CHAPTER 9

THE ROLE OF THE SSDL NETWORK IN DISSEMINATION OF THE PROPER MEASURING QUANTITIES

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1. INTRODUCTION

Most of the material developed in this chapter was extracted from publications of the International Atomic Energy Agency (IAEA). The IAEA/WHO SSDL Network, referred in this chapter as the SSDL Network, was setup in 1976 byboth the IAEA and the WHO. The author of this chapter has been the SSDL Officerat the IAEA, in charge of the operational aspects of the Network for more than 10 years and then, co- scientific secretary of the Network for another 10 years. During these 20 years' work at the IAEA, the author of this chapter has been both an activeactor and also a witness of the developments of the SSDL Network. This account of developments, achievements, challenges and perspectives of the SSDL Network naturally reflects these evolutions as seen by the author.

The reasons of the establishment of the SSDL Network are explained in the historical context of the development of external beam radiotherapy and its expansion to low- and middle-income (LMI) countries. The SSDL Network was established with a strong link to the international measurement system and has keptthis link throughout these years. It can be stated, without any doubt, that the quality of radiation dosimetry performed by SSDL Network members has been greatly strengthened in the 1990s, thanks to the introduction of the ISO/IEC guide 25 (1990)and to the signing of the International Committee for Weights and Measures - Mutual Recognition Arrangement (CIPM MRA, 1999).

The number of SSDL Network members continues to increase, growing from about 10 laboratories in 1976 to almost 90 at the end of 2021, mainly due to IAEA support and the introduction of a more stringent radiation protection regulations in an increasing number of countries that require traceability of radiation measurements in individual and area monitoring. The reasons for this expansion willbe reviewed. Finally, a brief perspective of the future of the SSDL Network as well as concluding remarks will be given at the end of this chapter.

2. HISTORICAL DEVELOPMENTS

This section starts with a brief history of metrology and radiation dosimetry in order to better understand the developments that lead to the establishment of the SSDL Network.

The current international metric system of measurements was setup at the end of the 18th century with the signing, in Paris on 20th May 1875, of the international treaty called the Metre Convention (1875). The Treaty established a framework for the participating countries to work together on measurement science and standards. Under the auspices of the 'Conférence Générale des Poids et Mesures (CGPM)', the arrangements for the propagation and improvement of the International System of Units (SI) were initiated. That same treaty also established the International Bureau of Weights and Measures (Bureau International des Poids et Mesures, BIPM) with its headquarters in Sèvres, France. Although the Metre Convention is considered as the foundation for the current SI, it should be noted that previous ancient civilizations such as the Egyptians, Greeks, and Romans successfully established workable measurement systems and standards that were accepted and widely used in their territories. For example, according to information given in the Metrology Sine Qua Non website, about 2900 B.C, the Egyptians established by decree a fixed standard unit of length, called the Royal Egyptian Cubit. Of course, the history of metrology for ionizing radiation has a much shorter span, since X rays and radioactivity were discovered only at the end of the 19th century. Although ionizing radiation has been present throughout man's history in the form of cosmic rays and naturally occurring radioactive materials, it remained unnoticed until 1896, when Roentgen discovered the existence of X rays. In these early days, the users of X rays were not aware that large radiation doses could cause serious biological effects. In addition, in those days, there were no instruments to measure radiation. Instead, physicians were reportedly (Mario E. Schillaci, 1995) using the amount of skin erythema, produced on a human hand placed directly in the X ray beam, to set an upper limit of the X ray tube output for the treatment of patients. Fortunately, the importance of a unit of measurement of radiation was soon realized and the International Committee for Radiological Units and Measurements, ICRU (originally known as the International X Ray Unit Committee) was established. Soon after, radiation protection regulations were prepared in several countries and in 1928, the 'International X Ray and Radium Protection Committee', was created; it later became the International Commission on Radiological Protection (R.H. Clarke and J.Valentin, 2009).

Since their establishment, the ICRU and ICRP have both provided internationally accepted recommendations on radiation quantities, units, measurements, and protection. Medical physicists and radiation physics experts from Primary Standards Dosimetry Laboratories (PSDLs), SSDLs, hospitals and universities, working under the auspices of national professional associations, have made full use of such recommendations to develop dosimetry codes of practice and guidance on radiation dosimetry used in radiotherapy and radiation protection dosimetry. The IAEA has built on these achievements and developed internationally harmonized dosimetry codes of practice for radiotherapy dosimetry (IAEA TRS- 398, 2000 and IAEA TRS-483, 2017) and X ray diagnostic radiology (IAEA TRS 457, 2007).

Clinical interest in radiotherapy increased a lot in the 1950s, due to the development of the first 6 MV X rays and compact linear accelerators. But the production of the first external beam radiotherapy units that used cobalt-60 sources at that time was a major milestone. This is due to the net physical advantages of cobalt-60 sources over radium sources and kilovoltage X ray units, such as cost- effectiveness, higher dose rates at a longer source-to-surface distance, and skin- sparing in the dose buildup region. The benefits of cobalt-60 units were recognized immediately and several countries launched the production of such technology during the next few years. The relatively low cost, reliability and availability of these units made them the favored external beam radiotherapy treatment modality, especially in low- and middle-income countries for the next 50 years.

A. The establishment of the IAEA/WHO SSDL Network

Although it is not possible to identify the exact date of the conception of the SSDL Network, there is some evidence that the idea of setting up such laboratories emerged in the 1960s by a small group of medical physicists working at the IAEA in Vienna, who formulated a programme aimed at assisting the development of radiotherapy in Latin America (IAEA, 2000). At that time, it was the only region in the developing world where radiotherapy was used extensively. In the mid-sixties, the group enlarged to other physicists, and proposed that the IAEA organize and perform a dose comparison service using mailed Thermo-Luminescent Dosimeters (TLDs). The first pilot postal dose comparisons were conducted by the IAEA during 1965–1966, using TLDs and Fricke dosimeters (IAEA 2019). The WHO joined the audit programme in 1968 and since then, it has co-operated with the IAEA for the implementation of the dosimetry audit programme. The follow-up on dosimetry deviations identified through the IAEA/WHO TLD audits revealed that the absence of a reference dosimetry laboratory in many countries, as well as the lack of trained clinical medical physicists, were a serious obstacle for quality radiotherapy dosimetry. In addition, it was also realized that the BIPM and the PSDLs alone cannot provide the amount of calibration work which has arisen from the widespread requirement for accurate and traceable measurements in many countries. Consequently, the IAEA and WHO joined efforts and proposed the establishment of a regional dosimetry laboratory in South America, linked to the international system of measurements. In 1968, an international panel was invited by the IAEA to attend a meeting in Caracas, Venezuela to discuss ways to improve radiotherapy dosimetry in South America. The panel recommended, among other topics, the establishment of SSDLs with the support of the IAEA and WHO. The Caracas meeting can be considered as the starting point of the SSDL Network. The panel also recommended the preparation of a basic manual in radiotherapy dosimetry and the launching of a training programme for medical physicists.The IAEA implemented these three recommendations.

The Manual of Dosimetry in Radiotherapy was published (IAEA, 1970) and several training programmes for medical physicists were organized. Regarding the recommendation on the establishment of SSDLs, the IAEA convened another meeting in 1974 in Rio de Janeiro, Brazil with the participation of representatives from 6 PSDLs, BIPM, WHO and IOMP. The panel recommended the establishment of a Network of SSDLs as well as an Advisory Council; the Secretariat function of the Network being shared by the IAEA and WHO. Clearly, the Rio meeting paved the way for the establishment of the SSDL Network. In 1976, the SSDL Network and its Advisory Council were formally established by the IAEA and WHO. The Advisory Council, later renamed 'SSDL Scientific Committee' (SSC) aimed at assisting the Secretariat in all matters concerning the Network by reviewing and assessing the activities of the SSDL Network and making recommendations to the IAEA and WHO. The terms of reference of the SSC were later reviewed and the membership increased to ensure a proper review of all other inter-related activities of the IAEA's Dosimetry and Medical Radiation Physics (DMRP) Section. Indeed, this change in the terms of reference of the SSC was highly desirable, due to the close connections between the SSDL work and other medical physics activities conducted by DMRP, such as the development of dosimetry techniques and codes of practice, education and training of medical physicists, etc. In addition, the SSC membership is reviewed every 5 years and new members are designated to cover the main programmatic activities of the DMRP. The SSC meets every two years at the IAEA Headquarters; its report is distributed to all the SSDL members through its publication in the SSDL Newsletter. Updated information on the SSDL and the SSC is available on the relevant IAEA website (IAEA DOLNET). The SSC recommendations are drawn-up, following presentations by IAEA staff and open discussions with SSC members. Throughout these years, the SSC has conducted critical reviews of the IAEA activities in medical radiation physics, including the SSDL Network activities and provided non-binding but informed guidance to the IAEA and WHO. There is no doubt, that throughout its existence, the SSC has greatly contributed to the development and strengthen the network.

B. Achievements and challenges

At the time of its establishment, the SSDL Network had only 9 known laboratories. After less than 2 years, there were 30 laboratories in the Network. In addition, 11 National Primary Standards Laboratories became affiliated members, and 5 international organizations (BIPM, ICRU, IEC, IOML, IOMP) joined the Network as collaborating organization. At the end of 2021, the SSDL Network included 88 SSDLs, 16 affiliated PSDLs and 5 international organizations (IAEA DOLNET). There is no doubt that the SSDL Network became an established and consolidated international Network. For this achievement, credit should first be given to the authorities of the countries that put the necessary efforts and resources for the establishment of an SSDL, but also to the highly engaged members of the SSC and support given by the BIPM, several PSDLs and WHO, and finally to the tremendous support given by the IAEA throughout these years. Indeed, the IAEA has played a major role in the establishment of many of the laboratories which nowform the SSDL Network. Its assistance has ranged from small projects, involving expert's advice and/or training of SSDL staff and/or provision of dosimetry equipment, to large-scale projects in which the IAEA has supported the planning and design of the SSDL facilities as well as the provision of the SSDL equipment, support for its commissioning and training of the staff both on-site and in well- established SSDLs. It is estimated that at least 50% of the current SSDL members have benefited from the support of the IAEA through its technical cooperation programme. In addition, the IAEA through its Dosimetry Laboratory located in Seibersdorf, Austria, provides not only cost-free calibrations to its SSDL members,but also organizes dosimetry comparisons and offers expert advice as well as practical training opportunities to SSDL staff. For example, during 2007-2020, the IAEA has issued 1188 calibration certificates to 78 countries, covering calibrations in external beam radiotherapy, brachytherapy, X-ray diagnostic radiology and radiation protection level dosimetry (IAEA, 2021). The IAEA Dosimetry Laboratoryevolved gradually over the years, extending the range of its calibration services and widening the scope of its training opportunities for the benefits of the SSDL Networkmembers. It is considered as the central Laboratory of the SSDL Network.

SSDL network members as of March 2022. The updated list is available on the IAEA website: "https://ssdl.iaea.org/Home/Members"

In the area of information exchange, the IAEA in cooperation with several professional societies and international organizations, convened several international meetings with the aim to provide a forum where advances in radiation dosimetry, at standards laboratories and hospitals, were reviewed and discussed. The most recent event was the International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS 2019), held in Viennaon 18 to 21 June 2019. The Symposium facilitated interactions between radiation metrologists, medical physicists, safety specialists and researchers in radiation dosimetry, with participants coming from advanced as well as LMI countries. The Symposium included topics related to dosimetry standards, medical dosimetry andradiation protection dosimetry with a specific focus on areas where research and development is needed. Very few international meetings facilitate such interactions between radiation metrologists, clinical medical physicists and scientists engaged in the development of new dosimetry standards, computational dosimetry, the traceability chain, codes of practices and cross-cutting research and in so doing, encourage collaborative opportunities in these fields. The highlights of IDOS-2019 were published by Meghzifene & al (2019).

Following the introduction of the MRA (1999), the IAEA has prepared its Calibration and Measurement Capabilities (CMCs). These CMCs were evaluated by all Regional Metrology Organizations and subsequently entered into Appendix C of the BIPM Key Comparison Database (BIPM KCDB), after the review and approval by the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB). The signing of the MRA by the IAEA places metrology of ionizing radiation in LMI countries, having a laboratory member of the SSDL Network, at the level of international recognition with no precedence in the past, allowing for the world-wide recognition of their standards and calibration certificates. In addition, the IAEA has prepared training manuals and publications, such as TRS 469 (IAEA,2009) and TECDOC 1585 (IAEA, 2008) in the area of radiation dosimetry addressed to SSDLstaff and medical physicists working in hospitals. In order to encourage a continuous exchange of information among SSDL members and provide a repository of scientific and technical information for SSDLs, the IAEA also maintains a website dedicated to the SSDL Network’s activities (IAEA DOLNET).

C. The role of secondary standards dosimetry laboratory

The main function of an SSDL is to maintain secondary standards whose calibrations are directly traceable to the SI, either through the IAEA, a PSDL or directly to the BIPM, and use them to calibrate end-users ‘instruments. Generally, many countries would require that the SSDL operate under a quality management system, such as ISO/IEC-17025 (2017) and be designated by the competent national authority for the provision of its calibration services. In addition, an SSDL may be required to be accredited by a recognized body.

In the 1960s and 1970s, the SSDLs were established mainly to provide calibrations for external beam radiotherapy. The scope of their calibration work has expanded greatly over the years, and nowadays, include radiation protection measurements, diagnostic radiology and brachytherapy. SSDLs with the right infrastructure and trained staff also offer calibration of well type ion chambers used in therapeutic and diagnostic nuclear medicine. While some SSDLs offer the full range of calibration services, others may offer only one or a few ones. It all depends on the needs of end-users, importance of infrastructures using radiation sources and radiation emitting devices in the country, as well as the capabilities of the SSDL. Some SSDLs offer dosimetry audits to radiotherapy hospitals, either through mailed dosimeters, using TLDs or Optically Simulated Luminescence Dosimeters (OSLs), or on-site visits with electrometers and ion chambers. This type of service requires well-trained staff in radiotherapy physics at the SSDL to follow-up on possible dosimetry deviations with clinical medical physicists working in radiotherapy. A word of caution on this type of audit of radiotherapy beam outputs performed by SSDLs: it is important to avoid any potential conflict of interest and ensure that the SSDL staff does not have a dual function in this situation. The hospital medical physicist should be the one performing the determination of the radiotherapy beam output, following a recognized dosimetry code of practice such as TRS-398 (2000) or TRS- 469 (2017) with the use of a calibrated dosimeter. Whereas the SSDL staff, with no connection to the hospital, should use the SSDL equipment (ion chamber, electrometer, barometer, thermometer) and perform an independent measurement. It is important to note that the radiotherapy beam output determination lies under the responsibility of the clinical medical physicist (employed by the hospital) and thus, he/she should be the one conducting the measurements used for the treatment of patients. Any dosimetry deviation, considering the uncertainty of measurements, between the dose outputs determined by the SSDL staff and hospital staff should be investigated, explained and reconciled. These dosimetry verifications conducted by an SSDL staff may be used to fulfill the dosimetry audit requirement imposed by some quality systems implemented in radiotherapy hospitals.

The author has also witnessed a case where a radiation safety inspector working for the regulatory authority was the one performing the measurements of the beam outputs of the radiotherapy machines used to treat patients. This practice should not be encouraged. The regulatory authority has the responsibility for checking and ensuring that the dosimetry in a radiotherapy department is performed by a clinically qualified medical physicist and in compliance with its legal requirements, but should not be the one performing routine beam output measurements used to treat patients. SSDLs perform an important supporting function for the radiation protection regulatory body by providing measurement traceability for all end users in the country.

Since many SSDLs have a very good radiation dosimetry infrastructure and well-trained staff, they can contribute to the training of medical physicists. For example, SSDLs can setup practical sessions for the determination of radiotherapy beam outputs, depth dose measurements, determination of beam quality, etc. The use of an SSDL infrastructure allows to reduce the amount of machine time used for the training of medical physicists in a radiotherapy department. For the training of radiation protection officers, the SSDL can be used to demonstrate an example of good practice when working with radiation sources and X ray units, and show how to use instruments and conduct radiation measurements with X and gamma-rays, etc.

From the perspective of the IAEA, a laboratory fulfilling the general criteria set forth in its SSDL Network Charter (2018) may become a member of the SSDL Network. Further guidelines on the designation of SSDLs, as well as information about the facilities needed for an SSDL and about the duties of the members in theNetwork are given in the Charter. The extent to which an SSDL involves itself in theNetwork will depend on many circumstances, but any SSDL can take at least advantage of all networking opportunities such as exchanging information onscientific and technical matters as well as sharing similar experiences.

D. International traceability in the SSDL Network

Since its inception, ensuring traceability of measurements has always been a main objective of the SSDL Network. Indeed, the main organizations involved in the international system of measurements for radiation dosimetry, i.e. the BIPM andthe ICRU, supported by PSDLs, contributed to the establishment of the SSDL Network at the Rio Panel meeting in 1976 (IAEA, 2000). As affiliated members of the SSDL Network and members of the SSC, these organizations continue to provide their support to the SSDL Network.

At the SSDL level, traceability is achieved through the calibration of their secondary standard dosimeters (ionization chambers and electrometers) at the IAEA or any affiliated PSDL. Since the IAEA uses the calibration services of the BIPM and PSDLs to calibrate its own instruments, implements a stringent and peer-reviewed quality system (IAEA 2021), and regularly participates in international comparisons, the measurement uncertainties for calibrations at the IAEA Laboratoryare comparable to those at other affiliated laboratories. SSDLs may also use the Key Comparison Database (BIPM) to identify a metrology institute that offers the needed calibration services. Other instruments that are used in the dose determination, such as the barometer and thermometer, should also be calibrated at a recognized laboratory to ensure traceability of all measurements to the SI system.

For practical reasons, some SSDLs calibrate only their reference ionization chambers, without the electrometer. In this case, the calibration of the ionization chamber is given in terms of Gy/C. When a separately-calibrated ionization chamberis used in conjunction with an electrometer, its readings should be corrected to take into account the electrometer calibration factor. The ideal situation for SSDLs is to calibrate their reference ionization chamber together with the electrometer (Gy/Scale division) and separately (Gy/C). In this way, SSDLs will have more flexibility since they can use their calibrated electrometer with any other calibrated ionization chamber.

Traceability alone is not sufficient to ensure quality work at the SSDL. The establishment of a QMS is also required. The QMS helps SSDLs demonstrate thattheir laboratory work is conducted in accordance with internationally accepted recommendations, and that the calibration services as well as the performance of all equipment is maintained at the required level of quality. According to the SSDL Charter (IAEA, 2018), SSDLs interested in becoming a member of the Network should have at least the first draft of their QMS established in line with the ISO/IEC 17025 requirements. In addition. the QMS will also require that an SSDL participate in regular dosimetry comparisons such as those organized by the IAEA or Regional Metrology Organizations (RMOs.) The participation in a comparison enables an SSDL to verify the consistency of its reference standards and validate its calibration procedures and related measurement uncertainty. If the SSDL is in a country that is a signatory of the CIPM MRA, the comparisons can also be used to validate its CMCs. As shown in the summary of the 2017-2018 IAEA-SSDLs comparisons published in the SSDL Newsletter No. 69 (IAEA, 2019), most SSDLs' results are within the IAEA acceptable criteria and demonstrate quality calibration services by SSDLs.

It should be noted that traceability of measurements is also required in other fields, such as radiation protection, therapeutic nuclear medicine and diagnostic imaging (nuclear medicine and X-Ray diagnostic radiology) and high-dose dosimetry used in food or blood irradiation. The need for traceability in measurements in all these fields should not be interpreted as a requirement for the accuracy level that is used in radiotherapy. Instead, it means that radiation measurements conducted in these other fields have to be linked to the SI System through an unbroken metrology chain. It is only under these conditions that comparisons for radiation measurements made with different instruments and under different conditions are meaningful.

E. Evolution and trends of the SSDL Network

As technology and science advances, all laboratories will have to accommodate the changes and adapt their equipment and workflow. It is a fact that the evolution of artificial intelligence (AI), coupled with advances in digitalization, automation of routine measurement, robotic instrument positioning and remote access technology will shape tomorrow's work of many laboratories, including SSDLs. Maybe, the SSDL of tomorrow will evolve to become a fully automatized and remotely-accessible laboratory with an integrated and AI-driven QMS. SSDLs should be prepared to gradually integrate new developments, while ensuring quality laboratory results. It is important that any new developments or work process modification is fully tested and validated before it is integrated in routine laboratory work. In addition, staff training should be part of the integration of any new development in the SSDL.

In the meantime, the scope of the SSDL work is expected to increase to fully cover the needs of traceability of radiation measurements in all fields. In addition to calibrations, SSDLs with the adequate infrastructure are also expected to increase and expand their external dosimetry audits to include brachytherapy, nuclear medicine and X-ray diagnostic radiology. These dosimetry audits can be conducted with ionization chambers or other passive dosimeters such as OSLs or TLDs. SSDLs have also the potential to become a national hub for the development and harmonization of radiation dosimetry throughout the country. SSDLs should join efforts with other professional societies (such medical physicists and radiation protection officers) to jointly work on the adoption of international codes of practices such as the IAEA TRS-398 or TRS-469, ICRU and ISO recommendations such as ISO 4037:2019 (2019). It is the only way to ensure traceability of all radiation measurements as well as harmonization of radiation dosimetry practice in the country. This harmonization will for example, certainly contribute to quality clinical trials among hospitals and strengthen the radiation protection system in the country. Accreditation of SSDLs will continue to be needed to fully respond to increasingly more stringent regulatory requirements as well as to the needs of quality and transparency in the laboratory work.

It is the opinion of the author that international support to the Network will also gradually shift from direct support to the establishment of the SSDL infrastructure to the reinforcement of harmonization of work in the Network. A Fully integrated SSDL Network platform with member access that includes all relevant scientific and technical information will promote exchange of information on calibration and dosimetry issues among SSDLs and facilitate online training and provision of remote expert advice. The existing IAEA DOLNET (IAEA) is a first steptowards the establishment of such an integrated SSDL platform.

F. Conclusion

The SSDL Network was established in the early sixties as an internationally coordinated action in response to identified gaps in external beam radiotherapy dosimetry. It has later expanded its calibration services in response to the need for traceability of measurements in other areas, such as radiation protection and recently, in X ray diagnostic radiology and brachytherapy. The SSDL Network has helped raise awareness on the need for traceability and standardization in radiation dosimetry among health authorities and professionals, and provided a framework for sharing information and improving calibration and auditing services for the benefits of patients and radiation-exposed workers in many countries. The results achieved so far have had a very positive impact on the dosimetry in radiotherapy and contributed to improved patient treatment. Although some progress has been achieved in the last 10 years in the standardization of dosimetry in X ray diagnostic radiology, the continuous lack of clinical medical physicists with dosimetry expertise in many radiology and nuclear medicine departments, especially in low- and middle- income countries remains the main obstacle for the implementation of appropriate dosimetry protocols. In addition, in many LMI countries, access to traceable calibrations in these fields remain a challenge.

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