



## **CODES OF PRACTICE AND PROTOCOLS FOR THE DOSIMETRY IN REFERENCE CONDITIONS OF PROTON AND ION BEAMS**

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The advantages of radiotherapy protons and heavier charged-particle beams, the technological feasibility, and the clinical results obtained so far have led to the establishment of about 20 treatment facilities worldwide and plans to open another 20 proton and light-ion therapy centres in the next five years. In order to meet the expanding capabilities of treatment techniques, considerable effort has been devoted during the last fifteen years to the development of the dosimetry and calibration of such beams. This paper reviews these developments and summarizes the present status of Codes of Practice and protocols for the dosimetry in reference conditions of proton and ion beams.

The first dosimetry protocol for heavy-particle radiotherapy beams, AAPM TG 20 [1], was based on the use of Faraday cups and calorimeters, whereas ionization chamber dosimetry received little attention. Following the trends in “nuclear particle” radiotherapy, TG 20 included recommendations for specifying “dose to tissue”. The lack of availability of a harmonized set of data for the different particles made this protocol to include data for stopping-powers and for the mean energy required to produce an ion pair in air,  $W_{air}$ , from multiple authors, without enough attention being paid to their consistency. The increased focus into proton beams was materialized in the publication of the ECHED Code of Practice [2], dedicated exclusively to protons, where ionization dosimetry received more attention than in TG 20. It was not until the publication of the Supplement to the ECHED recommendations [3] that ionization chambers having a  $^{60}\text{Co}$  calibration factor were recommended as a reference detector for proton dosimetry, and data supplied for chambers with different wall materials. The emphasis on ionization chamber-based proton dosimetry was complemented with a recommendation for using water as dosimetry phantom material and the necessary data on tissue and water to air stopping-power ratios and  $W_{air}$ . One of the most interesting aspects of the ECHED Supplement was the use of the proton stopping-power data in then just released ICRU-49 [4] report. In order to achieve homogeneity in the dosimetry and dose delivery at institutions implementing heavy-particle radiotherapy, the two protocols, TG 20 and ECHED, recommended periodic dosimetry intercomparisons among the different centres. Several ionization chamber intercomparisons performed in the early nineties revealed that the different physical data in the two protocols were the main cause of the observed substantial differences in absorbed dose determination in proton therapy centres. Calorimetry studies performed at a number of institutions confirmed the findings of the ion chamber intercomparisons, indicating that the adoption of a uniform set of data and a common dosimetry protocol would be necessary to achieve consistency in the dose delivered to patients in all proton centres.

In the following years, the publication of the ICRU 59 [5] report represented an attempt to harmonize clinical proton dosimetry worldwide and to promote the dissemination of the new radiation metrology standards in terms of absorbed dose to water. Practical problems associated with the use of Faraday cups and calorimeters were fully recognized by the ICRU report, and the role of these methods in proton dosimetry was minimized, favouring that of ionization chamber dosimetry. Upon the adoption of ICRU 59 in multiple proton centres, international dosimetry intercomparisons using ionization chambers calibrated in terms of air kerma in  $^{60}\text{Co}$ , have shown, as expected, a considerable improvement in their homogeneity with the result that all participants agreed within  $\pm 0.9\%$  in their calibration of a common beam using their own instrumentation. This result encouraged the use of ICRU 59 worldwide for the calibration of clinical proton beams. On the other hand, detailed analysis

of the intercomparison data and recent publications have indicated that improvements and corrections to ICRU 59 are needed.

The International Code of Practice IAEA TRS 398 [6], based on standards of absorbed dose to water for external radiotherapy beams, includes recommendations for the calibration of protons and heavier ion radiotherapy beams. For protons, TRS 398 differs substantially from ICRU 59 in that it has adopted recent developments in the field of ion chamber dosimetry and considers a thorough revision of some of the physical quantities involved in proton dosimetry. The effect of the more accurate fluence-averaged stopping power ratios in TRS 398 is a minor difference of 0.5% with ICRU 59, but the ratio of  $W_{air}$  values, protons to  $^{60}\text{Co}$ , differs by 2.3%; 0.6% of this difference is due to the conceptually different use of  $W_{air}$ -values for ambient air (ICRU) and dry air (IAEA). The approximate definition of  $k_Q$  in ICRU 59, which excludes chamber correction perturbation factors at  $^{60}\text{Co}$  (that enter in the denominator of  $k_Q$ ), together with the use of a different  $W_{air}$ -ratio and very similar  $s_{w,air}$  values, causes differences in  $k_Q$  values between  $-2.6\%$  and  $+1.5\%$ , depending on the chamber type and proton beam quality. Both recommendations consider chamber perturbation factors in proton beams to be unity. The expected future improvements in proton dosimetry will probably focus on chamber specific factors and perturbation effects in protons, as recent Monte Carlo studies and dosimetry comparisons indicate that depending on the chamber type, perturbation effects can be up to 1%.

## REFERENCES

- [1] AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE Task Group 20 (AAPM): Protocol for heavy-charged particle therapy beam dosimetry. AAPM Report No. 16 American Association of Physicists in Medicine, New York (1986).
- [2] VYNCKIER, S., BONNETT, D. E., AND JONES, D. T. L. Code of practice for clinical proton dosimetry, *Radiotherapy and Oncology* 20: 53- 63 (1991).
- [3] VYNCKIER, S., BONNETT, D. E., AND JONES, D. T. L. Supplement to the code of practice for clinical proton dosimetry. *Radiotherapy and Oncology* 32: 174-179 (1994).
- [4] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS Clinical Proton Dosimetry Part I: Beam Production, Beam Delivery and Measurement of Absorbed Dose. Report 59 of the International Commission on Radiation Units and Measurements, ICRU, Bethesda, MD (1998).
- [5] INTERNATIONAL ATOMIC ENERGY AGENCY Absorbed dose determination in external beam radiotherapy: An international Code of Practice for dosimetry based on standards of absorbed dose to water Technical Report Series TRS-398, IAEA, Vienna (2000).