Therapies
- Management Principles

5. ASSESSMENT AND EVALUATION

Each module should be formally assessed and the mechanism could include any one or a combination of written examinations, oral examinations, laboratory reports, presentations, certified attendance registers, research reports and progress reports. National qualifications authorities ideally provide guidelines on the structure, level and evaluation mechanism required for academic certification of the programme.

6. PROGRAMME ACCREDITATION

It is expected that the standard university course assessment and evaluation takes place on a regular basis as applied to all other academic programmes. For medical physics programmes which are required to prepare students for clinical training in the health professional environment, consultations with the national Professional Bodies and the input of the National Responsible Authority are highly recommended. Experienced auditors and International Organizations are available to provide advice, validation and/or accreditation of such programmes, e.g. IOMP, the Commission on Accreditation of Medical Physics Educational Programs (CAMPEP).

APPENDIX I. SAMPLE TEACHING CONTACT HOURS

Module and Sub-Modules	Hours
Anatomy and Physiology as applied to Medical Physics	
Anatomical nomenclature	
• Origin of anatomical names	1
• Prefixes and suffixes	1
• Anatomical position and body plane terminology	2
Structure, Physiology, Pathology, and Radiographic appearance (X ray, CT, MRI and nuclear medicine imaging) of:	
• Bones and bone marrow	2
• Brain and CNS	2
• Thorax	2
• Abdomen	2
• Pelvis	2
• Respiratory, digestive, urinary, reproductive, circulatory, lymphatic and endocrine systems	14
Total:	28
Radiobiology	
Classification of radiation in radiobiology	1
Cell-cycle and cell death	1
Effect of cellular radiation, oxygen effect	1
Type of radiation damage (tissue, organ and whole body)	1
Cell survival curve	1
Dose-response curve	1
Early and late effects of radiation; effects on the developing embryo	1
Modelling, LQ model, α/β ratio	1
Fractionation, EQD_{2Gy}	1
Dose rate effect	1

Module and Sub-Modules	Hours
TCP, NTCP and EUD	1
Tolerance doses and volumes, (QUANTEC)	1
Normal and tumor cell therapeutic ratio	1
Radiosensitizers, protectors	1
Total:	14
Radiation Physics	
Overview of Modern Physics	
• Historical overview	1
• Atomic and nuclear structure	2
• Radioactive decay	2
• Elementary quantum mechanics	2
Photon interactions	2
Neutron interactions	2
Charged particle interactions	2
Multiple scattering theories	2
Stopping power	
• Restricted, unrestricted	2
• LET	1
Transport equation	
• Charged particle slowing down	2
• CSDA	1
Introduction to Monte Carlo techniques	2
Overview of non-ionizing radiation physics	2
Total:	25

Module and Sub-Modules	Hours
Radiation Protection	
Radiation protection detectors (GM, proportional counters, scintillators, TLDs, ionization chambers, neutron detectors)	4
Exponential attenuation, HVL, inverse square law, TVL	2
Shielding calculations	4
Operational dosimetry	2
Legal framework for radiation protection	2
Occupational, public exposure and annual limits	1
Emergency procedures	2
ALARA	2
Justification	2
Radioactive transport and waste management	2
Risk assessment and communication of risk	1
Total:	26
Research Methodology & Project	
Ethics	
• Helsinki Agreement	1
• Basis of clinical trials	1
• Ethics review/committees	1
Professionalism	
• Clinical governance	2
• Quality management	4
• Code of conduct	1
• Management of medical equipment	2
Statistical methods in research	4
Computational tools and analysis	4

Module and Sub-Modules	Hours
Peer review/Journal club	
Presentation skills	
• Scientific communication	
• Techniques of instruction	
Project	
• Research planning, literature review	
• Data gathering and processing, critical analysis	
• Scientific writing, authorship, integrity, plagiarism	
Total:	20
Medical Imaging Fundamentals	
Mathematical methods	2
Tomographic reconstruction techniques	2
Linear systems	2
Introduction to image acquisition and processing	4
Perception	2
Registration, segmentation and fusion	4
Evaluation of image quality, concepts and quantities	4
Total:	20
Radiation Dosimetry	
Quantities and units	2
Charged particle equilibrium	2
Fano theorem	1
Cavity theory	4
Radiation standards	3
Calibration traceability	3

Module and Sub-Modules		Hours
Calibration coefficients		2
Radiation dosimeters		2
Small field dosimetry (fundamental aspects, protocols)		2
	Total:	21
Physics of Radiation Oncology		
Overview of clinical radiotherapy and radiobiological basis		2
Radiation therapy equipment (accelerators, ^{60}Co teletherapy, cyclotrons, kV generators)		4
Basic photon radiation therapy		4
Patient setup, including positioning and immobilization		2
Simulation, virtual simulation, DRRs, image registration		4
Dosimetric functions and basic treatment planning		3
Dose calculation algorithms and heterogeneity corrections		4
Prescribing, reporting and recording according to the ICRU		3
Basic electron radiation therapy		3
Brachytherapy including the ICRU Report 38 and the AAPM TG 43 formalism		4
• HDR/LDR		2
• Equipment and sources		2
• Treatment planning		2
Inverse planning and optimization for IMRT		4
Small-field radiotherapy equipment and techniques		2
Image guidance and verification in radiotherapy		2
Radiation therapy information systems		1
Principles of quality management in radiation oncology		2
	Total:	50

Module and Sub-Modules	Hours
Physics of Nuclear Medicine	
Production of radionuclides and radiopharmaceuticals	2
Detectors and electronics	2
Non-imaging Instrumentation	
• Dose calibrators, Well counters	2
• Probes	1
Imaging Instrumentation	2
• Planar, Whole-body	2
• SPECT	2
• PET	2
• Hybrid imaging	2
Internal dosimetry	4
Quantitative imaging	1
Radionuclide therapy	2
Image quality and noise	2
Principles of quality management in nuclear medicine	2
Total:	28
Physics of Diagnostic and Interventional Radiology	
X ray production including spectra	1
Exposure parameters and influence on image quality	2
X ray Imaging	
• Radiography	4
• Mammography	2
• CT	4
• Fluoroscopy and interventional radiology	2

Module and Sub-Modules	**Hours**
• DXA, dental and tomography	2
• Patient dose and system optimization	2
Ultrasound Imaging	
• Acoustic properties of biological tissues	2
• Wave, motion and propagation, acoustic power	1
• Modes of scanning	4
• Transducers	2
• Doppler	2
• Safety	2
MRI	
• Physics of MRI	2
• MR image formation	3
• MR instrumentation	2
• MRI methods	2
• MR contrast and image quality	3
• Safety and quality control	2
Clinical applications and artefacts	4
Dual and Multi-modality Imaging	2
Principles of quality management in radiology	2
Total:	54
Cumulative total contact hours:	**261**

APPENDIX II. SAMPLE PROGRAMME IN MEDICAL PHYSICS

An example of the relative grading (weighting) and lecturing effort required of a post-graduate programme in medical physics is shown in Table II.1. The weighting is the contribution per module to the final grade and the contact hours do not include the self-study component of the student, but represent the hours that the teaching Faculty need to dedicate to formal interaction with the students. Laboratory hours represent the practical sessions, often carried out in a clinical environment.

TABLE II.1. AN EXAMPLE OF A MEDICAL PHYSICS ACADEMIC PROGRAMME STRUCTURE

Module	**Weighting**	**Contact Hours**	**Laboratory Hours**
Anatomy and Physiology as applied to Medical Physics	5%	30 h	
Radiation Physics; Radiation Dosimetry	10%	40 h	10 h
Radiation Protection; Radiobiology	15%	50 h	
Professional and Scientific Development	10%	40 h	
Medical Imaging Fundamentals; Physics of Nuclear Medicine; Physics of Diagnostic and Interventional Radiology	20%	80 h	40 h
Physics of Radiation Oncology	15%	60 h	40 h
Advanced Subject or Additional Topics	5%	20 h	10 h
Research Project	20%	10,000 words	
Total:	**100%**	**320 h**	**100 h**

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ISSN 1018-5518