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DOSIMETRY FOR SMALL SIZE BEAMS SUCHS AS IMRT AND STEREOCTIC RADIOTHERAPY, IS THE CONCEPT OF THE DOSE AT A POINT STILL RELEVANT? PROPOSAL FOR A NEW METHODOLOGY

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RAPPORT CEA-R-6243 – Aimé Ostrowsky, Jean-Marc Bordy, Josiane Daures, Loïc de Carlan, Franck Delaunay

«Dosimétrie pour les faisceaux de petites dimensions pour la RCMI et la stéréotaxie. Le concept de dose en en un point est il adapté ? Proposition pour une nouvelle méthodologie»

Résumé – Assurer la traçabilité de la dose absorbée délivrée à la tumeur pour les champs de rayonnements de petite et très petite tailles comme ceux utilisés dans les nouvelles modalités de traitement passe habituellement par l'utilisation de dosimètre dont la dimension est plus petite que celle du champ de rayonnements. L'absence de technologie permettant de mettre au point un dosimètre absolu pour établir une référence primaire dans un laboratoire national de métrologie ne permet pas une mesure directe de la dose absorbée en un point et implique l'utilisation de dosimètre de transfert, actif ou passif, de petite dimensions. Ce rapport a pour objectif d'introduire une nouvelle catégorie de grandeur dosimétrique pour la radiothérapie similaire au concept de Produit Dose Surface utilisé en radiodiagnostic. L'introduction d'une telle grandeur a des conséquences sur l'ensemble de la chaine métrologique incluant la planification du traitement aboutissant au calcul de la dose absorbée à la tumeur.

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RAPPORT CEA-R-6243 – Aimé Ostrowsky, Jean-Marc Bordy, Josiane Daures, Loïc de Carlan, Franck Delaunay

«Dosimetry for small size beams such as IMRT and stereotactic radiotherapy, Is the concept of the dose at a point still relevant? Proposal for a new methodology»

Abstract **-** Solving the problem of traceability of the absorbed dose to the tumour for the radiation fields of small and very small dimensions, like those used for new treatment modality usually results in the use of dosemeters of much smaller size than those of the beam. For the realisation of the reference in primary standards laboratories, the absence of technology likely to produce absolute small-size dosemeters leaves no possibility for the direct measurement of the absorbed dose at a point and implies the use of passive or active small-size transfer dosemeters. This report intends to introduce a new kind of dose quantity for radiotherapy similar do the Dose Area Product concept used in radiology. Such a new concept has to be propagated through the metrology chain, including the TPS, to the calculation of the absorbed dose to the tumour.

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Introduction

In external radiotherapy, the treatment plan of the patient, and therefore the absorbed dose distribution in 3D around the tumour, is calculated by dedicated software called Treatment Planning System (TPS). In order to do these calculations, the TPS needs, among others parameters, experimental input data measured during the commissioning of the LINAC. One of the parameters is the output factor which is investigated to take into account the differences between the reference conditions for the determination of the absorbed dose to water (particularly square field of 10x10 cm² at a depth of 10 g/cm² as mentioned in the IAEA TRS-398 protocol) and the conditions used for the treatment, namely smaller irradiation field sizes. The TPS calculations are tricky and today new treatment modalities, such as Intensity Modulated Radio Therapy (IMRT) and those corresponding to special treatment unit (Cyberknife, tomotherapy, Vmax or Arc therapy) intended to increase the dose to the tumour while keeping as low as possible the dose to the healthy tissues, use smaller beam sizes farther from the reference calibration conditions. Therefore, the role of the TPS in delivering the right dose to the tumour becomes more critical and although TPS improvement is an active field of research, another approach of interest consists in a LINAC calibration closer to the irradiation conditions during the treatment (i.e. in small fields).

The first approach to solve this calibration issue is based on the measurement of ouput factors down to very small irradiation fields using “point detectors” like small volume ionization chambers and primary standard such as calorimeter using small probes. The European Association of National Metrology Institutes (EURAMET) project named

External Beam Cancer Therapy (EBCT), started in April 2008, is based on this approach aiming at defining new standards for radiation therapy in small irradiation fields down to 2x2 cm². For field sizes lower than that, down to a few mm², the absence of technology likely to produce absolute small-size standard leaves then no possibility for the direct measurement of the absorbed dose at a point and implies the use of passive or active small-size transfer dosemeters. This leads to an increase of the associated uncertainty and increases the complexity of the measurement methodology.

Rather than to direct the research towards a miniaturization of the detectors in order to carry out a “measurement at a point”, another approach is to introduce a new kind of dosimetric standard definition. The solution suggested here after, based on existing technologies, consists of an approach similar to the one used to measure exposures in diagnosis, namely the Dose Area Product (DAP). Rather than using a small detector measuring only a part of the radiation field, a large detector will measure the complete radiation field. Of course, the measured signal will vary with the beam size as well as the DAP.

This concept can be applied for the primary instrument as well as for the working standard instrument, for example an ionization chamber. The main requirement for this detector is that its calibration coefficient does not depend on the field size. Therefore, this detector can then be used to calibrate the LINAC beams whatever the field size. Thus, the TPS, rather than calculating the distribution of the doses in a volume starting from the dose at a point (or in a small volume) could then carry out this calculation starting from a “dose area”. This evolution should have to be propagated through the metrology chain, including the TPS, to the calculation of the dose to the tumour.

Hereafter, the stages of the traceability of the reference along the metrological chain from the national laboratory of metrology to the end-user, the medical physicist are chronologically reviewed.

1 – Reference value measurement

Material: A graphite calorimeter, whose surface is larger than that of the beam, is placed perpendicular to the beam axis, at the reference depth.

Technology requirements: The thickness and the density of the core, those of all the shielding and back scattering material and the thickness of the vacuum gaps must be constant on all the surface of the detector. Thus, the centring of the detector in the beam is not a critical parameter.

> Note: This characteristic can be checked by scanning the detector with a stable collimated beam of small surface.

Quantity to be measured: It corresponds to the “dose area” for which we will adopt the symbol “DA”. This quantity looks like a DAP. If the 2D relative profile of the beam is known, it is possible to calculate the distribution of the absolute absorbed dose at any point of the beam. However the measurement of the 2D profile is not easy especially for small fields and can lead to an uncertainty not compatible with the radiotherapy needs. By analogy with the DAP, the unit of DA is Gy.cm².

> Note: when using a calorimeter smaller than the beam, only a part of the radiation is detected. In the configuration suggested here, the rise in temperature in the core of the calorimeter corresponds to the totality of the dose “delivered” by the beam, that is to say DA. For a given radiation quality, the rise in temperature thus varies with the surface of the beam.

Technological feasibility: The use of a graphite calorimeter of large size is possible because the conduction of heat in graphite is fast enough for not disturbing the measurement. A reduced number of thermistors for the electric calibration and the measurement of the rise in the temperature during the irradiation is thus a viable solution. It is thus possible to carry out an absolute measurement of DA whatever the shape of the 2D profile of the beam.

2 – Calibration of the dosemeter

As described before, the principle of using a primary standard larger than the field can be also applied to the transfer instrument.

Material: a plane dosimeter whose surface is larger than that of the beam. It is laid out in water at the depth of reference.

Technological requirements: The thickness of the walls at the front and the rear and of the volume of detection, of such a dosimeter must be constant on the whole surface of the detector. Thus, the centring of the detector in the beam is not a critical parameter. This characteristic can be checked by scanning the detector with a stable collimated beam of small surface. No stem correction is needed. The detector must have an energy response as constant as possible in order to avoid any influence due to the variation of the energy inside the beam and when the size of the field varies.

Calibration coefficient: it is equal to “DA / Rs”, Rs being the reading of the dosemeter corrected for the influence quantities. Rs can be for example a collected charge or a current.

One of the field sizes to be used can be 2x2 cm^2 which would make it possible to be traceable to the absorbed dose in a point such as given by the LNHB within the framework of contract EMRP of metrology “External Beam Cancer Therapy”.

> Note: In the usual case of an ionisation chamber smaller than the beam size associated with an electrometer, only a part of the beam is detected. In the aforementioned configuration, the charge collected corresponds to the totality of the dose delivered by the beam which is DA. Therefore, for a given radiation quality, the collected charge varies with the surface of the beam.

Technological requirements: plane parallel ionisation chambers with large surfaces already exist. A special design dedicated to this application can be necessary but does not present major mechanical difficulty. If an ionisation chamber is chosen as transfer dosemeter, the wall must be thick enough and made of material with a stopping power ratio between the wall material and air as constant as possible.

3 – Commissioning of the LINAC of the end user

During the commissioning, a large number of measurements is made in order to provide to the TPS all the data needed to the calculation of the dose to the tumour under the clinical conditions. Among then, the absolute dose value in the reference conditions, usually 1 cGy/MU in a 10x10 cm² field at a depth of 10 g/cm² and the output factor.

The general principle is to be able to switch from a reference expressed in terms of absorbed dose under the classical reference conditions at a point to a dose distribution in the volume under specific conditions.

Adoption of a new quantity such as DA does not modify the philosophy of this operation; it only substitutes DA for the absorbed dose in a small volume. This substitution however requires modification of TPS calculation models.

Conclusions

In this report, a new concept is proposed for the dosimetry of small irradiation beams in external radiotherapy. This concept consists in replacing the quantity of “absorbed dose at a point” in reference conditions to “absorbed dose on the whole surface of the beam”. This concept is complementary to the classical one since it can only be used for small irradiation fields. Some specific features for such an approach are summarized here after.

As written before, the building of graphite calorimeter of a surface large enough (a dozen of cm²) to measure DA is possible, as well as the manufacturing of large surface plane parallel ionisation chamber. The determination of a proper wall material “air equivalent” could be a problem. It is also necessary to stress the quality of manufacture which is essential for this kind of detector and which exceeds what is usually commercially available. A technical demonstration of the calibration with an existing material is necessary.

The principal difficulty lies in the modification or the adaptation of the TPS. The demonstration must be made that a calculation algorithm based on the measurement of a Dose Area allows sufficient precision on the doses distributions in and around target volume. So the implementation of this new methodology requires the support of the manufacturers because that modifies the algorithm of calculation implemented in the TPS and implies the use of new type of detectors.

Annex: Principle of the graphite calorimeter (LNHB design)

The annex describes the calorimeter named GR9 which is the current standard for absorbed dose to graphite at LNHB. This design will be adapted to the requirements of the measurements of quantity such as DA. The calorimeter components are manufactured in very high purity graphite, very fine grain, grade 5890 PT from Carbone Lorraine. The mean mass density is 1.82 g/cm^3.

The calorimeter is constituted of three concentric bodies (core, jacket, shield), put inside the block. These bodies are separated from each other by vacuum gaps in order to provide good thermal insulation.

The core, the sensitive element, is a flat cylinder of 3 mm thick and 16 mm in diameter.

The jacket is a graphite cylindrical box of 9 mm in height and 24 mm in diameter (external dimensions). The jacket thickness is 2 mm so that the gap between the core and the jacket walls is 1 mm. Its mass is 4.9 g. For assembling it, the jacket is split into two parts along its mid plan.

The shield is a graphite cylindrical box of 15 mm in height and 32 mm in diameter (external dimensions). The shield thickness is 2 mm so that the gap between the shield and jacket walls is 1 mm. Its mass is 11 g. For assembling it, the shield is split into four parts.

These different bodies are maintained by means of 3 silk threads taut in the median plan of the core, providing 1 mm gap between the bodies.

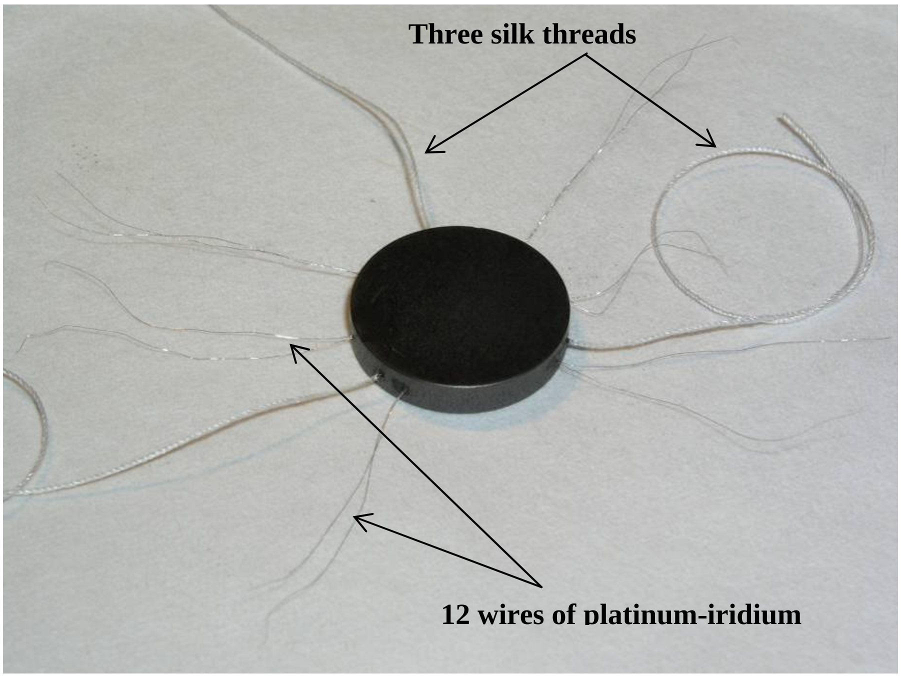
As graphite is porous, airtightness is provided by a Mylar film of 0.10 mm in thickness added on the front side and rear side of the calorimeter and by a lateral wall of PMMA 15 mm in thickness. The PMMA part ensures the rigidity of the whole calorimeter. The total thickness of the calorimeter is 32 mm and the external diameter is 18 cm including the block. The sensitive part of the calorimeter is only the core (16 mm in diameter). For measuring a quantity like DA (defined in this report) the diameter of the core has to be enlarged and therefore the diameter of the jacket and the shield have to be enlarged too.

This calorimeter is specially designed for measurements in phantom. The phantom is a right parallelepiped with 30 cm side and 20 cm depth. A cavity of 18 cm in diameter has been drilled along the beam axis in order to receive the calorimeter. The depth of measurement in the phantom is achieved by adding graphite slices of different thickness before and behind the calorimeter. The external PMMA part of the calorimeter is 7.5 cm distant from the beam axis; outside the direct beam in the reference conditions so that the irradiation comes only from the scattered beam. The minimum depth of the core from the entrance surface of the beam is a limitation, especially for low energy electron beams.

The reference point of the calorimeter is the geometrical center of the core which is the geometrical center of the block.

Thermistors are used for temperature measurements as well as for electrical heating of the different bodies. Their sizes are small in order to limit the mass of impurities amount and their sensitivity has to be high enough to allow precise measurements.

Here after are pictures, radiographies and diagrams of the different part of the calorimeter. Compare to this design the core, the jacket and the shield of the new calorimeter will have a larger diameter in order to be larger than the size of the radiation beam for measuring DA.



Picture 1: Core with its 6 thermistors embedded in the graphite and the 3 silk threads to maintain the core in the jacket and the jacket in the shield

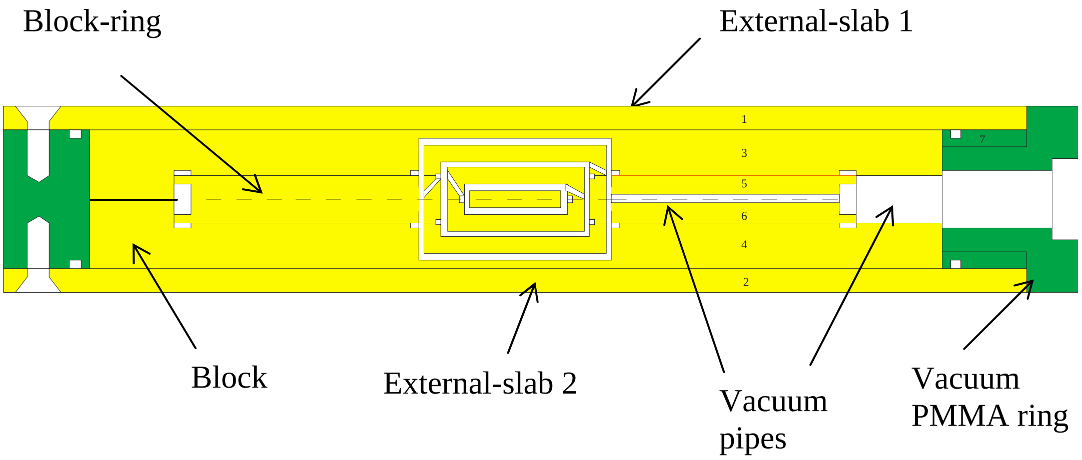
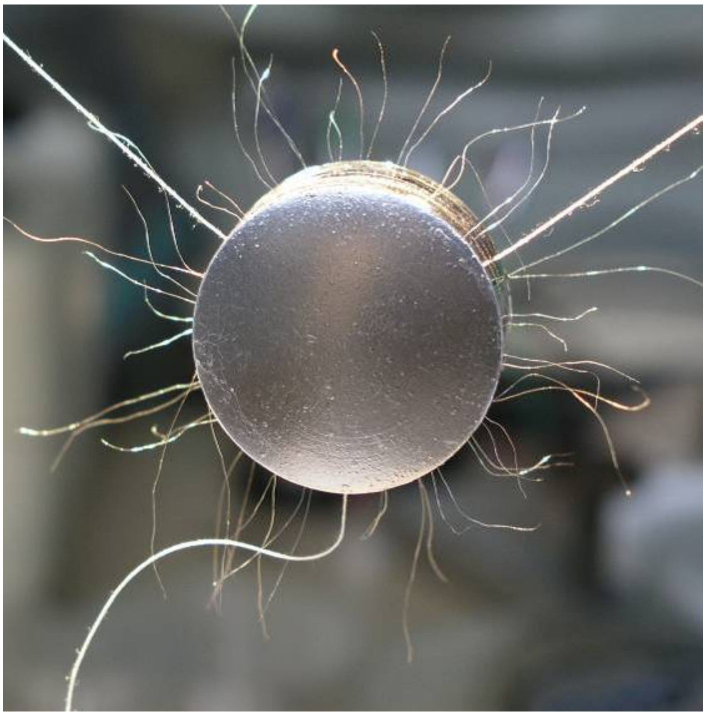
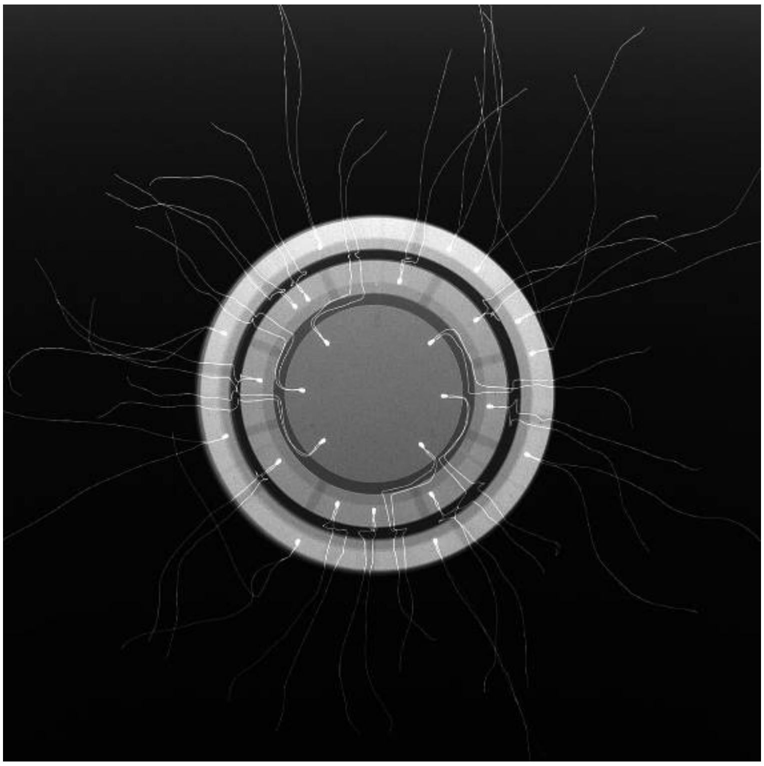


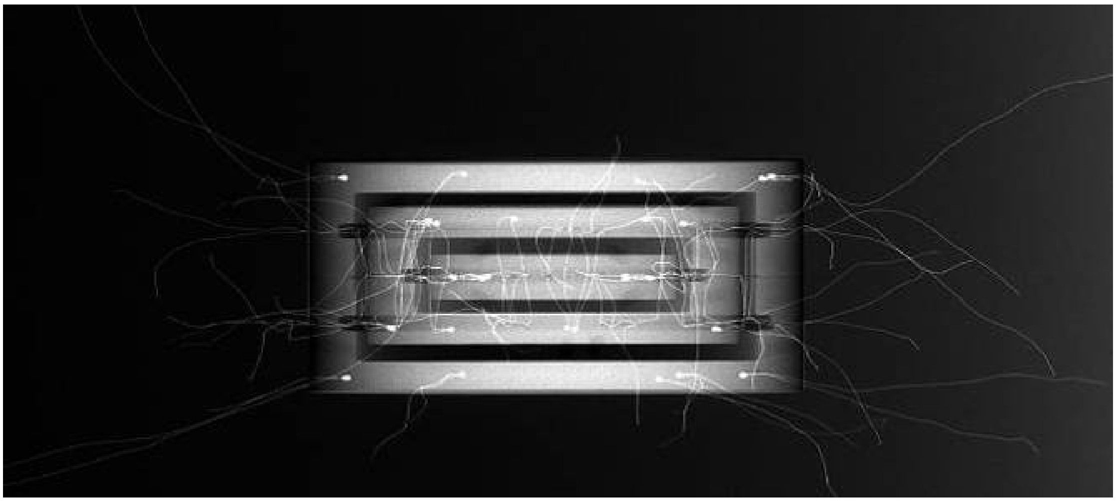
Figure 1: Cut view of the calorimeter



Picture 2: Outward appearance of the central part of the calorimeter, one can see the shield with the thermistor wires and the 3 silk threads



Picture 3: Radiography (front view) of the central part of the calorimeter, one can see the 3 bodies. In the centre the core with 6 thermistors, around it the jacket with 10 thermistors and around this former the shield with 10 thermistors.



Picture 4: Radiography (side view) of the central part of the calorimeter, one can see the 3 bodies. In the centre the core (only 2 thermistors are visible), around it the jacket (only 5 thermistors are visible) and around this former the shield (only 8 thermistors are visible)