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Education of Radiation Metrologists for Secondary Standards Dosimetry Laboratories

VIENNA, 2023

TRAINING COURSE SERIES

76

EDUCATION OF RADIATION METROLOGISTS FOR SECONDARY STANDARDS DOSIMETRY LABORATORIES

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TRAINING COURSE SERIES No. 76

EDUCATION OF RADIATION METROLOGISTS FOR SECONDARY STANDARDS DOSIMETRY LABORATORIES

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The secondary standards dosimetry laboratories (SSDLs) calibrate instruments used to measure the amount of radiation in different fields. The laboratories are the critical link between primary standards dosimetry laboratories and end users. The IAEA has published international dosimetry codes of practice and other publications that form the basis of the technical procedures needed for measurements and calibrations. Qualified staff with specific competencies are needed so these procedures are implemented consistently across SSDLs.

The IAEA and World Health Organization (WHO) coordinate the IAEA/WHO Network of Secondary Standards Dosimetry Laboratories. Many SSDLs in the Network were established or upgraded as part of an IAEA Technical Cooperation Project. The IAEA designs and coordinates training courses for technical staff, prepares publications and e-learning material and organizes symposia in the field of dosimetry.

A shortage of adequately trained staff is a serious obstacle to the appropriate operation of an SSDL and its recognition. There is no standardized definition of or education framework for the role of radiation metrologists, who carry out technical work in SSDLs. As a result, the competencies in SSDLs can vary significantly. The SSDL Scientific Committee, which advises the Network Secretariat, suggested drafting a publication on the education of radiation metrologists.

The aim of this publication is to provide information to authorities and stakeholders responsible for or interested in SSDLs on the training and competencies needed for personnel working at an SSDL. It also provides a framework for the education, practical training and competencies of radiation metrologists responsible for SSDL activities, which can be used to harmonize the education of radiation metrologists. A model is included to identify potential gaps and define a professional development plan to cover the necessary competencies of the role of radiation metrologists. This publication may also be useful for other radiation physics laboratories.

The IAEA officers responsible for this publication were P. Toroi and Z. Msimang of the Division of Human Health.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Accurate radiation dose measurements are needed wherever ionizing radiation is used, whether to ensure safety of the people and the environment, or to ensure proper diagnostic imaging and/or treatment outcome of a patient. Particularly in radiation oncology, successful treatment depends on the accuracy of dose delivery to the patient. Accurate patient dosimetry is important also in diagnostic imaging, in which clinical investigations are responsible for the vast majority of the man-made radiation burden [1]. Radiation protection of radiation workers and estimation of their radiation exposure are legal requirements in most countries and consistent measurements are essential. The International Basic Safety Standards (IAEA Safety Standards Series No. GSR Part 3) stipulates that the governments shall make provision for the calibration of the radiation monitoring and measuring equipment [2]. It also puts a responsibility on license holders to ensure measurements performed using dosimeters used for patient dosimetry are traceable to a standards dosimetry laboratory [2].

In 1976, the International Atomic Energy Agency (IAEA) together with the World Health Organization (WHO) established a Network of Secondary Standards Dosimetry Laboratories (SSDLs), known as the IAEA/WHO SSDL Network [3]. The Network, through SSDLs designated by the IAEA Member States, provides traceability for dosimetry to the International Measurements system, the SI. The main services of the SSDL Network members are the dissemination of radiation dosimetry quantities to end users by instrument calibration and assistance in how to use the calibration results in their application.

The work in a calibration laboratory requires specific knowledge and competencies. The IAEA/WHO SSDL Network Charter requires that

> "The SSDL shall have technical and managerial personnel who have the authority, qualifications and competence to operate the specific equipment needed for radiation measurements, perform calibrations, evaluate the results and authorize calibration certificates. The personnel shall be qualified based on appropriate education, training, experience and demonstrated skills, as required" [3].

The ISO/IEC 17025 standard also states that

> "The laboratory shall ensure that the personnel have the competence to perform laboratory activities for which they are responsible and to evaluate the significance of deviations." [4]. In addition, "The laboratory shall document the competence requirements for each function influencing the results of laboratory activities, including requirements for education, qualification, training, technical knowledge, skills and experience" [4].

To define and assess the required competencies requires a systematic approach.

1.2. OBJECTIVE

The aim of this publication is to provide guidance to authorities, and stakeholders responsible or interested, on how to fulfil the above need and to implement requirements of qualification and competence for the professionals working in SSDLs. However, this model can also be applied to other radiation physics laboratories. A qualified radiation metrologist (QRM) is a highly specialized professional who has undergone postgraduate academic education, followed by a structured and supervised practical training, to achieve independence in their profession whether it is in dosimetry, radioactivity and/or neutron measurements. In this publication the term ‘radiation metrologists’ and QRM are used for professionals working in a dosimetry laboratory, who are qualified and have mastered all the competencies needed for their role in the SSDL.

1.3. SCOPE

While the focus of this publication is on the guidance for the education of a radiation metrologist, a competency framework is introduced to facilitate the documentation of basic competencies recommended for the technical staff responsible for the key SSDL activities. It is hoped that the implementation of the recommendations given in this document will lead to an effective, systematic, and internationally harmonized approach to the education of QRMs. Even though the publication is focussed on SSDLs, it may be used by primary and other dosimetry laboratories e.g. accredited laboratories.

Depending on the number of activities and resources of the SSDL, there may be several members of staff having different roles and responsibilities. Typically, the roles include the head of the laboratory, a staff responsible for co-ordinating the quality management system (might be given a title of a quality manager or quality co-ordinator), a staff responsible for radiation protection activities (might be given a title of radiation protection officer), a staff responsible for security of radioactive material (might be given a title of security officer), and QRM. Depending on the size and resources of an SSDL, the head of the laboratory, quality manager, radiation protection officer, or security officer, for instance may be shared between other laboratories. However, the aim is to have at least one QRM in each SSDL.

Theoretical knowledge is not enough to become a QRM, appropriate skills and attitudes to implement the knowledge in practice are needed. Competencies can serve as a solid foundation of performance management in any field, including the work in radiation dosimetry laboratories. The competency framework and model presented are based on the adoption of a comprehensive quality management approach in SSDLs, encompassing professional education, with the ultimate goal of quality improvement. The model can be used by SSDLs or their parent organization to assess the competencies of the existing or new staff. It can help to identify gaps in education to assist training facilities on what competencies need to be strengthened and consequently provide the necessary training. The competency model is a key tool for teams who are planning to establish a dosimetry laboratory, to help identify the human resources and required competency-based training. Similar competency-based frameworks and training programmes have been published, including the IAEA’s Training Course Series on clinical training of medical physicists [5-8] and TECDOC-1254 [9], respectively.

The academic and practical training programme in this publication provides a set of competencies for QRMs to work in an SSDL. The programme aims at covering the core components of the SSDL work and concentrates on calibration related activities. This includes implementation of the SSDL quality management systems and performance of internal audits. However, there might be other functions of the SSDL, such as dosimetry audits at hospitals, which might need additional competencies. An academic programme without the practical training component can prepare a student for radiation dosimetry research or industry. An academic programme without the practical training is not sufficient for an individual to become a qualified QRM.

1.4. STRUCTURE

This publication provides information on training requirements for radiation metrologists and on evaluating competencies. Section 2 describes the international environment the SSDL operates under, and the skills required. Section 3 focusses on the educational requirements and what is needed to provide academic and practical training. Section 4 covers the practical training programmes, the attitudes needed, and the competency levels and how to conduct assessments for trainees. Section 5 introduces the competency framework.

2. FUNCTIONS AND FEATURES OF AN SSDL

The major service of an SSDL is the dissemination of radiation dosimetry traceability to end-users through instrument calibration. Related to this function, the radiation metrologist provides information on calibration procedures and practical advice to end-users on the appropriate use of the calibration information for that instrument in the field. Those SSDLs with the relevant facilities and expertise, may also provide other services, which may include but are not limited to performing dosimetry audits, teaching, and providing training to radiation metrologists and end-users. The following Sections briefly describe the functions and features of SSDLs. This information describes the complexity of an SSDL and serves the purpose of identifying the related competencies and their variety.

2.1. INTERNATIONAL METROLOGY SYSTEM AND TRACEABILITY

Figure 1 illustrates the traceability chain for dosimetry measurements globally.

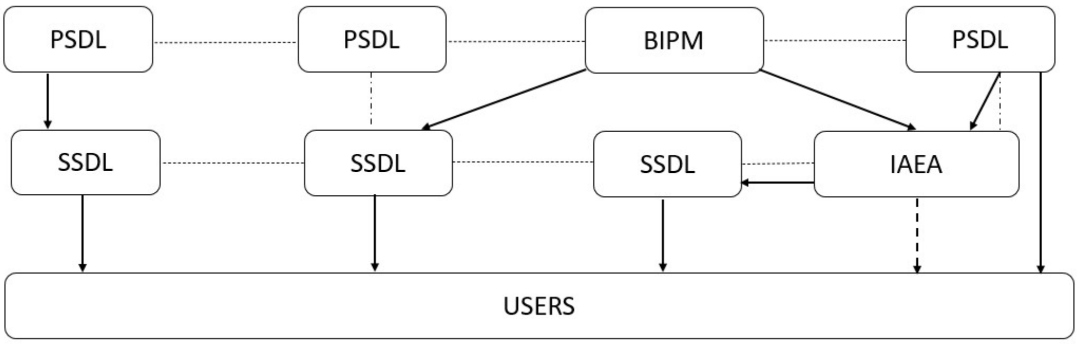

FIG. 1. A simplified representation of the international measurement system for radiation dosimetry. The arrows represent the calibrations which ensure the traceability chain to the international measurement standards and the dotted lines indicate comparisons of primary standards laboratories (PSDLs) linking to the Bureau International des Poids et Mesures (BIPM) and secondary standards dosimetry laboratories (SSDLs). The dashed arrow represents exceptional calibration of a user instrument by the IAEA in the event that a country has no SSDL and has very limited resources (reproduced from Ref. [3]).

Accurate dosimetry is required at the user level in order to be able to perform measurements that are reliable and comparable to those performed by other end-users under similar conditions. Different formalisms for dosimetry are applied in the medical and industrial use of radiation and they are typically based on international or national protocols. Therefore, the aim of the international measurement system is to ensure that there is a degree of equivalence in measurements for a specific quantity, regardless of where they are performed.

The International Committee for Weights and Measures (CIPM) has established a mutual recognition arrangement (CIPM MRA) for Member States of the Metre Convention and Associate States of the General Conference of Weights and Measures [10, 11]. The CIPM MRA allows for the calibration and measurement capabilities (CMCs) of each signatory National Metrology Institute or Designated Institute, to be accepted by all the other signatories.

To achieve and maintain international recognition, each member of the CIPM MRA or SSDL Network should have a national designation, take part in relevant measurement comparisons, and demonstrate the quality of their measurements through a peer reviewed quality management system (QMS) in line with the ISO/IEC 17025 [3, 4, 10, 12, 13].

The objective of the SSDLs is to promote and ensure appropriate accuracy and consistency of dosimetry. By providing calibrations for end-users, the SSDLs provide metrological links to the international measurement system. The SSDL Network thus serves to achieve worldwide harmonization in radiation measurements that can be traced back to the measurement standards of the BIPM and the primary standards dosimetry laboratories (PSDLs). Consequently, the role of the metrologists in an SSDL is to support the fulfilment of these activities with the relevant competencies and the highest work standards.

2.2. RESOURCES

In line with the ISO/IEC 17025 [4] and SSDL Charter [3] requirements,

> "The SSDL shall have technical and managerial personnel who have the authority, qualifications and competence to operate the specific equipment needed for radiation measurements, perform calibrations, evaluate the results and authorize calibration certificates" [3].

Consequently, several roles and competencies are needed to perform the SSDL operations including appropriate premises, calibration facilities, equipment, quality management systems and support services necessary to manage and carry out its laboratory activities. "The facilities and environmental conditions shall be suitable for the laboratory activities and shall not adversely affect the validity of results" [4].

The required equipment includes, but is not limited to, irradiators, calibration bench, measurement standards (e.g. ionization chambers), electronic measuring instruments and reference materials and ancillary equipment (e.g. barometers, thermometers, and hygrometers). As for measurement standards, the SSDLs are equipped with reference dosimetry standards whose calibration is traceable to primary standards either directly or through the IAEA.

The characteristics of the required resources in an SSDL are often very specific and the SSDL may be the only institute in the country using those kinds of instruments. The facility requirements are dependent on the planned activities, and it is of highest advantage to the laboratory if a QRM is involved at the planning stage. In addition, dedicated equipment is required for the calibration work and proper technical and performance specifications are needed to purchase appropriate items. Adequate competencies would be beneficial in those cases, to allow the QRM to best support the SSDL work.

2.3. CALIBRATION PROCEDURES

The QRMs in an SSDL will use appropriate methods and procedures for all laboratory activities, including the evaluation of the measurement results and estimation of measurement uncertainties as well as statistical techniques for data analysis. The equipment is to be operated as prescribed, and different modes of operation may prevail. The calibration procedures are to be compatible with the dosimetry protocols recommended nationally or internationally [14-18]. Non-standard methods or methods used outside their intended scope need to be properly validated before they are used on routine work. The analysis of results is to be performed in a systematic way and following documented procedures. The SSDL has to ensure that the technical records for each service contain the results, a copy of the final calibration certificate that was issued and sufficient information for the users to identify factors affecting the measurement result, as well as its associated measurement uncertainty.

2.4. QUALITY MANAGEMENT SYSTEM

The SSDLs establish a Quality Management System (QMS) in line with the ISO/IEC 17025 standard [4] for measurement capabilities to be acceptable. The purpose of the QMS is to maintain and improve the reliability of calibrations and other laboratory activities. The QMS contains managerial and technical procedures which are applied in the SSDL. The roles and responsibilities of the staff and actions leading to potential non-conformance are defined.

The scope and contents of the QMS is to cover the services and the resources of the laboratory and reflect the organizational procedures and policies pertinent to each SSDL. While many features of the quality system are common amongst laboratories with similar capabilities, equipment and responsibilities, the laboratory QMS cannot be copied from other organizations. It has to reflect what is being practised at the SSDL.

2.5. RADIATION SAFETY AND SECURITY OF RADIOACTIVE MATERIAL

The responsibility for radiation protection and safety is included among the SSDL-managed activities. A safe and secure working environment for all laboratory activities is to be ensured including the promotion of safety and security culture. The design of calibration facilities and monitoring of occupational exposure has to conform to the relevant national and international regulations. QRMs consequently need appropriate competencies to use the radiation sources safely, securely and respond in a case of a radiological emergency or security event.

2.6. RESEARCH

An effective way of maintaining and developing the practice as well as the competencies of the SSDL staff is to undertake research activities. Participation in research projects coordinated within the regional metrology organizations (RMOs), or national projects, or IAEA Coordinated Research Projects (CRPs) are good approaches and provide effective networking of SSDL’s activities.

2.7. COMMUNICATION AND STAKEHOLDER ENGAGEMENT

Effective communication within the SSDL and with stakeholders is crucial for the SSDL’s operation and sustainability. Ineffective communication with stakeholders may negatively impact on the funding of the laboratory, access, and use of the SSDL services by end users. SSDL staff need to be able to identify gaps in the market, in their area of expertise, and write proposals for input into the strategic direction of their organization relating to the needs for dosimetry in the country and the region. Since developing and maintaining a QMS is fundamental, SSDL staff need to be able to communicate in writing and review their internal procedures and processes.

3. EDUCATION REQUIREMENTS

A professional can be considered a QRM once a relevant academic qualification followed by a structured and supervised practical training programme has been completed. Ongoing recognition of QRMs are to be established through defined mechanisms of peer review and maintenance of competency through continuous professional development (CPD). Figure 2 schematically shows the possible pathways toward becoming a QRM, clearly highlighting the main building blocks of the education and training process.

3.1. RADIATION METROLOGY ACADEMIC PROGRAMME

Solid theoretical knowledge underpins the work of a QRM and prepares the candidate for the practical training. Such theoretical knowledge can be provided in different ways and through the collaboration of different entities and stakeholders. In some context the knowledge is provided through a specific extensive course organized for instance under the lead of specific national bodies. Such courses often are conducted in collaboration with academic entities. In other instances, the knowledge can be provided directly as part of an academic pathway. The possible pathways are typically identified and appropriately recognized nationally. In case of an academic degree specifically in metrology, for its specialized nature, this can be identified – similarly to other specialized professions such as medical physics – as a postgraduate level degree. Fig. 2 shows a pathway that may be followed by a candidate for initial and continuous training.

3.1.1. Admissions criteria

The pre-requisites for entering a radiation metrology academic programme, can be:

- Postgraduate-level or PhD-level or equivalent degrees in physics or engineering science;
- Undergraduate-level degree (BSc) in any field of physics or an equivalent relevant physical or engineering science.

The candidates entering a radiation metrologist academic programme are typically requested to be in possession of a 3–4 years undergraduate degree in physics or an equivalent relevant quantitative physical science or physics-engineering science core degree. There is a need for national qualifications authorities to determine the local degree equivalence prior to student registration in the radiation metrology programme, as there are significant variations in the composition of university level education worldwide [19]. Universities might establish minimum requirements in terms of prerequisite knowledge necessary for students' admission to a postgraduate-level radiation metrology academic programme. For students with MSc or PhD or equivalent, it will be necessary to interrogate the academic transcript of the degree to establish which modules they need to cover in the radiation metrology programme.

3.1.2. Academic faculty

The academic faculty involved in delivering a theoretical programme in metrology is to preferably include at least one instructor holding a PhD in physics and specialization could be in medical physics, radiation dosimetry, radiation physics, etc.. The lack of faculty with a PhD degree will most likely limit the ability of the institution to offer a strong research component, considering that a programme typically includes a component relevant to independent research (e.g. final thesis/report) [19]. Teaching may be provided by full-time academic staff with the assistance of QRMs working in Standard Dosimetry Laboratories. To ensure the programme is aligned to the needs of the professional field, it is crucial that at least one QRM is formally involved in the development and coordination of the programme.

3.1.3. Academic programme

The aim of the academic programme is to introduce students to the principles of ionising radiation dosimetry, and to prepare them for a practical, structured, and supervised training programme (laboratory-based).

For the academic programme, a minimum duration of one year is recommended but this needs to be determined by the relevant involved stakeholders, typically academic institutions and adequately recognized by the national authority. Table 1 gives the main modules that are to be covered and suggestions are provided where other academic programmes may overlap in content. It also shows the relative weighting that may be adopted to determine contact hours. Contact hour is a measure that represents a one-hour period of scheduled instruction. Appendix I gives an outline of the SSDL-specific and adapted core modules.

There are modules that are not SSDL-specific and may be offered in other university programmes (e.g. related to physics or medical physics). Many of these modules are consistent with the Postgraduate Medical Physics Academic Programmes [19]. Other formats of learning (self-studying, e-learning) could be used to deliver or complement the modules. This academic programme when successfully completed is a partial fulfilment to becoming a QRM.

TABLE 1. THE CORE MODULES FOR POSTGRADUATE ACADEMIC PROGRAMMES IN RADIATION METROLOGY

Module name	Applicable academic programme	Suggested weighting
Radiation physics	Physics or Medical Physics	20%
Fundamentals of dosimetry	Physics or Medical Physics	20%
Metrology system	SSDL specific	10%
SSDL resources	SSDL specific	10%
Data analysis and uncertainties	SSDL specific	10%
Radiation protection and radioactive material security functions, measures, and concepts	Adapted from Medical Physics	15%
Applications of radiation	Adapted from Medical Physics	10%
Professional and scientific development	Universal	5%

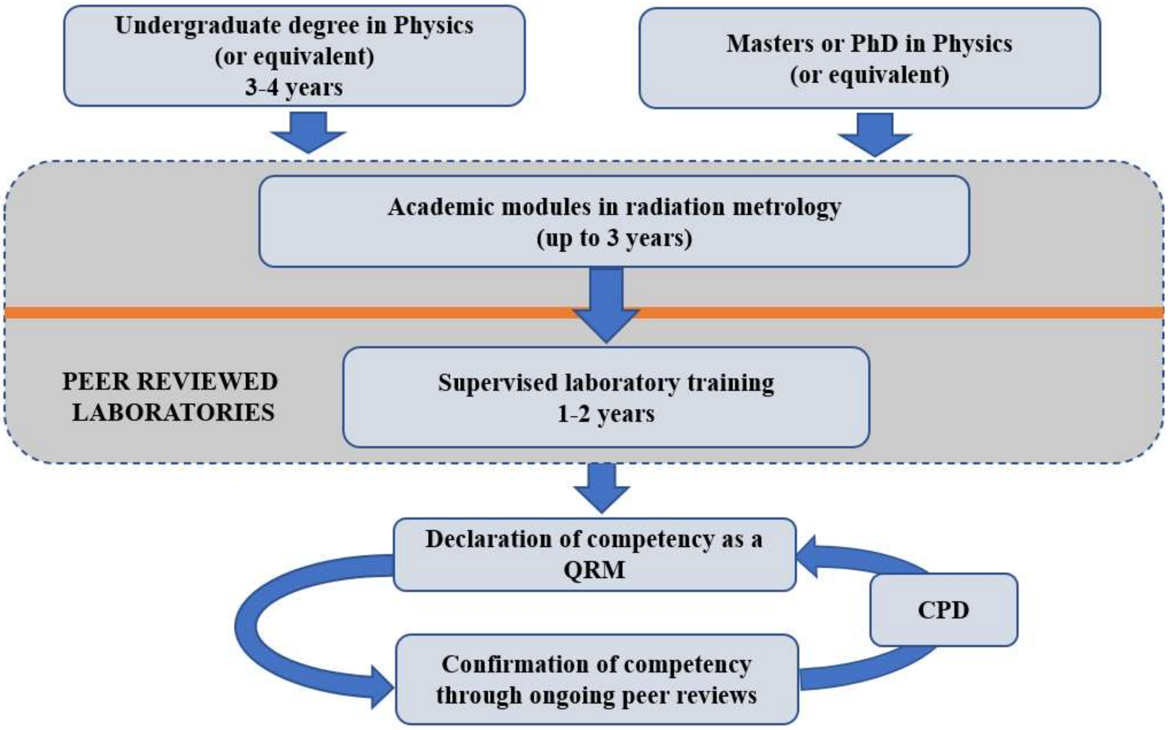

FIG. 2. Recommendations on minimum requirements for the academic and practical training of a Qualified Radiation Metrologist. [20]

3.2. RESOURCES FOR LABORATORY TRAINING

Linking the academic institution or university with a dosimetry laboratory, an agreement or Memorandum of Understanding (MoU) may be signed, providing students with supervised access to a PSDL or SSDL equipment [19]. A PSDL/SSDL be a laboratory that has been peer reviewed under the CIPM MRA [10] or accreditation process for compliance to ISO/IEC 17025 [4]. It would be advantageous if as part of the practical training the student is exposed to at least the following equipment at the partner metrology laboratory:

- Gamma beam irradiator;
- X ray irradiator;
- Calibration bench;
- HVL measurements assembly;
- Radiation detectors (ionization chamber, electronic personal dosimeter, etc.,);
- Electrometer/s;
- Cables, connectors, and adapters;
- Ambient conditions monitoring equipment;
- Phantoms.

Because students will be exposed to a radiation exposure environment and some customer information, all local liability issues concerning equipment, health and safety, radiation safety and protection, professional, professional ethics and confidentiality need to be clarified in the MoU.

Internet connectivity and access to computer workstations with basic computational software is important. The computational software that focuses on processes (codes, scripts, versioning) and that is compliant with FAIR principles, so that approaches may be shared both within SSDLs where multiple metrologists reside and across SSDLs, where possible. Library access including electronic journal access and the relevant reports and publications from the major metrology international reference organizations is important (e.g. IAEA, BIPM, ICRU etc.).

4. PRACTICAL TRAINING PROGRAMMES

The practical training of radiation metrologists is to include supervised work at an SSDL/PSDL that has been peer reviewed under the CIPM MRA [10] or an SSDL/WHO Network that is accredited for capabilities in accordance with ISO/IEC 17025 [4] requirements. The practical training is to be acquired through a competency-based training under supervision of a radiation metrologist/scientist for a minimum duration of one year. The entrance requirement for accessing a practical training programme in radiation metrology is a postgraduate academic education in radiation metrology (or equivalent), as per Section 3.

The competency areas which are to be achieved during practical training together with their suggested relative weight, are given in Table 2. Appendix II describes competencies for practical training of radiation metrologists as per Table 2.

TABLE 2. THE COMPETENCY AREAS TO BE ACQUIRED BY A QRM DURING PRACTICAL TRAINING AT A LABORATORY AND THE SUGGESTED RELATIVE WEIGHT OF EACH

Competency area	Relative weight
Metrology system and traceability	20%
SSDL resources	20%
Calibration procedures	30%
QMS	10%
Radiation protection and security of radioactive material	10%
Professional ethics	10%

The specific competencies that can be acquired in a given laboratory will depend on the calibration services (e.g. external beam radiation therapy, brachytherapy, radiation protection, diagnostic radiology, nuclear medicine). Laboratories that provide personnel dosimetry services could include competencies related to this service. Competencies in reference dosimetry are needed to provide advice to end-users and it is best practice for laboratories to participate in international reference dosimetry audits.

However, since not all hosts of practical training will be able to provide competency-based training in all dosimetry laboratory services, a cooperative network of host laboratories can be established. Likewise, specific competencies to strengthen QRMs, in case services offered in their laboratory change or expand, can be identified within the cooperative network. Additional competencies may also be offered as part of a CPD system for instance.

4.1. RECORD OF PRACTICAL TRAINING

Formal documentation of competencies acquired during practical training at a laboratory is advisable. Examples of the competencies in each area are provided in Appendix II. It is important that the competencies are recorded in a structured portfolio. The portfolio provides an opportunity to demonstrate the breadth and depth of the competencies.

A portfolio could incorporate the following elements [21]:
- Curriculum vitae;
- Progress reports;
- Summary of Competency Achievement demonstrating the level of competency achieved in each sub-module;
- Samples of work prepared by the student, assignments on key competencies;

- Evidence of research conducted during the practical training: papers published in a peer reviewed journal, presentations delivered covering key aspects of the learned competencies.

The student together with the supervisor are to review the portfolio at regular intervals, discuss progress, analyse missed opportunities, and address where further effort is required.

It is recommended that a student keeps track of their training detailing their experience and gaps for the day to assist with discussions with the supervisor and the preparation of the portfolio. This could be in a form of a logbook which can also be used to demonstrate that sufficient work has been performed.

4.2. PROFESSIONALISM AND ATTITUDES FOR A QRM

Professionalism and the appropriate attitude are an integral part of all competencies and are to be evaluated accordingly. A poor or unsuitable attitude might have a negative impact on the quality of calibration services. A QRM should have, in addition to specified knowledge and skills, a proper attitude towards tasks performed in a dosimetry laboratory.

Examples of attitudes are:

- Attention to detail;
- Ethical;
- Understanding the importance of recording processes;
- Ability to follow policies, procedures and instructions;
- Open, honest and tactful communication;
- Ability to receive and evaluate criticism and/or correction;
- Team work;
- Respect for timelines;
- Understanding the importance of implementing and adhering to safety and security cultures;
- Customer (end-user) service orientation;
- Maintaining level of awareness and transparency;
- Proactiveness.

4.3. COMPETENCY LEVELS

The assessment of existing competencies is also the basis for an SSDL to evaluate the status and potential need in terms of additional staff training. As defined in the IAEA SRS 79 [22], competencies are groups of related knowledge, skills and attitudes (KSAs) needed to perform a particular job. Four different levels of competency for an SSDL are defined in Table 3, referring to 1 as the lowest, and 4 the highest and most complete level of competency. This scale aims at facilitating the competency assessment in SSDLs. Examples of uses of this scale are provided in Appendix III.

TABLE 3. COMPETENCY LEVELS TO BE USED TO EVALUATE A RADIATION METROLOGIST

Level No.	Description	Definition
1	Entrance level	Basic KSAs acquired, but not sufficient to carry out a task.
2	Working under supervision	Able to apply the relevant KSAs to perform a task under supervision of a competent staff.
3	Working independently	Able to apply the relevant KSAs to independently perform a task.
4	Supervising others	Achieved level 3 with full confidence. In addition, able to supervise, check and validate the work of other staff, evaluating their level of competency.

4.4. ASSESSMENT OF COMPETENCIES

The assessment of competencies is usually done throughout the practical training programme against clearly set criteria. This assessment will include lower-level assessments (informal, all along the process) and higher-level assessments (for instance the practical session to validate the whole training) and the review of the portfolio.

There are several components to the periodic assessment of a trainee. The supervisor can schedule a competency assessment at any agreed time. The assessment's focus is on one or a number of the following factors: calibration work i.e. qualified staff formally observe routine tasks as ongoing assessment of competence; topic-focussed, i.e. practical work is assigned and responsibility given once the competencies within a particular module are covered. It is expected that many of the competencies will be assessed on several occasions. For example: a particular competency might be worked on for some time and the student assessed as having obtained a level of 2. The student might then be rostered to another area and return to work on the first competency at a later stage with a second assessment being conducted at the end of this period. Following any assessment of competency, the trainee can be provided with supportive and corrective feedback. A competency assessment is not just reviewing technical ability but also attitudes, such as safe practice and communication skills, as expected of a QRM.

There are many possible methods by which competencies may be assessed. The assessor may:

- Listen to a trainee demonstrating a task to someone else;
- Use oral assessment in a regular supervisor-student meeting;
- Request short written report and provide assessment and constructive feedback;
- Use practical assessment including oral questioning during a routine task;
- Set equipment trouble-shooting case studies;
- Request a list of key steps involved in completing a task;
- Review the portfolio;
- Request a presentation to departmental staff.

To perform a comprehensive assessment, it is recommended that the candidate, whose competence is being assessed, complete a variety of assignments such as responding to oral/written questions, practical exercises, demonstrations and/or presentations, and conducting calculation and measurement. It is recommended that the trainee is not evaluated by any of the supervisors involved in their training.

5. COMPETENCY FRAMEWORK AND MODEL

The competency framework and model provide a basis for international standardization and harmonization of competencies needed for QRMs and contribute to strengthening radiation metrology worldwide. In addition, it offers a methodology for performing a skills gap analysis in the competencies relevant to the services offered by SSDLs. The overview of the QRM programme is given in Fig. 3. In some instances, it could be possible to run the academic programme and the practical training in parallel.

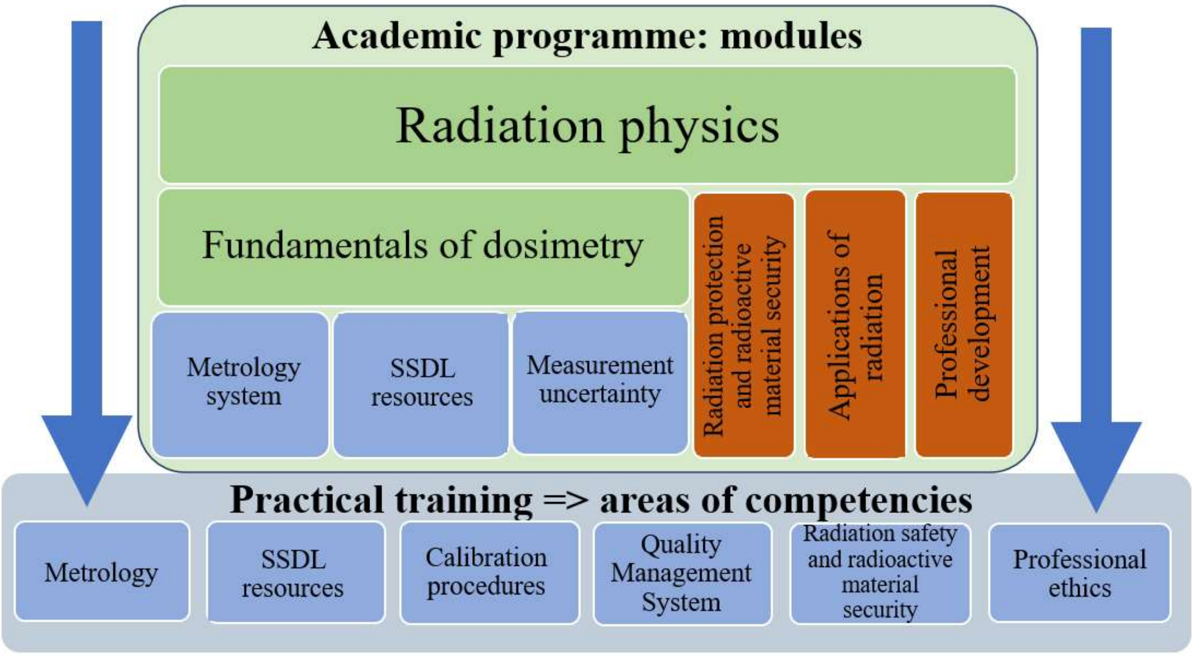

FIG. 3. Overview of the recommended programme for a Qualified Radiation Metrologist, including the academic programme and the areas of competencies (practical training). Modules shown in the figure are those listed in Table 1 and Table 2 for the practical training.

5.1. ACADEMIC PROGRAMME

Due to insufficient critical mass, needed to sustain education programmes in training institutes, there is currently no academic programme exclusively dedicated to train radiation metrologists. Typically, there may be only one SSDL in each country thus the number of professionals needed to be trained is very low. Consequently, to ensure sustainability and to optimize resources, it is important that Member States consider regional/cross regional or international collaborations in pursuit of capacity building in this domain.

5.2. PRACTICAL TRAINING

The current practice entails SSDLs recruiting university graduates in science or engineering and ideally identifying training requirements for new staff, considering the competencies required to perform the job. The training requirements may include additional scientific or technical knowledge and on-the-job training on laboratory specific processes and procedures to ensure that the new staff reaches competency to perform their assigned tasks, as per the requirement of ISO/IEC 17025 [4]. This approach can work for SSDLs with a well-established quality management system, qualified and experienced staff, having sustainably structured and well-organized processes to perform and maintain capacity building through internal processes. The same cannot be assumed for laboratories that are in the planning or establishment process that have no qualified and experienced staff. These laboratories can request training of new or existing staff in well-established laboratories or have an expert train staff onsite. In these cases, performing an appropriate gap analysis of existing competencies will help the SSDL to ensure that the training requested meets their needs.

5.3. CONTINUOUS PROFESSIONAL DEVELOPMENT AND PEER REVIEW OF QRM COMPETENCIES

It is expected that the competency of a QRM will be nationally recognized officially, for instance through a system of peer review or as part of the process of laboratory accreditation. It is recommended that a system of maintenance of knowledge and competencies is also put in place through continuous professional development (CPD) activities. CPD will also address needs of specific and new competencies required by SSDL staff, for instance in case of expansion of the SSDL services. The feasibility of formalising a CPD programme is advisable, taking into consideration the role and responsibility of QRMs in the measurement chain.

All QRM training programmes ideally result in appropriate national and international recognition. Streamlined and coordinated efforts among different providers of academic and practical training are recommended.

It is to be noted that a certification process for QRMs does not currently exist at an international level even though some countries have established it, see [23, 24]. It is hoped that such process, based on these IAEA guidelines, will be defined in the near future.

APPENDIX I.

RECOMMENDED ACADEMIC SYLLABUS FOR RADIATION METROLOGISTS

For the modules that are usually offered in academic medical physics programmes, as detailed in Table 1, the outline of the content may be found in the IAEA TCS 56 (Rev.1) [19].

I.1. RADIATION PHYSICS

Objective: The module introduces the fundamental quantities and concepts that describe the physical interactions of ionizing radiation with matter. Content from the medical physics programme is provided in the IAEA TCS 56 (Rev.1) [19].

I.2. FUNDAMENTALS OF DOSIMETRY

Objective: The module introduces dosimetric quantities and units and includes the historical development of the theories that justify the design and use of air ionization chambers, based on charged-particle equilibrium and/or cavity theory. These concepts are further developed into formalisms and methodologies that are applied through international codes of practice for dosimetry. Content from the medical physics programme is provided in the IAEA TCS 56 (Rev.1) [19].

I.3. METROLOGY SYSTEM

Objective: The purpose of this module is to provide a comprehensive overview of international measurement system and traceability. International requirements for recognition of calibration services and different types of comparisons are covered. Basic principles of typical primary standards and dissemination of traceability in dosimetry are described.

Content:

- International metrology system.
  - Introduction to metrology and legal metrology;
  - The fundamental constants and the SI;
  - Traceability;
  - Metrology standards and guidance;
  - The CIPM MRA [10];
  - International Vocabulary of Metrology [25] including types of standards (Primary, Secondary, Working, Transfer);
  - The International organizations (BIPM, OIML, IAEA);
  - IAEA/WHO SSDL Network and Charter [3].
- Radiation standards.
  - Primary Standards Dosimetry Laboratories (PSDLs);
  - Secondary Standards Dosimetry Laboratories (SSDLs);
  - Dosimetry Formalisms, International Standards and Codes of Practice;
  - Development and validation of technical procedures;
  - Calibration;
  - Testing and verification.
- Comparisons and audits.
  - Different types of comparisons;

    - Different types of audits;
    - Analysis of comparison results;
    - Calculating degrees of equivalence;
    - Correlations in uncertainty of measurements.
- Quality Management.
    - Total Quality Management System;
    - ISO/IEC 17025 [4].

I.4. SSDL RESOURCES

Objective: The module provides technical guidance for the establishment or upgrade of an SSDL. The module defines facility requirements and key equipment used for calibrations. The module introduces the basic principles on the electronic components and functioning of devices and systems typically used in radiation metrology.

Content:

- SSDL facilities.
    - Facility requirements and design;
    - Bunker construction, shielding calculation and verification;
    - Safety and security.
- Irradiation units and positioning systems.
    - Gamma irradiators (radiation protection and radiotherapy);
    - X ray irradiators (diagnostic and therapeutic kilovoltage, radiation protection);
    - Other radiation sources (brachytherapy, neutron, beta, etc.);
    - Calibration bench;
    - Ancillary equipment for positioning and reading of dosimeters (lasers, optical telescope, cameras, etc.);
    - Radiation safety items;
    - Beam properties (spectra, dose rate, time structure, HVL, μ/ρ and mean energy, etc.).
- Measuring equipment.
    - Radiation detectors (ionization chambers, electronic personal dosimeters, etc.);
    - Electrometers;
    - Cables, connectors, adapters;
    - Phantoms;
    - Ambient air monitoring equipment.
- Electronics.
    - Principles of voltage, current and charge measurements;
    - Electrometers for charge and current measurement, basic circuitry;
    - High-voltage generators;
    - High voltage dividers;
    - Causes of noise and hum (ground loops, electromagnetic interference) and solutions;
    - Use of oscilloscopes for displaying detector signals;
    - Electromagnetic compatibility.

I.5. DATA ANALYSIS AND ESTIMATION OF UNCERTAINTIES

Objective: The module provides guidance for the handling of measurement data including data analysis, probability modelling and describing measurement fluctuations. Standard methodologies and practices for data management are introduced, and the use of statistical methods to estimate measurement uncertainties for all radiation metrology measurements.

Content:

- Data management.
  - Data collection, organization and storing;
  - Computational tools and analysis;
  - Statistical methods;
  - Information technology with emphasis on networking and data integrity;
  - Database management;
  - Reporting.
- Uncertainty estimation and GUM principles [26].
  - Errors and uncertainties;
  - Accuracy and Precision;
  - Typical sources of uncertainties;
  - Absolute and relative uncertainty;
  - Type A Standard uncertainty;
  - Type B Standard uncertainty;
  - Law of propagation of uncertainty;
  - Combined and expanded uncertainty, coverage interval, coverage factor;
  - Uncertainty budget;
  - Probability distribution functions;
  - Sensitivity coefficients;
  - Degrees of freedom;
  - Uncertainty correlations;
  - Principles of Monte Carlo methods of uncertainty estimation;
  - Reporting of measurement results and their associated uncertainty.

I.6. RADIATION PROTECTION AND RADIOACTIVE MATERIAL SECURITY FUNCTIONS, MEASURES AND CONCEPTS

I.6.1. RADIATION PROTECTION

Objective: The module introduces the basic principles and philosophy of radiation protection. Attention is given to radiobiology, regulatory aspects, safety, personnel monitoring instrumentation, radiation survey instruments, waste management, emergency procedures and risk assessment. Content was adapted from the medical physics training detailed in the IAEA TCS 56 (Rev.1) [19].

Content:

- Introduction, historical perspective, and sources of radiation.
- Principles and philosophy.
  - Justification, optimization (As Low As Reasonable Achievable) and dose limitation;
  - Radiation effects;

    - Quantities and units;
    - Exponential attenuation, half-value layer (HVL), inverse square law, tenth-value layer (TVL).
- Radiobiology.
    - Classification of radiation;
    - Effects of radiation on cells, tissues and organs;
    - Type of radiation damage (tissue, organ and whole body) and repair;
    - Dose rate effect;
    - Pregnancy (radiation effects on embryo and foetus);
    - Extrapolation to low doses and risk models (Linear, no Threshold (LNT) model and the consequences of any proposed deviations from the LNT predictions);
    - Early and late effects of radiation.
- Regulatory infrastructure.
    - Legal framework for radiation protection;
    - International Basic Safety Standards (IBSS), National Academy of Sciences Biologic Effects of Ionizing Radiation (BEIR), International Commission on Radiological Protection (ICRP), etc.;
    - National regulations.
- Radiation measuring instruments.
    - Calibration and operation;
- Radioactive waste and radioactive source management and transport.
- Occupational, public exposure and annual limits.
- Radiation emergency procedures.
- Risk assessment.

I.6.2. RADIOACTIVE MATERIAL SECURITY

Objective: The module introduces the basic principles and concepts of nuclear security of radioactive material and associated facilities. Attention is given to the security of radioactive material in use or in storage, as well as associated facilities and associated activities, against unauthorized removal of the radioactive material and sabotage performed with the intent to cause harmful radiological consequences. Content was adapted from Model Academic Curriculum in Nuclear Security detailed in Nuclear Security Series No. 12-T (Rev.1) [27],

Content:
- Introduction to nuclear security.
    - Legal and regulatory framework for nuclear security;
    - Risk based nuclear security systems and measures: detection, delay and response;
    - Interface of nuclear security with safety;
    - Preventive and protective measures against insider threat;
    - Information and computer security (information confidentiality, integrity, and availability);
    - Nuclear security culture;
    - Security management.
- Protecting material, facilities and activities.
    - Threat and vulnerability assessment for radioactive material, associated facilities and activities;

        - Design basis threat;
        - Representative threat statement.
- Principles and security systems (design, evaluation, technologies, equipment);
- Security of radioactive material in transport;
- Detecting and responding to nuclear security events involving radioactive material.

I.7. APPLICATIONS OF RADIATION

Objective: The module introduces a student to the physics principles and technical aspects of all applications of ionising radiation. The principles and the operating modes of the different equipment used in medical and non-medical fields are given. The definitions and use of quantities to describe the radiation beams and radioactive source are given. Some of the content was adapted from the medical physics training detailed in the IAEA TCS 56 (Rev.1) [19].

I.7.1. NON-MEDICAL USE OF RADIATION

Content:
- Industrial.
    - Non-destructive testing;
    - Sterilization of medical devices;
    - Foodstuff irradiation;
    - Nuclear gauges;
    - Oil industry.
- Research.
    - Biomedical research;
    - Agriculture;
    - Hydrology;
    - Detector development;
    - Linear accelerators and other types of accelerators (synchrotron).
- Environmental.
    - Sludge and wastewater treatment;
    - Flue gas treatment.
- Safety and Security.
    - Cargo and body scanning;
    - Accident and emergency situations.

I.7.2. RADIATION ONCOLOGY

The content was adapted from the medical physics training detailed in the IAEA TCS 56 (Rev.1) [19].
Content:
- Overview of clinical radiotherapy and radiobiological basis.
    - Radiation effects: direct and indirect;
    - Dose-effect relationship;
    - Dose fractionation;
    - Radiobiological effectiveness.
- External Beam Radiation therapy equipment.

  - Functional principles and safety aspects of radionuclide and generator type irradiators;
  - Dosimetry equipment;
- Photon and electron beams.
  - PDD, Profiles, Isodose curves (concepts);
  - Dose ratios (percent depth dose (PDD), tissue-maximum ratio, etc.);
  - Output factors (head scatter factors, total scatter correction factor, etc.);
  - Factors influencing dose distribution (field size, energy, etc.).
- Beam characterization.
  - Spectra;
  - Beam quality specification (kV & MV photons, electrons, protons & ions);
  - Code of practices (IAEA TRS 398, IAEA TRS 469, IAEA TRS 483, IAEA TRS 277, etc.).
- Overview of quality management in radiotherapy.
  - Quality Assurance (QA) concepts (standards, tolerance, etc.);
  - QA of radiotherapy equipment, Dosimetric and beam characteristics QC;
  - Dosimetry Audits as a part of clinical audit.
- Brachytherapy.
  - High dose rate (HDR) and low dose rate (LDR);
  - Equipment and sources;
  - Source calibration;
  - Principles and functioning of remote and manual afterloading (low- and high-dose rate, applicators);
  - Guidelines (IAEA TECDOC-1274);
  - QA in brachytherapy (source strength, source positioning, equipment);
  - Safety (emergency procedures).
- Sources of uncertainty in dose application to the target volume.

I.7.3. INTRODUCTION TO PHYSICS IN NUCLEAR MEDICINE

The content was adapted from the medical physics training detailed in the IAEA TCS 56 (Rev.1) [19].

Content:
- Radionuclide production.
  - Generators;
  - Cyclotrons;
  - Reactors.
- Nuclear Medicine (NM) instrumentation.
  - Dose calibrators;
  - Well counters;
  - Probes.
- NM imaging devices.
  - Planar, whole-body;
  - SPECT;
  - PET;
  - Hybrid systems (PET-CT, PET-MRI).
- Overview of quality management in nuclear medicine.

    - Dose calibrator;
    - Scintillation probes and well counters;
    - Audits.
- Reference levels.
- Radiopharmaceutical therapy.
    - Activity measurements;
    - Dosimetry;
    - Quantitative imaging.

I.7.4. INTRODUCTION TO THE PHYSICS IN RADIOLOGY

The content was adapted from the medical physics training detailed in the IAEA TCS 56 (Rev.1) [19].

Content:

- X ray production.
    - Principle of X ray production, X ray spectrum;
    - X ray tubes (stationary & rotating);
    - Filtration;
    - Half-value layer;
    - Line focus principle and heel effect;
    - Factors influencing the output.
- Mammography.
    - Mammography X ray tubes (target, focus spot, filtration, etc.).
- CT.
    - Components;
    - Overview of CT dosimetry;
    - CT technology: factors influencing dosimetry.

- Overview of additional imaging modalities: factors influencing dosimetry.
    - Principles of dental radiography/panoramic;
    - Principle of Dual X ray energy Absorptiometry.
- Overview of Patient/clinical dosimetry.
    - IAEA TRS 457;
    - Organ dose;
    - Diagnostic reference levels.
- Overview of quality management in radiology.
    - QA concepts (standards, tolerance, etc.);
    - QA of radiology equipment;
    - Audits.

I.8. PROFESSIONAL ETHICS

Objective: Students need to be familiar with ethical principles applied to scientific methods and research. The ability to draft scientific reports, and critically review and cite literature, are necessary outputs. The clear and accurate communication of research methods and results, to a wide range of audiences is important in science. Information technology tools are applied extensively in the workplace of a radiation metrologist to facilitate basic data collection and analysis. The use of proprietary software also needs to be acknowledged in research and data presentation. Radiation metrology students would benefit from being exposed to, and participating in, scientific meetings, oral presentations of research and peer review processes.

This syllabus is not only intended to cover ethical issues in science and research, but also in the professional conduct of a radiation metrologist. In addition to becoming familiar with general ethical principles and codes of conduct applicable to a workplace, the student is to be introduced to typical situations in which a choice of actions is needed, some of which would be considered unethical or undesirable, according to current international and national standards.

Content:

- Ethics.
- Research Project.
    - Research planning;
    - Proposal design;
    - Literature review and copyright;
    - Data gathering and processing;
    - Critical analysis;
    - Scientific writing;
    - Authorship, integrity, plagiarism
- Statistical methods in research.
- Presentation skills.
    - Scientific communication;
    - Techniques of instruction;
- Professionalism.
    - Code of conduct.

APPENDIX II.

DESCRIPTIONS OF COMPETENCIES FOR PRACTICAL TRAINING OF RADIATION METROLOGISTS

II.1. METROLOGY SYSTEM AND TRACEABILITY

Objective: To understand the international measurement system for radiation dosimetry, including key concepts and functions within the system.

Prerequisite
- Metrology system;
- Data analysis and uncertainties.

Sub-Modules
- International metrology system;
- International measurement system;
- Reference standards in metrology;
- Standards and requirements in metrology;
- Comparisons.

Knowledge
- International metrology system (BIPM and OIML);
- International metrology organizations: IAEA, BIPM, RMO, CCRI, CIPM etc.;
- Fundamental constants for SI units;
- Mutual Recognition Arrangement (CIPM-MRA);
- Role of the SSDLs, PSDLs, IAEA and the BIPM in metrology;
- Design, types, and typical uses of primary and secondary standards;
- Traceability chain of relevant measuring instrument;
- Legislation and standards related to metrology and traceability;
- Metrology comparisons.

Skills
- Appropriate use of SI units;
- Describe the role of an SSDL and its function;
- Use the BIPM Key Comparison Database (KCDB) for Calibration and Measurement Capabilities (CMCs) and comparisons;
- Practical implementation of national and international requirements;
- Participate and/or pilot a comparison;
- Evaluate, estimate uncertainty components and potential correlations, and prepare and evaluate uncertainty budgets for comparison purposes.

Attitudes
- As described in Section 4.2.

Assessment
- The competency's assessment is to be performed against each of the knowledge, skills and attitudes described;
- Participation in a comparison and/or in audit.

Information sources

- SSDL Charter [28];
- SSDL Network website, https://ssdl.iaea.org;
- ISO/IEC 17025 [29];
- BIPM: www.bipm.org;
- CIPM-MRA [10];
- GUM [29];
- IAEA-TECDOC-1585 [30];
- Uncertainty in measurement: the ISO guide [31];
- Human Health Campus: https://humanhealth.iaea.org;
- IAEA, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [28].

II.2. SSDL RESOURCES

Objective: To have knowledge and skills to design, commission and maintain technical resources of an SSDL.

Prerequisite

- SSDL resources.

Sub-Modules

- Facility requirements;
- Irradiator systems;
- Equipment;
- Commissioning & Quality Control.

Knowledge

- Bunker design;
- Environmental conditions;
- Designs and types of irradiation systems;
- Designs and types of dosimetry equipment;
- Principles of instrument design and function;
- Ancillary equipment such as thermometers, barometers, hygrometers;
- Acceptance and commissioning of laboratory equipment.

Skills

- Preparation of technical specifications of SSDL equipment;
- Evaluation of the needs and technical parameters of equipment to enable appropriate decisions;
- Acceptance and commissioning of laboratory equipment.

Attitudes

- As described in Section 4.2.

Assessment

- The competency's assessment is to be performed against each of the knowledge, skills and attitudes described.

Information sources
- SSDL Charter [3];
- SSDL Network website;
- ISO/IEC standard 17025 [4];
- IAEA guide on establishment of an SSDL [30];
- Codes of practice [14-18, 31-33].

II.3. CALIBRATION PROCEDURES

Objective: To perform accurate measurement.

Prerequisite
- Fundamentals of dosimetry;
- Metrology system;
- SSDL resources;
- Data analysis and uncertainties.

Sub-Modules
- Operation of calibration equipment.
    - Quantity and unit to be measured/calibrated;
    - Operation of the irradiation facility;
    - Typical uses of electrometers and the principles of charge and current measurements;
    - Modes of operation and response of dosimeters;
    - Operation and use of auxiliary measurement equipment (thermometers, barometers, hygrometers);
    - Reference conditions, influence quantities and correction factors.
- Calibration procedures.
    - Calibration setup and measurement procedure (tip-to-tip, replacement, pre-irradiation);
    - Determination of reference value of the quantity;
    - Application of relevant code of practice;
    - Knowledge and understanding of customer requirements.
- Estimating measurement uncertainties and analysis of results.
    - Data analysis, use and validation of the software;
    - Calculation and validation of the calibration coefficient and corrections;
    - Understanding each measurement equation and uncertainty components of every part of the equation;
    - Critical review of calibration certificate.

Knowledge
- Definition of the quantity.
    - The physics principles and the unit of measurements;
    - Correction factors involved.
- Different irradiation facilities.
    - Fundamentals;
    - Operation;
    - Maintenance.

- Equipment used with different radiation beams and quantities (reference standards (ionization chambers), electrometers, field instruments, auxiliary equipment).
    - The physics principles and design;
    - Associated correction factors;
    - Characteristics of operation, handling, and maintenance.
- Reference working conditions and valid ranges of the environmental conditions.
    - Influence quantities;
    - Monitoring and evaluation of correction factors to take the ambient conditions into account.
- Calibration set-up and measurement procedures.
    - Effects of distance;
    - Effect of orientation of the detectors;
    - Electrical connections;
    - Importance of recording the procedures;
    - Understanding the tip to tip and substitution methods used during calibration of instruments;
    - Importance of pre-irradiation of detectors;
    - Leakage current measurements;
    - Charge, current and dose measurements.
- Traceability of the secondary standard to a primary standard.
    - Applying the measurement equation and each of its components to obtain the reference value;
    - Considering different codes of practice for different radiation beams and quantities to be determined and how to use them.
- Stability of measurements.
    - Repeatability;
    - reproducibility;
    - Statistical evaluation of the data.
- Validation of results.
    - Verification of the correction factors;
    - Statistics and the estimation of measurement uncertainties following the GUM;
    - Common typical mistakes and how to detect and correct for them.
- Calibration certificate, following international standards (ISO/IEC 17025).
    - Knowledge of the information to provide for the correct use and understanding of the calibration coefficient determined;
    - Knowledge on the responsibility for signing the certificate.

Skills

- Safe operation of the irradiation facility;
- Handling of secondary standards, ionization chambers and electrometers used for charge and current measurements;
- Handling and maintenance of the different types of radiation dosimeters for different radiation beams and quantities to be measured;
- Handling of the auxiliary equipment needed for the determination of a radiation quantity;
- Monitoring of ambient conditions and correction of the measured data;
- Setting up the instruments;
- Measurement procedures, including calculation of the reference value and calculations of the measurement uncertainties;

- Preparation of the data analysis file (use, validation, data analysis, criteria for accepting or rejecting results);
- Criteria to evaluate the information provided in the calibration certificate.

Attitudes
- As described in Section 4.2.

Assessment
- The competency's assessment is to be performed against each of the knowledge, skills and attitudes described.

Information sources
- SSDL Network website;
- IAEA guide on establishment of an SSDL [30];
- Codes of practice [14-18, 31-33].

II.4. QUALITY MANAGEMENT SYSTEM

Objective: To develop knowledge and skills to prepare and implement a Quality Management System (QMS) for the SSDL, including managerial and technical requirements, quality manual and quality audits.

Prerequisite
- Metrology system.

Sub-Modules
- Quality systems;
- General requirements;
- Resource requirements;
- Process requirements;
- Management system requirements.

Knowledge
- Quality management system.

Skills
- Writing of QMS documents including laboratory management and technical procedures;
- Document control;
- Performance of QMS audits especially internal audit;
- Identification of areas for improvements;
- Performance of root cause analysis.

Attitudes
- As described in Section 4.2.

Assessment
- The competency's assessment is to be performed against each of the knowledge, skills and attitudes described.

Information sources

- ISO/IEC standard 17025 [4];
- SSDL Charter [3];
- SSDL Network website;
- IAEA guide on establishment of an SSDL [30].

II.5. RADIATION PROTECTION AND RADIOACTIVE MATERIAL SECURITY

Objective: To develop knowledge and skills to manage radiation safety and security of radioactive material in the SSDL, radiation protection regulations, radioactive material security regulations, personnel monitoring and procedures for occupational and public exposure and emergency preparedness, including assessment of radiation risk.

Prerequisite

- Radiation protection.

Sub-Modules

- Biological effects and radiation risk;
- Regulations and requirements;
- Duties of the radiation safety officer;
- Radioactive source custodian;
- Radioactive waste management;
- Room and source shielding;
- Personnel monitoring;
- Occupational and public exposure;
- Radioactive material security;
- Emergency preparedness.

Knowledge

- Biological effects and relative radiation risks, including radiation risk assessment and procedures to minimize risks;
- National radiation protection regulations and how they are applied locally (Local Rules);
- Duties of a radiation protection officer, including arrangements for personal protective equipment and personnel monitoring;
- Control of the existing radiation sources, radioactive material security, computer security of any instrumentation and control equipment, and safety of the area, including contamination checks, and reporting any abnormal incidents;
- Usage of unsealed sources (only radioactivity metrology as used for nuclear medicine), including relevant need for safe storage and disposal of any radioactive waste;
- Periodic checks of radiation doses measured outside the room when the source is in use and inside the room when the source is in the safe position, and follow-up actions if recommended limits are exceeded;
- Daily doses and recommended limits for occupational and public exposure (how to monitor, record, and report to the appropriate person any deviations from expected values);
- Emergency preparedness and planning of emergency actions for worse case scenarios (source sticking or non-retraction, power failures, fire, flood, earthquake, hurricanes, or other natural events, also considering theft, malicious intents, or actions).

Skills

- Implementation of radiation protection and radioactive material security practices;
- Air kerma rate measurements, ambient dose equivalent measurements and checking of any contamination around irradiation equipment and radiation sources;
- Arrangement of personal dosimetry;
- Practice of the emergency plan;
- Training others in radiation safety and radioactive material security;
- Identification and reporting of security events;
- Performance of calculations for operational quantities;
- Running of a personnel monitoring service.

Attitudes

- As described in Section 4.2.

Assessment

- The competency's assessment is to be performed against each of the knowledge, skills and attitudes described.

Information sources

- IAEA, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [28];
- IAEA Safety Standards Series No. GSG-7 on Occupational Radiation Protection [33];
- Code of Conduct on the Safety and Security of Radioactive Sources, IAEA/CODEOC/2004, IAEA, Vienna (2004) [34];
- Security of Radioactive Material in Use and Storage and of Associated Facilities, IAEA Nuclear Security Series No. 11-G (Rev.1) [35];
- Computer Security for Nuclear Security, IAEA Nuclear Security Series No. 42-G [36].

II.6. PROFESSIONAL ETHICS

Objective: To develop knowledge and skills to manage stakeholder interactions including communications with customers and maintaining ethical principles of the profession.

Prerequisite

- Professional and scientific development and Metrology system.

Sub-Modules

- Ethics;
- Scientific writing;
- Teaching and supervising;
- Research;
- Negotiations, giving advice and communication;
- Customer care and managing customer requests;
- Customer database/registry;
- Networking and collaboration.

Knowledge

- Professional ethics;
- Data confidentiality, management, and copyright;

- Design research and methodologies following SMART (Specific, Measurable, Attainable, Relevant and Timely) principle and evaluation of results;
- Scientific writing;
- Teaching;
- Time management;
- Database management;
- Networking;
- Contract management.

Skills
- Preparation of project plan/s;
- Identification of research needed;
- Ethical and diplomatic behaviour;
- Clear, concise, and targeted communication and writing;
- Decision making in ethical dilemmas, maintaining alignment to the code of ethics;
- Communication and negotiation;
- Teaching others appropriately and in alignment to regulations;
- Ability to understand what the customer wants and negotiate what they should be asking for, advising appropriately, and communicating diplomatically.

Attitudes
- As described in Section 4.2.

Assessment
- The competency's assessment is to be performed against each of the knowledge, skills and attitudes described.

Information sources
- Scientific Journals;
- Code of conduct and/or ethics;
- ISO/IEC 17025 standard [4].

APPENDIX III.

IMPLEMENTATION OF THE COMPETENCY FRAMEWORK AT SSDLS FOR QRMS

The competency model discussed in Section 5 could be implemented for peer review or self-assessment of QRM at a SSDL. The implementation will promote the provision of continuous training and encourage individual development of the staff. The process of assessment (and self-assessment) of competencies should accompany the whole career of the QRM, as new competencies may be needed for the integration of new technologies and equipment, as well as to ensure that the level of competency is maintained at the required standard. The assessment of the competencies of a radiation metrologist (either a trainee or an existing person of the SSDL organization) is the process of reviewing knowledge, skills and attitudes to perform a task, comparing them against established requirements and making a judgment at which level the competency has been achieved. The purpose is twofold:

- To confirm that a person can perform the task in accordance with the required competence;
- To identify gaps, if any, in the education to allow the person to address them until the required level of competency is attained.

A good example of practical assessment is to organize a calibration exercise where the results can be compared to confirmed values. An example of recording and documenting the results of an assessment connected with the training plan, see example given in III.3.

Implementing competency models effectively requires time and resources and there is no single approach. While the guidelines listed below are not an exhaustive list of items to consider, they provide examples of best practices.

III.1. DOCUMENTATION OF COMPETENCY REQUIREMENTS

Based on the ISO/IEC 17025 [4] requirements, “The laboratory shall document the competence requirements for each function influencing the results of laboratory activities, including requirements for education, qualification, training, technical knowledge, skills and experience.” [4]. The documentation of competency requirements should ideally be included in the job descriptions, and thus the competency framework model can be used to harmonize the structure of job descriptions for different positions at the SSDL.

In addition to individual competency requirements, the SSDL should have all the required competencies for the assigned roles covered on appropriate levels. Table 4 shows the competencies at the SSDL. QRMs working in SSDLs are expected to reach at least level 3 in each of the competencies, and level 4 if they are required to supervise others. For radiation metrologists that will not be involved in research, development and teaching a competency level of 2 is sufficient for that activity. In addition, it is recommended to have at least one person on level 4 for each topic of competency.

TABLE 4. EXAMPLE OF COMPETENCY LEVELS RECOMMENDED FOR AN SSDL HEAD AND QRM

Competency	SSDL Head	QRM
Metrology system and traceability	4	3-4
SSDL resources	4	3-4
Calibration procedures	4	3-4
QMS	4	3-4
Radiation protection and radioactive material security	4	3-4
Research, development, and teaching	4	2-4
Communication and stakeholder interactions	4	3-4

III.2. COMPETENCY GAP ANALYSIS

Individual assessment and gap analysis can be used as a base for personal development and training programme. The SSDL level gap analysis provides information if the SSDL has an appropriate level for all competencies required in their area of operation. This might be used to define the gaps which can be covered by training the existing staff or acquiring and/or training new staff members.

An example of a gap analysis matrix of the SSDL staff competencies is shown in Table 5. In this example, some QRMs have other assigned roles besides calibration: QRM1 is assigned the responsibility of managing the quality system, QRM2 the role of research and development, and QRM3 has the responsibility for radiation protection. In this example, the SSDL has identified an appropriate level for all their required competencies, but further training is needed in some topics for three of the staff members: SSDL head, QRM3 and QRM4. The example demonstrates that the division of the required competency levels among different roles in the laboratory enables the overall competencies to be achieved at the SSDL level, considered as a combination of the team’s individual competencies.

TABLE 5. EXAMPLE OF A GAP ANALYSIS OF COMPETENCY ASSESSMENT OF VARIOUS STAFF AT AN SSDL AGAINST THE REQUIRED COMPETENCIES FOR THE SSDL (R: REQUIRED COMPETENCY LEVEL, A: RESULT OF COMPETENCY ASSESSMENT, G: COMPETENCY WITH A GAP MARKED BY X)

Competency	Individual levels: Position of a staff member															SSDL level		
	SSDL Head			QRM1			QRM2			QRM3			QRM4					
	R	A	G	R	A	G	R	A	G	R	A	G	R	A	G	R	A	G
Metrology system and traceability	4	2	X	3	4		4	4		3	2	X	3	4		4	4	
SSDL resources	4	4		3	3		4	4		3	2	X	3	2	X	4	4	
Calibration procedures	4	2	X	4	4		4	4		3	3		3	3		4	4	
QMS	4	3	X	4	4		4	4		4	4		3	3		4	4	
Radiation protection and radioactive material security	4	4		3	3		4	4		4	4		4	4		4	4	
Research, development, and teaching	4	4		2	2		4	4		2	2		4	2	X	4	4	
Communication and stakeholder interactions	4	4		3	3		4	4		3	4		4	3	X	4	4	
Individual level	Further education and/or training needed			Competent			Competent			Further education and/or training needed			Further education and/or training needed			Competent		

The competency model with competency assessments can be used when planning for recruitment of new staff. If the SSDL has indicated a specific lack of competency in the gap analysis, this information may be used to identify a suitable candidate who will have the competence needed. After recruitment, the results of competency assessments can similarly be used for planning the training programme for the newly recruited staff member.

III.3. TRAINING PLAN

One of the ISO/IEC 17025 [4] requirements is for each laboratory member to have a training plan. The competency model can be used for specifying training needs and preparing a training plan. The continuous training plan is well in line with the professional attitude to have an open mind for continuous improvement.

For well-established laboratories the training plan for a new staff member may focus on the job training. In addition, technical onsite visits, and training periods at other SSDL's may be complementary. Newly established laboratories might need either to directly recruit an external expert to provide training onsite or to send their new staff for external training.

The training plan and the assessment criteria (in conformity with the competency requirements) should be defined prior to the start of the training period. The result of the assessment should be documented in written form (e.g. portfolio) and retained as a proof of qualification of the radiation metrologist. An example on documenting the training plan and subsequent assessment is shown in Table 6.

A radiation metrologist in training is expected to reach at least level 3 in each of the recommended competencies to be qualified. A training plan for the staff should be tailored to the priorities of the laboratories and organized in modules in such a way that staff will be able to perform the relevant tasks of their job description. The competency evaluation is needed for each calibration capability.

TABLE 6. AN EXAMPLE OF THE COMBINED TRAINING PLAN IN METROLOGY SYSTEM AND TRACEABILITY, AND DOCUMENTATION OF THE RESULTS OF ASSESSMENTS

Topic	Current level (aim)	Training plan Learning Objectives	Time	Assessment and approval New level	Comp. date	Approved by
International metrology system	1 (3)	a) Demonstrate knowledge of international metrology (IAEA, BIPM, CCRI and RMO websites and documents): SI-system, CIPM-MRA, SSDL Charter. b) Describe what calibration services are globally available (BIPM KCDB and IAEA DOLNET). c) Explain the process of CMC submission and update.	Q1 2021			
Reference standards for metrology	1 (3)	a) Describe the traceability chain of all the standards available in the SSDL. b) Identify which primary standard they are traceable to (SI) and what primary standards are available. c) Interpret the content of a calibration certificate from a PSDL. d) Implement a new calibration coefficient from a PSDL.	Q2 2021			
Standards and requirements in metrology	1 (3)	a) Explain what your national legislation and international Basic Safety Standard says about calibrations. b) Define how this is implemented in your country.	Q1 2021			
Comparison	1 (3)	a) Examine published comparison protocols and reports. b) Perform a measurement exercise, following a comparison protocol.	Q3 2021			

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GLOSSARY

attitude: Feelings, opinions, ways of thinking, perceptions, values, behaviour, and interests of an individual which allow a job or task to be undertaken to the best ability of that individual. Attitudes cannot wholly be taught directly and are partly a consequence of the organizational culture [22]. This includes ethics and paying attention to detail for radiation metrologists.

BIPM: International Bureau of Weights and Measures, is an intergovernmental organisation.

calibration bench: A three-dimensionally movable positioning and alignment bench that is used to accurately position reference dosimeters and instruments to be calibrated in the radiation beam [30].

CBA: Central beam axis

CIPM: International Committee for Weights and Measures

competence: Combination of knowledge, skills and attitudes (KSAs) needed by a person to perform a particular job. All three are important and interrelate [22].

contact hour: A measure that represents a one-hour period of scheduled instruction.

education: Aptitude, knowledge, values, and skills (academic and practical training).

FAIR: Findable, Accessible, Interoperable, Reusable [37]

gamma beam irradiator: A system which consists of a container (head) housing the radioactive source, a source movement mechanism or a shutter and a field collimation system [30].

HVL measurements assembly: A system that includes metallic filters, a rigid holder for positioning the filters at the central beam axis, a special collimator to create a narrow beam geometry and to remove scatter from filters used for the determination of the half value layer (HVL) [30].

knowledge: Familiarity with something and can include facts, descriptions and information acquired through experience or education. It can refer to both the theoretical and the practical understanding of a subject [22].

qualified radiation metrologist: A scientist with required competencies working in a metrology laboratory responsible for the calibration of instruments used to measure ionising radiation.

radiation physics laboratories: A laboratory established with the intent to provide traceability for dosimetry, radioactivity and/or neutron measurements.

skill: Learned capacity to perform a task to a specified standard [22].

total quality management system: A comprehensive quality management system that is all inclusive of the processes for running an organisation and delivering on its services.

X ray irradiator: A system which consists of an X ray tube, generator and their cooling, control systems, X ray housing, shutter and a field collimation system [30].

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