

Roadmap for Ionising Radiation no. 1

Dosimetry and Radionuclides in Health Care (Jacco de Pooter, VSL and Jean-Marc Bordy, LNHb)

Drivers and Challenges

The last decades the application of ionising radiation based techniques in **healthcare has evolved considerably** allowing for **advanced diagnostic and therapeutic modalities**. The therapeutic application is dominated by external beam radiotherapy applied in the treatment of cancer. Currently, there are about **4 million new cases of cancer in Europe per year**. These figures are predicted to increase in the future due to the improvement of diagnostic methods and the global ageing of the population in Europe. About 75% of cases are treated using radiotherapy (alone or with chemotherapy and/or surgery), it is estimated that **about 50% of successful treatments can be attributed to radiotherapy**. Recently developed treatment modalities and new irradiation facilities may lead to a further increase in the use of radiotherapy techniques.

The European Basic Safety Standard Directive [1] requires that appropriate quality assurance programmes including quality control measures and dose or administered activity assessments are implemented by the undertaking, for the medical exposure of patients in the course of radiotherapy (including targeted radionuclide therapy). More specific, ICRU report 24 [2] gives quantitative requirements for dose assessments in the framework of quality assurance for external beam radiotherapy. Advancing technology has enabled the introduction of complex forms of radiotherapy in the treatment of cancer, in which dose is delivered in ways that are far removed from established reference dosimetry. While treated volumes can now conform closely to the defined target, so reducing damage to surrounding normal tissue, the accuracy with which the dose is delivered may fall short of the requirements given by ICRU Report 24. These methodologies raise metrological problems for which (i) the traceability of tumour doses to primary standards and (ii) the validation of the treatment plans have to be demonstrated which are key elements in patient safety and has been emphasised in the European Basic Safety Standard [1] proposed by the European Commission. For the next ten years, it is expected that this development continues to enable better targeting of the tumour with a reduced dose to the healthy tissue allowing optimal individualised patient care [3]. This will be accomplished by:

- online imaging techniques with help of Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI)
- the use of radiation beams with better physical properties like protons and carbon ions [4]
- highly focused dose distributions delivered by rotational radiotherapy
- novel brachytherapy sources emitting lower energy photons for better conformation of the dose distribution to the target volume
- robotic techniques allowing for online target volume tracking.

Therefore, new dosimetric techniques are needed to bridge the gap between the dosimetry for these new techniques and the currently applied reference dosimetry [5].

Next to external beam radiotherapy and brachytherapy also other techniques in cancer treatment such as Targeted Radionuclide Therapy (TRT) are increasing and evolving (e.g. new imaging modalities, tracers, radionuclides and carriers). In TRT high doses to tumor cell are given to tumour cells. Since no standardized dosimetric and dose calculation techniques are available accurate dose assessment is not possible.

New compact facilities for proton therapy are studied which will lead to increase the use of the treatment modalities based on these particles. The use of such particles raised the question of the patient's neutrons doses resulting of the hadron interaction with tissues. Dedicated methods for measuring or evaluating the neutrons doses are necessary. Whatever is the treatment modality, it is necessary to define which quantity has to be used to report neutron "doses" for patient in order to harmonize these practices so that to facilitate comparison between treatments in terms of side effects.

In addition to the new online imaging techniques, for diagnostic applications the use of practical quantities such as computerized tomographic dose index, C_K , required to study dedicated references. This point is very important taking into account the high patient's doses for CT exams and the very large number of diagnostic exams, reaching all in all more than 1 per person per year on average, in developed countries.

Recently eye lens doses have received a lot of attention because of some epidemiological studies showing that the threshold dose for cataract induction, if there is one, could be lower than that assumed. Therefore, ICRP issued a "Statement on Tissue Reaction" including a revision of the eye lens limit (Paragraph 3) that lowers the annual limit to 20 mSv. On the other hand, the operational quantity for eye lens, $H_p(3)$, is not usually monitored. The ORAMED project proposes for an overall procedure for eye lens dose assessment, better suited calibration phantoms, a new sets of air kerma to $H_p(3)$ conversion coefficients for mono-energetic photons and electrons and the definition of a procedure for type test and calibration of eye lens dosimeters.

Beyond the particular case of eye lens dosimetry, the calculations of conversion coefficients for $H_p(3)$ raised questions of their calculation methods for all the operational quantities (H_p , H' , H^*); up to now conversion coefficients values are based on kerma approximation, this lead to large discrepancies with protection quantities for energies where electronic equilibrium is not reached. New calculations including electron transports will contribute to improve the situation. This topic being of interest for the assessment of the dose received by the 23 million workers exposed to radiation.

Targets

Improved metrology for Dosimetry and Radionuclides in Health Care will lead to:

- sustained improvements of patients' Quality of Life by achieving a higher cure rate while reducing the side effects; second cancer risks and physiological effects;
- sustained improvement of patient safety;
- against the background of the rapid development of new radiotherapy modalities (including brachytherapy and targeted radionuclide therapy), it will facilitate faster clinical dissemination of new innovative radiotherapy techniques;

- safe working environment for European workers with a better evaluation of risks for occupational exposures;
- a lower radiation burden to the European citizen by improved optimisation of dose and image quality;
- Support the publication of new standard and dosimetry protocols following the development of therapy and diagnostic methods.

Deliverables

- i. Verification of dose planning and treatment for external beam therapy using specially designed phantom for 3D measurements.
- ii. Measuring quantities and dosimetry methods for small fields in radiotherapy.
- iii. Individualised dose planning and treatment for targeted radionuclide therapy.
- iv. Radiobiological models for treatment planning in radiation therapy with emphasis on target volume.
- v. Dosimetry protocols for new modalities using a variety of energies and radiation types
- vi. Use of medical information from X-ray, computerized tomography and nuclear medicine imaging to optimize of dose and image quality information for diagnostic imaging and online imaging of treatments.
- vii. Standardized dosimetry for combined therapy and online imaging systems (using Computerized Tomography and Magnetic Resonance Imaging).
- viii. Quantities and metrology for predicting late effects and secondary cancers.
- ix. Quantities for neutron dosimetry adapted to therapy.
- x. Traceability for dose estimations of workers including dosimeters, measuring quantities and calibration procedure (e.g. Derive conversion coefficient from air kerma into $H'(3)$ for photons; Verification, for electrons, that $H'(3)$ could be estimated by $H_p(0.07)$ or $H_p(10)$, mixed exposures beta-photon).
- xi. Development of enhanced dosimetry techniques required for the radiation sterilization of novel medical devices and combination products containing active pharmaceutical and biological components.

Technologies

The deliverables will contribute to enable technological innovation in various domains:

- New primary standards for new radiotherapy modalities.
- Development of new dosimetry instruments (e.g. dosimeters and phantoms), dose reconstruction systems, and traceability.
- Nuclear imaging applied to dose planning for TRT verified by phantom measurements.
- Development and use of Biological and Functional Imaging techniques for radiotherapy.
- Standardized methods and measurement protocols for dosimetry in radiotherapy.

These innovations will benefit the industry of medical equipment, hospitals and patients. Furthermore it will widen the measurement capabilities of metrological institutes and knowledge transfer.

Enabling Science

Monte-Carlo simulation of radiation transport, detector modelling, and development of primary standards technology will allow to see the objectives of this roadmap through successfully.

References

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