IAEA HUMAN HEALTH REPORTS No. 15

Medical Physics Staffing Needs in Diagnostic Imaging and Radionuclide Therapy: An Activity Based Approach

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MEDICAL PHYSICS STAFFING NEEDS IN DIAGNOSTIC IMAGING AND RADIONUCLIDE THERAPY: AN ACTIVITY BASED APPROACH

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ENDORSED BY:
INTERNATIONAL ORGANIZATION FOR MEDICAL PHYSICS

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FOREWORD

Over the past few decades, radiation medicine has become a major tool of modern medicine. The roles of its three disciplines — diagnostic and interventional radiology, nuclear medicine, and radiation oncology — in the diagnosis and treatment of chronic and acute disease continue to expand, owing to their rapid technological development. However, their application is accompanied by a considerable risk and requires competent professional staff to ensure safe and effective patient diagnosis, treatment and management. Medical physicists have been recognized as vital health professionals with important responsibilities related to the quality and safety of applications of ionizing radiation in medicine.

Although the role of the medical physicist in radiation oncology has been well established for many years (owing to the high doses involved and the possibility of tissue reactions (deterministic effects) to patients as illustrated by well documented accident reports), the corresponding role of the physicist in medical imaging is underestimated, despite the fact that the vast majority of the population's exposure to ionizing radiation is due to medical imaging and despite the radiation injuries reported in computed tomography and interventional radiology. The contribution of the clinical medical physicist to image quality and thereby avoidance of misdiagnosis, for example in breast cancer screening, is a good example of how a life could be saved. In nuclear medicine, the application of high technology equipment, such as PET/CT, requires a medical physicist's skills of patient dose determination along with the more traditional roles of radiation protection, waste management and equipment quality control. A traditional and obsolete belief in the field of medical imaging is that the main functions of a medical physicist in nuclear medicine are those of radiation protection and contamination and waste management, while in diagnostic and interventional radiology the main function is seen as that of tube testing and quality control. These misperceived roles not only limit the contribution of medical physicists but are no longer adequate to meet the needs of modern radiation medicine in terms of quality and safety.

In view of the publication of the new International Basic Safety Standards and IAEA Human Health Series No. 25, these guidelines have been developed for the necessary medical physics staffing levels in medical imaging (diagnostic and interventional radiology and nuclear medicine) and radionuclide therapy. This publication follows the relevant example of IAEA Human Health Reports No. 13, which includes staffing levels for medical physicists in radiation oncology.

The recommended staffing levels are proposed based on the roles and responsibilities of the medical physicist as they are described in the IAEA Safety Standards Series No. GSR Part 3, International Basic Safety Standards, and Roles and Responsibilities, and in IAEA Human Health Series No. 25, Education and Training Requirements for Clinically Qualified Medical Physicists. These roles and responsibilities include: installation design, technical specification, acceptance and commissioning of equipment; the calibration and verification of measurement instruments; the technical supervision of equipment operation and maintenance; the quality management of the physical and technical aspects of radiation medicine; radiation dosimetry of radiation sources and patients; radiation safety and protection of patients, staff and the general public; the optimization of the physical aspects of procedures; clinical computing and networking; research and development; and education and training.

This publication contains a comprehensive method for the estimation of the staffing requirements for medical imaging departments in order to support established services that are delivered locally. Additional resources are required to support the initiation of new services as well as the expansion or upgrade of existing services. Similarly, the introduction of new education and training programmes also requires additional staffing resources.

The publication and algorithm have been developed by the drafting committee (D. McLean (Australia), S. Holm (Denmark), M. Brambilla (Italy) and M.C. Martin (United States of America)), based on similar recommendations and estimations regarding the time and efforts required to perform the described medical physicist duties. The publication underwent a process of broad external review by medical physicists from around the world and the received input from numerous contributors has been used to improve the final publication.

This publication has been endorsed by the International Organization for Medical Physics (IOMP). The IAEA officers responsible for this publication were H. Delis and G.L. Poli from the Division of Human Health.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The aim of medical physics services in diagnostic imaging and radionuclide therapy is to improve patient care through better safety, effectiveness and efficiency in needed diagnosis and treatment. In order to plan and initiate new services as well as expand or upgrade existing services, there is a need to provide guidelines that recommend appropriate staffing levels to support medical physics services.

Diagnostic imaging (in the context of diagnostic radiology and nuclear medicine) and radionuclide therapy are critical to modern medicine and are well established in health care Level I and II countries. Their current impact in countries with Level III and IV health care levels is minimal outside major capital cities [1].

Requirements for the regulation of radiation are established in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [2], which is applicable to medical exposure and stipulates the role of the medical physicist in radiation safety, describing, in brief, three key roles in equipment calibration, quality assurance and dosimetry. The medical physicist is responsible for these activities and his or her direct involvement increases with equipment and activities involving higher complexity and with higher radiation risk. Such equipment and associated activities will include, for example, computed tomography (CT) scanners, interventional angiographic units and mammography units as well as the practice of nuclear medicine.

The medical physicist is a member of the multidisciplinary team involved in diagnosing and treating patients with ionizing and non-ionizing radiation, and contributes to ensuring a high standard of quality of service in hospitals and clinics. In the present publication, a medical physicist is considered to be “a health professional with specialist education and training in the concepts and techniques of applying physics in medicine and competent to practise independently in one or more of the subfields (specialties) of medical physics” [2]. The term corresponds to ‘clinically qualified medical physicist’, with roles and responsibilities and appropriate education and training, as described in Roles and Responsibilities, Education and Training Requirements for Clinically Qualified Medical Physicists, IAEA Human Health Series No. 25 [3].

1.2. OBJECTIVE

The different elements of the IAEA staffing algorithm are based on the roles and responsibilities of the medical physicist as they arise from the requirements of good practice, as highlighted in international guidelines [3–6]. In many instances, these recommendations are related to good clinical practice and in certain cases might not be reflected in national regulations that primarily relate to radiation safety. Medical physics services designed to meet minimal national regulations, intended only to cover the regulatory requirements, are typically well below the levels needed for good clinical practice. However, in cases of environments with limited resources and environments that prioritize the safety aspects of clinical practice, medical physics services only covering the basic equipment, patient and radiation protection aspects (these are usually the elements required by national legislation) could be considered a minimum initial solution, which should be brought up to good clinical practice levels as soon as feasible.

Staffing requirements for medical physicists who provide services in medical imaging and radionuclide therapy have historically been hard to quantify. The first known publication to tackle this area was issued by the American Association of Physicists in Medicine (AAPM) [7], in which weighting factors were applied to an algorithm input based on the number and type of radiological equipment. The existence of patient, research and teaching related input factors was also recognized but not quantified. More important was the realization that, in order for a medical physicist service to function efficiently, a support staff at least equal in number to the medical physicists is normally required. Recent publications deal with the topic of medical physics staffing [8, 9], with a European Commission publication [6] quantifying the weighting factors for the additional inputs associated with patients, service, research and teaching. Additionally, Ref. [6] includes weighting factors for a full medical physics service with a ratio of 1.5 support staff for each medical physicist. When clinical input data was analysed with this algorithm, the number of support staff required was calculated to be very similar to the value of 1.5 suggested by AAPM Report No. 33 [7].

The additional input category of radiation protection has also been isolated in the latest European Federation of Organisations for Medical Physics document [5]. A model has also been developed in Australia [10] with the inputs of regulatory requirements and additional good practice inputs, which also demonstrated that a detailed model could be simplified in the typical Australian context to obtain reasonable agreement with the detailed algorithm by considering only the number of patients examined in a radiology department.

1.3. SCOPE

The scope of this publication is to describe the characteristics of an algorithm developed to determine the recommended staffing levels for clinical medical physics services in medical imaging and radionuclide therapy. The numbers of the required medical physicists and medical physics staff derived from the algorithm is based on best practice, as described in international guidelines, and the algorithm is not designed to represent the current situation in all countries. Additional duties of the medical physicist, such as participation in research and support for radionuclide production, are considered separately and can be removed from the final calculation. The same provision is made for the duties of the radiation protection officer, which is a role commonly undertaken by medical physicists [3], especially in limited resource environments. Further, this algorithm has been tested under a variety of field conditions to ensure its general applicability. Finally, this publication aims to give some recommendations on the size of a service that can give patients a safe, effective and efficient diagnosis, treatment or both.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.4. STRUCTURE

In Section 2 of this publication, a general description of the formulation of the algorithm is provided and details of the required input and the expected output are provided. Section 3 is the core part of this publication, describing the different elements of medical physics services and quantifying the level of support in terms of the full time equivalent (FTE) of a clinically qualified medical physicist required to adequately provide these services. Different models of medical physics services are briefly described in Section 4, while the advantages of medical physics departments in terms of efficiencies gained are explained and quantified. To demonstrate the application of the proposed staffing model, three indicative examples of the application of the algorithm are presented in Section 5 for health facilities of different sizes and offering different services. Finally, Section 6 provides the conclusions of this publication and highlights the limitations and assumptions for the application of the proposed staffing algorithm.

A spreadsheet has been developed to facilitate calculations of the staffing needs following the guidance of this publication. The source file as well as the three worked examples described in Sections 5.1–5.3 can be found on the attached CD-ROM and also downloaded from the IAEA publications web site.

2. STAFFING REQUIREMENTS ALGORITHM

A detailed algorithm to describe diagnostic imaging and radionuclide therapy staffing levels for medical physicists has been developed. A number of example scenarios are also provided. The components of the algorithm include input variables, weighting factors and output variables, with the output being the number of medical physicists (FTE) needed to deliver the service.

It is also recognized that a medical physics service cannot function effectively without support staff. ‘Support staff’ not only includes professionals fully assigned to medical physics services or departments, but also staff members with partial duties related to radiation protection or routine quality control which are delegated and supervised by the medical physicist.

Appreciable efficiencies can be achieved when a medical physics service is large. This can be achieved by combining the roles of diagnostic radiology and nuclear medicine in one service department and by providing regional services to a group of hospitals, also in order to share resources and improve the quality of service [5].

The algorithm is designed to calculate the number of medical physicists needed to provide adequate medical physics services, assuming that they are established and delivered locally. It should be noted that if the services are in the process of being set up, they will initially require considerably more time and effort. Moreover, if these services are being provided at different sites, additional factors should be considered, such as travel time.

The full time equivalent for medical physics activities within clinical research and development as well as academic teaching should be self-assessed in order to take into consideration the variety of activity in these areas.

2.1. FORMULATION OF THE ALGORITHM

The algorithm, in its simpler formulation, calculates the total number of medical physicists, N_{MP}, required as:

$$N_{\mathrm{MP}} = N_{\mathrm{sum}}\varepsilon = \left(\sum_{X=1}^{6} N_X\right)\varepsilon \tag{1}$$

where N_1 to N_6 are the estimated number of FTE medical physicists required for each of the following six factors. These factors are: equipment dependent (Section 3.1), patient dependent (Section 3.2), radiation protection related (Section 3.3), service related (Section 3.4), training related (Section 3.5) and academic teaching and research related (Section 3.6). The factor ε compensates for the efficiency of scale as described in Section 4.2.

Each of these N_X values is individually calculated according to:

$$N_X = \sum_i w_i n_i \tag{2}$$

where w_i is the relevant weighting factor in terms of FTE per input quantity and n_i is the associated input parameter.

Additional adjustments have been taken into account, such as in the case of medical physics services covering multiple departments. These adjustments are explained in detail below and have been incorporated in the spreadsheet on the CD-ROM accompanying this publication.

2.2. ALGORITHM INPUTS

2.2.1. Input variable categories

Six categories of factors have been identified, which are dependent on or related to:

— Equipment;
— Patients;
— Radiation protection;
— Service;
— Training;
— Academic teaching and research.

For the first two categories, it is necessary to have separate tables of weighting factors (see Section 3) for both diagnostic and interventional radiology and nuclear medicine. The remaining four categories have tables common to both specialities; however, some inputs are distinct to each speciality.

2.2.2. Input variable types

The input variables unique to each category include:

— Number of equipment units;
— Number of patient procedures performed per year;
— Number of calculations for pregnant patients or possible skin dose reactions per year;
— Number of departments served by medical physics;
— Number of staff for whom occupational exposure monitoring is required;
— Equipment procurement and installations per year;
— Continuing professional development (CPD) hours required per year per physicist;
— Number of hours of training to be given per year;
— Number of medical physicists on staff.

2.2.3. Weighting factors

The weighting factors are in terms of FTE per input quantity. The FTE values given in Table 1 are based on a typical assumption of 220 working days (i.e. 44 working weeks, 10 days of holidays and 30 days of leave per year with 8 working hours per day). Given the limited precision of the applied FTE values, there is no reason to adjust for minor variations in working hours. However, in cases of major differences in the actual local number of working hours per year, the user should adjust the FTE results accordingly.

TABLE 1. EXAMPLES OF FTE VALUES AND THEIR EQUIVALENT IN DAYS AND HOURS

FTE	Days	Hours
0.1	22	176
0.01	2.2	18
0.005	1.1	9
0.001		2

This publication reflects recommended practice [2, 5–7] with corresponding weighting factors, and does not necessarily reflect current practice in many places, as some of the elements described in the algorithm might not be in use, especially in limited resource settings.

2.3. OUTPUT VARIABLE

The developed algorithm output gives the number of full time medical physicists in nuclear medicine and/or diagnostic and interventional radiology needed to provide the service. However, it is recognized that these persons should be supported by additional staff such as medical physics residents, medical radiation technologists, computer scientists and administrative staff. The algorithm also assumes that the most frequent and basic routine quality control testing, including wipe tests, is done by on-site technologists in nuclear medicine and radiographers in radiology, under the supervision of the medical physicist. The total number of support staff providing medical physics services should be at least equal to the number of medical physicists [6, 7].

A minor discrepancy between the actual and calculated number of medical physicists can be justified by differences in efficiencies and uncertainties in the input and weighting factors. However, significant differences might indicate over- or understaffed situations or lack of coverage of the recommended activities, or may result from more demanding local or national requirements.

3. DESCRIPTION OF THE INPUT VARIABLES AND ASSOCIATED WEIGHTING FACTORS

3.1. EQUIPMENT DEPENDENT FACTORS

The equipment dependent variables and weighting factors used in the algorithm are described in Table 2 for nuclear medicine and Table 3 for diagnostic and interventional radiology.

Associated duties of the medical physicist cover:

(a) A complete range of periodic equipment performance tests with associated documentation, carried out at least annually;
(b) Testing after major maintenance procedures that could affect the relevant parameters for assessing patient dose and displayed image quality;
(c) Review or evaluation of routine quality controls.

Medical physicists are sometimes also competent to provide professional support in other areas of medicine (photodynamic therapy, optical imaging, use of lasers, therapeutic use of ultrasound and physiological measurement, etc.). These modalities are not considered in this publication.

TABLE 2. EQUIPMENT DEPENDENT FACTORS FOR NUCLEAR MEDICINE

Input variable	Weighting factor (FTE)	Additional comments
Planar gamma camera	0.02	
SPECT systems	0.06	
SPECT/CT or PET/CT	0.1	Applies to the whole system, including CT. This includes quality control of associated image display devices.
PET/MR	0.1	Does not include safety aspects of magnetic resonance. This includes quality control of associated image display devices.
Cyclotron	0.5	Includes medical physics related duties associated with the radiopharmacy of the serviced departments (Type I and II [11]). If the department provides radiopharmacy services to external institutes (e.g. distribution of radioisotopes) or is involved in relevant research, this should be adjusted accordingly.
Other equipment (per item)	0.005	Includes: thyroid probes, radionuclide activity calibrators, sentinel lymph node probes, gamma counters, different types of isotope generator.

TABLE 3. EQUIPMENT DEPENDENT FACTORS FOR DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY

Input variable	Weighting factor (FTE)	Additional comments
CT scanner	0.04	Both fixed and mobile scanners used for radiology, radiotherapy. It does not include cone beam CT (CBCT) units for dental and angiography use.
Fixed radiography unit	0.01	Dental panoramic and CBCT units should be included here. Note that digital detectors are counted separately, as applicable.
Mammography unit	0.02	Including both screen film and digital units, also including biopsy and tomosynthesis.
Specimen cabinet units for biopsy analysis	0.001	
Fluoroscopy unit	0.01	Includes both fixed and mobile C-arm units used for basic fluoroscopy.
Interventional fluoroscopy unit	0.02	Both fixed and mobile units used for this purpose.
Portable/mobile radiography unit	0.004	Note that digital detectors are counted separately, as applicable.
Intra-oral dental X ray unit, DEXA (dual-energy X ray absorptiometry) unit	0.001	
Computed radiography detectors (per plate)	0.001	
Diagnostic radiology detectors (per detector)	0.004	
Image display device (per pair)	0.001	Applies only to primary interpretation stations.
Magnetic resonance scanner	0.04	This does not include safety duties. See Section 3.3.
Ultrasound unit	0.002	Includes all probes used clinically.
Reading and printing devices	0.002	Includes computed radiography readers and laser printers.
Dark rooms — wet processors	0.02	Includes all duties associated with film imaging, supervising sensitometric control of film processors, assessment of appropriate film screen systems, etc.

3.2. PATIENT DEPENDENT FACTORS

The patient dependent input variable weighting factors used in the algorithm are described below in Tables 4 and 5. They are intended to include all the duties of the medical physicist that scale with the number of patient procedures.

Associated duties cover:

(a) Radiation safety for patient management in radionuclide therapy;
(b) Patient specific dosimetry in radionuclide therapy;

(c) Patient dosimetry and risk assessment for individual patients (unintended exposures and paediatric, pregnant and breast feeding patients);
(d) Troubleshooting of technical and clinical physics issues related to patient examinations (e.g. sub-optimal image quality, artefacts).

TABLE 4. PATIENT DEPENDENT FACTORS FOR NUCLEAR MEDICINE

Input variable (per year)	Weighting factor (FTE)	Additional comments
Procedures with no image data (per 1000 patients)	0.01	Such as blood sampling, thyroid uptake, sentinel lymph node mapping
Imaging procedures (per 1000 procedures)	0.02	Imaging procedures including planar, SPECT(/CT), PET/CT
Outpatient radionuclide therapy (e.g. ^{131}I for thyrotoxicosis) (per 100 procedures)	0.05	For patient dosimetry and radiation safety
Inpatient radionuclide therapy (e.g. ^{131}I for thyroid carcinoma) (per procedure)	0.001	For patient dosimetry and radiation safety
Complex radionuclide therapy (e.g. ^{131}I mIBG (metaiodobenzylguanidine), ^{177}Lu, ^{90}Y) (per procedure)	0.005	For patient dosimetry and radiation safety
Risk assessment in pregnant or breast feeding patients (per calculation)	0.002	Includes dose assessment and reporting of results

TABLE 5. PATIENT DEPENDENT FACTORS FOR DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY

Input variable (per year)	Weighting factor (FTE)	Additional comments
CT procedures (per 1000 procedures)	0.01	
Interventional radiology and cardiology procedures (per 1000 procedures)	0.02	
Planar procedures (radiography, fluoroscopy, mammography, etc.) (per 1000 procedures)	0.001	
Dosimetry for individual patients for high dose procedures (e.g. skin doses) (per calculation)	0.002	Based on relevant parameters for assessing patient dose along with patient demographic data and projection orientation data. Includes reporting of results.
Risk assessment for pregnant patients (per calculation)	0.002	Includes dose assessment and reporting of results.

3.3. RADIATION PROTECTION RELATED FACTORS

The radiation protection related weighting factors used in the algorithm are described in terms of department dependent factors and staff dependent factors. These factors assume that radiation protection duties are to be carried out by the medical physicist. If this is not the case, a change should be made in the final calculation of required staff.

Associated duties cover:

(a) Development of relevant radiation management plans;
(b) General protection aspects for both ionizing and non-ionizing radiation in a hospital, including risk assessments and radiation protection surveys;
(c) Advice on the actions needed to comply with national regulations;
(d) Administration related to radiation licensing and registration, etc.
(e) Radioactive waste management;
(f) Counselling of pregnant staff;
(g) Occupational dose monitoring of staff;
(h) Investigation of high occupational doses and other radiation incidents;
(i) Control and calibration of monitoring and measuring equipment.

When considering the department related factors in Table 6, it should be noted that the weighting factors have been estimated based on the assumptions documented in the table. For cases of more than one department or for much larger departments, the number of department units has to be scaled accordingly by the user. In order to take into account the repetition in the activities involved with larger operations, each additional department unit is accrued at 50% of the rate indicated for the initial model department.

TABLE 6. RADIATION PROTECTION RELATED FACTORS

Input variable	Weighting factor (FTE)	Additional comments
Department dependent factors (per department)		
Diagnostic radiology department	0.05	This weighting factor is for what is assumed to be a typical radiology department unit, consisting of 3 CT scanners and 10 X ray rooms. For much larger or much smaller departments, scale the number of department units accordingly.
Interventional radiology department (catheterization laboratory)	0.05	A catheterization laboratory unit is assumed to consist of two interventional rooms. For much larger or much smaller departments, scale the number of department units accordingly.
Nuclear medicine department	0.2	Assuming a typical nuclear medicine department unit, consisting of four major imaging systems. For much larger or much smaller departments, scale the number of department units accordingly.
Cyclotron	0.1	Includes only the radiation protection responsibilities associated with the operation of a cyclotron.
Nuclear medicine radionuclide therapy ward	0.1	Assuming a typical nuclear medicine therapy ward unit, consisting of 2–4 beds. For much larger wards, scale the number of ward units accordingly.
Magnetic resonance safety (per scanner)	0.01	
Staff dependent factors (per year)		
Staff dosimetry reviews (per 100 staff)	0.01	Number of monitored staff.
Complex staff exposure incident evaluations (per case)	0.005	Includes incident management (e.g. for personal contamination) or in the case of occupational dose, exceeding a defined limit.
Risk assessment for staff (per case)	0.001	Examples are reports of the cumulated doses or evaluation of fetal dose in pregnant workers.

3.4. SERVICE RELATED FACTORS

The service related weighting factors used in the algorithm are described in Table 7. Associated duties cover:

(a) Ensuring compliance with local and national regulations and accreditation requirements, including regular inspections;
(b) Assessing and reporting typical doses and administered activities in standard radiological examinations [12, 13];
(c) Quality management including clinical audits [14–16];
(d) Equipment specification and evaluation;
(e) Equipment acceptance testing;
(f) Radiation protection advice for new installations;
(g) Testing protocol development.

Medical physicists should have the knowledge and skills to support clinical computing and networking [3]. They should be familiar with the core concepts and use of PACS (picture archiving and communication systems), RIS (radiology information systems) and HIS (hospital information systems). They should also be knowledgeable on how to store, handle and distribute patient images and data between different workstations. They collaborate with computer engineers for the verification of network integration and data transfer to ensure that all systems are functional and that patient data are protected against unauthorized access and breach of privacy. Relevant duties

TABLE 7. SERVICE RELATED FACTORS

Input variable	Weighting factor (FTE)	Additional comments
Department administration	0.2	Including internal meetings for budget, planning of activities and staffing issues. Applies only in the case of an independent medical physics department.
Dose management programme (per department)	0.04	Assessment of typical doses and administered activities in standard radiological examinations for a medium sized department. Determined typical patient dose indicators are to be compared to relevant diagnostic reference levels.
Quality management including clinical audits (per practice)	0.1	Documentation development and review of quality assurance policies, procedures and associated records, participation in quality assurance and safety committees, preparation and participation in audits and accreditation processes. This weighting factor applies for each practice (0.1 for diagnostic radiology and 0.1 for nuclear medicine) and not for a single composite department.
Equipment specification and evaluation (per procurement)	0.02	Assuming a unit of average complexity.
Equipment acceptance testing (per unit)	0.02	Includes commissioning and development of quality assurance baseline values. Assuming a unit of average complexity.
Radiation protection advice for new fixed installations (per equipment installation)	0.02	Including the shielding plan and confirmation for an average installation.
Testing protocol development (per protocol)	0.05	Includes development of equipment testing protocol, associated software development, development of phantoms.

are highly variable depending on the local situation and cannot be quantified in a uniform way. Therefore, the workload involved in such situations can only be quantified on a local basis.

3.5. TRAINING RELATED FACTORS

Medical physicists play a key role in the clinical training of other medical physicists and health professionals. Medical physicists lecture and develop educational material for medical practitioners, technologists and nurses, as well as for students, residents and technical maintenance staff. The training weighting factors used in the algorithm are described in Table 8.

TABLE 8. TRAINING RELATED FACTORS

Input variable	Weighting factor (FTE)	Additional comments
Number of CPD units required (per medical physicist)	0.02	The weighting factor assumes a requirement of 40 hours of CPD per year. When national requirements are different, the weighting factor will be scaled accordingly.
Delivering training (per hour delivered)	0.002	Training to health professionals (includes delivery and preparation).
Delivering training — medical physics registrar (resident) (per trainee)	0.1	Each medical physics resident is considered in the algorithm as 0.5 FTE of the supportive medical physics staff.

3.6. ACADEMIC TEACHING AND RESEARCH RELATED FACTORS

Medical physicists play a role in the academic education of health professionals and students, and in research and development. They evaluate new technologies and investigate the adoption of new procedures, assisting in the training of clinical staff for their implementation. They support the physical and technical aspects of clinical research and often have a leading role in the medical research team, particularly in centres of high technological complexity. Medical physicists play an important role in the clinical protocols used in applied research. They carry out research and development in medical physics and instrumentation, monitor current advances in specific areas of research, and design project plans with milestones, experimental methodology and estimated timeframes.

Academic teaching and involvement in research and development are duties additional to the work of a medical physicist that are not covered by the algorithm. These duties are highly variable depending on the specific context and cannot be quantified in a uniform way. Therefore, the quantification of the workload involved in such situations can only be done on a local basis and has to be added as additional FTEs to the results of the algorithm. These additional duties not covered in the context of this publication may include:

(a) Delivering academic teaching;
(b) Carrying out research led by the service;
(c) Participation in research ethics committees;
(d) Providing support to external research projects;
(e) Involvement in clinical research (e.g. additional quality assurance and dosimetry requirements, modelling, data management, medical statistics).

4. SERVICE MODELS FOR CLINICAL MEDICAL PHYSICS DELIVERY IN DIAGNOSTIC IMAGING

Diagnostic imaging is an indispensable service of modern medicine, at least in health care Level I and II countries. However, the role of medical physics services is not uniformly appreciated at the point of practice. This situation differs from that of radiation oncology where more extensive medical physics services are needed within a typical treatment department. The more extensive — but commonly more diffuse — radiology practice often results in medical physicists being employed only in large centres, often associated with university teaching hospitals. Often multiple radiology centres are serviced by small medical physics departments, perhaps with a single medical physicist, thus creating a fragmented and inefficient system of service delivery. Radiological centres that make extensive use of medical physics services, notably in Europe and North America, often do so to fulfil legal requirements for radiation safety and compliance with equipment performance standards, leading in many cases to the formation of larger service departments that might be regional health service departments or third party private service providers.

It also needs to be recognized that the service work of a medical physicist in diagnostic imaging varies greatly between different imaging facilities, and this is true even within a single country or region. Perhaps this is most evident in nuclear medicine where the support given by medical physicists also varies widely with the demands for research and teaching.

4.1. SERVICE SUPPORT STAFFING LEVELS

As mentioned in Section 1.2, it was realized early in the literature on diagnostic imaging physics services that efficient delivery of medical physics services requires support from non-medical physics personnel that should be recognized in workforce determinations. Such persons may be part of the medical physics service, or may be utilized from other departments. Examples of the different types of support staff that might be needed include secretarial and administrative support, technologists, medical physics residents, IT support, workshop and engineering support.

4.2. EFFICIENCIES OF SCALE

As mentioned above, much of the practice of radiology is delivered in smaller clinics where the required medical physics services might be significantly less than 1 FTE. In these cases, the use of the partial services of a medical physicist by a small centre lacks efficiencies that can be found in larger medical physics services with specialization in expertise, variety in equipment availability and efficiencies in administration.

Appreciable efficiencies can be achieved when a medical physics service is larger. This can be achieved by combining the roles of diagnostic radiology and nuclear medicine in one service department and by providing regional services to a group of hospitals, also in order to share resources and improve the quality of service. For these reasons, an efficiency of scale could be applied when the estimated number of FTE medical physicists N_{sum} is larger than 4, and therefore the factor ε (see Eq. (1)) is calculated as follows

$$\varepsilon = \begin{cases} 1 & \text{if } N_{sum} \leq 4 \\ \dfrac{4 + (N_{sum} - 4)RF}{N_{sum}} & \text{if } N_{sum} > 4 \end{cases} \tag{3}$$

where RF is the reduction factor that can be applied to the additional medical physicists required and depends on the skill and expertise mix of medical physics staff. This factor could be of the order of 0.6–0.8, leading to a reduction of up to 40% for any FTE exceeding 4.

Although it is recognized that efficiencies of scale also exist in the case of large medical physics departments with imaging and radiotherapy medical physicists, care should be taken when applying the appropriate reduction to correctly reflect the efficiencies gained from the skill mix of the staff.

4.3. FACILITY BASED MEDICAL PHYSICS SERVICE MODEL

The facility based medical physics service model covers both situations where there is a medical physics department within the institution and the case when the medical physicist is embedded within a diagnostic and interventional radiology or nuclear medicine department. This model has the advantage of proximity and dedicated attention to the specific clinical needs of the department, strengthening patient orientated medical physics activities, rather than equipment or regulatory compliance activities.

4.4. REGIONAL PUBLIC MEDICAL PHYSICS PROVIDER MODEL

Regional public medical physics services can vary from services provided for a tertiary research hospital to primary health care facilities. The advantage of such a model is that expertise can be concentrated to allow a diversity of activities, even at smaller centres, that would not otherwise be possible. For tertiary university hospitals in particular, a considerable effort can be spent in supporting or even in leading clinical research and in teaching, to assist in the promotion and sustainability of imaging standards or the development of new methods of practice. In other public medical physics models, services can be driven by regulatory demand and have much in common with private medical physics models (see Section 4.5) and may even exist in open competition with private commercial practice.

4.5. PRIVATE MEDICAL PHYSICS PROVIDER MODEL

In regions or countries where the public medical physics provider either does not exist or only provides a service to selected radiology and nuclear medicine facilities, private medical physics providers often establish services. In these cases, the work focus can be shaped only by regulatory requirements or regulatory and accreditation requirements. However, where contractors are not regulated, there is risk that the contract work may not even be compliant with government requirements.

Where the medical physics services are only established to comply with regulatory requirements, these tend to be focused on equipment compliance testing and areas of radiation safety that are identifiable through regulation. This arrangement has advantages in that the facility is aware of the cost of services and makes a strong effort to facilitate effective access to equipment and needed resources and correspondingly to implement needed recommendations to improve services. In this scenario, there is likely to be considerably less work performed in non-regulated areas of diagnostic imaging medical physics, such as work in justification and optimization of medical exposure.

5. STAFFING ALGORITHM EXAMPLES

In this section, complete worked examples are presented for three different scenarios.

5.1. SMALL INSTITUTION

The hypothetical small institution has a radiology department consisting of 1 CT scanner, 2 X ray rooms with fixed digital equipment, 1 digital mammography unit, 2 portable digital radiographic units and 2 pairs of primary reporting workstations. For the equipment dependent factors of the diagnostic radiology (DR) department (including the 5 DR detectors), approximately 0.11 FTE will be required. If this department carries out 8000 planar examinations and 5000 CT examinations, it will additionally require 0.06 FTE of a medical physicist for the patient dependent factors. The total for DR is then approximately 0.17 FTE of a medical physicist.

The second department is a nuclear medicine department with 1 planar and 1 SPECT gamma camera used for ^{99m}Tc only and 1 activity calibrator: approximately 0.09 FTE will be required. If this department carries out 5000 imaging procedures, it will additionally require 0.1 FTE medical physicists for the patient dependent factors. The total for nuclear medicine (NM) is then approximately 0.19 FTE of a medical physicist.

Radiation protection responsibilities for these two departments with 50 exposed workers in total will require a further 0.25 FTE of a medical physicist.

Other service elements, such as quality management with ongoing audits for both DR and NM departments, the procurement of 1 new piece of equipment per year (with corresponding acceptance testing and radiation protection advice for new installations), and 1 course of 10 hours delivered to staff of the institute will require an additional 0.36 FTE of a medical physicist.

Therefore, for this example of a typical small sized institution, the medical physics services will require 1 FTE of a medical physicist (assuming a requirement of 40 hours of CPD per year) with a recommended 1 FTE of support staff.

5.2. MEDIUM SIZED INSTITUTION

The hypothetical medium sized institution has a radiology department (fully digital, consisting of 2 CT scanners, 1 magnetic resonance (MR) scanner, 10 X ray rooms with fixed equipment, 2 mammography units, 5 portable radiographic units, 1 fluoroscopy C-arm and 10 pairs of primary reporting workstations) and an interventional radiology department with 2 interventional fluoroscopy units. For the equipment dependent factors (including the 17 DR detectors) of this DR department, approximately 0.41 FTE will be required. If this department carries out 50 000 planar procedures, 10 000 CT and 1000 interventional procedures and 5 risk assessments for pregnant patients, it will require approximately 0.18 FTE of a medical physicist for the patient dependent factors. The total for DR is then approximately 0.59 FTE of a medical physicist.

Additionally, this hypothetical institution has a nuclear medicine department with 1 planar, 1 SPECT gamma camera, 1 SPECT/CT used for a range of radionuclides, 1 PET/CT, 1 activity calibrator, 1 thyroid uptake probe and 1 gamma counter, with 1 type of isotope generator. For the equipment dependent factors of this NM department, approximately 0.3 FTE will be required. If this department carries out 6000 non-imaging procedures (including thyroid uptakes and radioimmunoassay analysis) and 13 000 imaging procedures, it will require approximately 0.32 FTE of a medical physicist for the patient dependent factors. The total for NM is then approximately 0.62 FTE of a medical physicist.

Radiation protection responsibilities for these three departments (DR, NM and interventional radiology), with 150 exposed workers in total, will require a further 0.32 FTE of a medical physicist.

Other service elements, such as establishment of typical doses and quality management with ongoing audits for all three departments, procurement of 1 piece of new equipment per year (with corresponding acceptance testing and radiation protection advice for new installations), 1 protocol development and 20 hours training delivered, will require an additional 0.47 FTE of a medical physicist.

Therefore, for this example of a typical medium sized institution, the medical physics service will require 2 FTE medical physicists (assuming a requirement of 40 hours of CPD per year) with recommended 2 FTE of support staff.

5.3. TERTIARY AND SECONDARY CARE INSTITUTION OR MEDICAL PHYSICS SERVICES COVERING MORE THAN ONE HOSPITAL

One department of the hypothetical tertiary and secondary care institution(s) is a medical physics department, responsible for a network of 7 DR departments, including a total of 12 CT scanners, 7 MR scanners, 90 X ray rooms with fixed equipment, 13 mammography units, 20 portable radiographic units, 20 fluoroscopy C-arm units, 4 interventional radiology laboratories with 8 interventional fluoroscopy units, 50 pairs of primary reporting workstations, 120 CR plates and 40 DR detectors. For the equipment dependent factors of this DR department, approximately 2.7 FTE will be required. If this networked institution carries out 100 000 planar, 55 000 CT and 3200 interventional procedures, 10 risk assessment for pregnant patients and 10 skin dose evaluations, it will require approximately 0.75 FTE of a medical physicist for the patient dependent factors. The total staff for DR is then approximately 3.45 FTE.

The second and third are two nuclear medicine departments (one of which has therapy wards) with a total of 5 SPECT and 3 SPECT/CT gamma cameras used for a range of radionuclides, 3 PET/CT, 5 activity calibrators, 2 thyroid uptake probes, 2 gamma counters and 6 sentinel lymph node probes and 2 different types of generators in use. For the equipment dependent factors of this NM department, approximately 0.98 FTE will be required. If this department carries out 10 000 non-imaging procedures (including thyroid uptakes and RIA analysis), 25 000 imaging procedures, 200 outpatient radionuclide therapies, 200 simple inpatient radionuclide therapies, 60 complex radionuclide therapies (e.g. radioembolization with ^{90}Y microspheres) and 5 risk assessment for pregnant patients, it will require approximately 1.21 FTE medical physicists for the patient dependent factors. The total for NM is then approximately 2.2 FTE medical physicists.

Radiation protection responsibilities for all departments with a staff of 1000 exposed workers in total, investigating 5 overexposures per year, will require a further 0.89 FTE of a medical physicist.

Other service elements, such as establishment of typical doses and quality management with ongoing audits for both DR and NM, 4 procurements of new equipment (with corresponding acceptance testing and radiation protection advice for new installations), 4 protocol developments, 50 hours training delivered and 2 internal medical physics residents will require an additional 1.66 FTE medical physicists.

Therefore, for this example of a network of university and general hospitals, the medical physics department will require approximately 8.4 FTE medical physicists (assuming a requirement of 40 hours of CPD per year) and an additional 7.4 FTE of support staff. However, assuming that this is a large medical physics department, efficiencies of scale could be achieved (see Section 4.2), reducing the number of required FTE medical physicists to 7 (with 6 FTE for support staff) if a reduction factor RF = 0.7 is considered.

6. CONCLUSIONS FOR CLINICAL MEDICAL PHYSICS DELIVERY IN DIAGNOSTIC IMAGING AND RADIONUCLIDE THERAPY

As described in this publication, the IAEA has developed an algorithm to provide guidance on the number of medical physicists needed to ensure safe, effective and efficient diagnostic imaging and radionuclide treatment of patients. It utilizes a large number of input categories and variable types, which allows the needed flexibility to give appropriate staffing levels over a wide range of facility sizes and local environments.

It should be noted that the algorithm is based on the assumption that the medical physics services are already established and that the travel time to the service departments is minimal.

The weighting factors used in this algorithm are the best estimates available at this time. They are based on the experience of the contributors to this publication with input from medical physicists throughout the world representing different regions and different country health care levels. Adjustments may need to be made in the future to accommodate the establishment of new services or developments within the imaging modalities. It should be noted that weighting factors could be amended in specific locations where the time taken for some tasks can be documented to vary from those recommended owing to local conditions. In such circumstances, the use of these amended weighting factors may give a more realistic outcome to the use of the algorithm.

In summary, for the present guidelines to be able to properly reflect the medical physics service needs, it is suggested that:

— The algorithm be applied to determine adequate staffing levels for a medical physics service for any size of facility.

— Additional consideration be given:
  - If new medical physics services are being established;
  - When equipment routinely requires increased supervision and maintenance (e.g. if the equipment is old);
  - When extensive support is provided to hospital information systems, radiology information systems and picture archiving and communication systems;
  - When there is significant travel time required between sites.

— Efficiencies that could be gained in the case of large or regional services be considered.

— If the service is involved in academic training or clinical research, additional staffing requirements be estimated separately, as these are highly dependent on local factors.

REFERENCES

[1] UNITED NATIONS, Sources and Effects of Ionizing Radiation (Report to the General Assembly), Vol 1: Annex A Medical Radiation Exposures, Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (2008).

[2] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Roles and Responsibilities, and Education and Training Requirements for Clinically Qualified Medical Physicists, IAEA Human Health Series No. 25, Vienna (2013).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Staffing in Radiotherapy: An Activity Based Approach, IAEA Human Health Reports No. 13, IAEA, Vienna (2015) CD-ROM.

[5] EVANS, S., CHRISTOFIDES, S., BRAMBILLA, M., The European Federation of Organisations for Medical Physics, Policy Statement No. 7.1: The roles, responsibilities and status of the medical physicist including the criteria for the staffing levels in a Medical Physics Department approved by EFOMP Council on 5th February 2016, Phys. Medica **32** 4 (2016) 533–540.

[6] EUROPEAN COMMISSION, European Guidelines on Medical Physics Expert, Radiation Protection 174, Annex 2: Medical Physics Expert Staffing Levels in Europe, Publications Office of the European Union, Luxembourg (2014).

[7] AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE, Staffing Levels and Responsibilities of Physicists in Diagnostic Radiology, AAPM Report No. 33, American Association of Physicists in Medicine, Colchester, VT (1991).

[8] SWISS SOCIETY FOR RADIOBIOLOGY AND MEDICAL PHYSICS, Medical Physics Staffing for Nuclear Medicine and Dose-intensive X-ray Procedures, Report No. 20, SSRMP (2009).

[9] ISAMBERT, A., et al., Medical Physics personnel for medical imaging: requirements, conditions of involvement and staffing levels, Radiat. Prot. Dosim. **164** 1–2 (2013) 130–133.

[10] WILKINSON, L., BRADY, Z., “Developing the case for diagnostic physicists in imaging”, presented at Combined Scientific Meeting on Imaging and Radiation in Personalised Medicine, Melbourne, Australia, 2014.

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Cyclotron Produced Radionuclides: Guidelines for Setting Up a Facility, Technical Reports Series No. 471, IAEA, Vienna (2009).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Dosimetry in Diagnostic Radiology: An International Code of Practice, Technical Reports Series No. 457, IAEA, Vienna (2007).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Dosimetry in Diagnostic Radiology for Paediatric Patients, IAEA Human Health Series No. 24, IAEA, Vienna (2013).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Management Audits in Nuclear Medicine Practices, 2nd edn, IAEA Human Health Series No. 33, IAEA, Vienna (2015).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Comprehensive Clinical Audits of Diagnostic Radiology Practices: A Tool for Quality Improvement, IAEA Human Health Series No. 4, IAEA, Vienna (2010).

[16] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Quality Management Systems - Fundamentals and Vocabulary, ISO 9000:2015, ISO, Geneva (2015).

GLOSSARY

calibration. "Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication".[1]

diagnostic imaging. Diagnostic imaging refers to a variety of non-invasive methods for identifying and monitoring diseases or injuries via the generation of images representing the internal anatomic structures and organs of the patient's body. The detailed images produced by these procedures are used to further inform the physician about the anatomic organization and functional working of the inner organs and structure of the patient's body, allowing the physician to inform the patient.

dosimetry. The theory and application of the principles and techniques involved in measuring and recording doses of ionizing radiation.

facility (medical radiation facility). A medical facility in which radiological procedures are performed.[2]

medical physicist. A health professional with specialist education and training in the concepts and techniques of applying physics in medicine and competent to practise independently in one or more of the subfields (specialties) of medical physics.[2]

clinically qualified medical physicist. Medical physicists who have received appropriate undergraduate education in physical or engineering sciences, followed by a professional competency training that includes an additional period of one to three years of academic education in medical physics at the postgraduate level and at least two additional years of structured practical training in a clinical environment, in one or more specialties of medical physics.[3] See also the definition of medical physicist in GSR Part 3.[2]

medical radiation technologist (radiographer). A health professional, with specialist education and training in medical radiation technology, competent to perform radiological procedures, on delegation from the radiological medical practitioner, in one or more of the specialties of medical radiation technology.[2]

quality assurance. The function of a management system that provides confidence that specified requirements will be fulfilled.[2]

quality control. A part of quality management focused on fulfilling quality requirements.[4]

quality management. All activities that organizations use to direct, control and coordinate quality. These activities include formulating a quality policy and setting quality objectives. They also include quality planning, quality control, quality assurance and quality improvement.[1]

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[1] BUREAU INTERNATIONAL DES POIDS ET MESURES, International Vocabulary of Metrology – Basic and General Concepts and Associated Terms, 3rd edn, JCGM 200:2012, BIPM, Sèvres, France.

[2] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Roles and Responsibilities, and Education and Training Requirements for Clinically Qualified Medical Physicists, IAEA Human Health Series No. 25, Vienna (2013).

[4] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Quality management systems - Fundamentals and vocabulary, ISO 9000:2015, ISO, Geneva (2015).

radiation protection officer. A person technically competent in radiation protection matters relevant for a given type of practice who is designated by the registrant, licensee or employer to oversee the application of regulatory requirements.[5]

radiological medical practitioner. A health professional with specialist education and training in the medical uses of radiation, who is competent to perform independently or to oversee radiological procedures in a given specialty.[5]

radiopharmacy. The areas of the nuclear medicine department devoted to the production and preparation of radiopharmaceuticals.

radionuclide therapy. The use of radiopharmaceuticals in patients for therapeutic purposes.

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[5] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

LIST OF ABBREVIATIONS

AAPM	American Association of Physicists in Medicine
CBCT	cone beam computed tomography
CPD	continuing professional development
CT	computed tomography
DR	diagnostic radiology
FTE	full time equivalent
NM	nuclear medicine
PET	positron emission tomography
SPECT	single photon emission computed tomography

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