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(Invited) Energy dependence of detectors for 3D dosimetry of light ion beams

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Mapping and verifying 3D dose distributions form an essential procedure in the adequate treatment process of cancers with radiotherapy. The main requirements for 3D dosimeters are a spatial resolution sufficient for resolving the dose variations of interest, efficient readout and a response proportional to dose. Common methods to obtain 3D dose distributions include, scanning systems with point detectors such as ionisation chambers or diodes, linear or 2D arrays composed of ionisation chambers or diodes, 2D films and 3D-distributed radiosensitive agents in gels or plastics.

Point detectors are usually not efficient for 3D dosimetry but have some applications, e.g. if the volume to be scanned is limited or if it is sufficient to obtain dose profiles along three axes only. Linear arrays are efficient to obtain 2D dose maps but can still require long acquisition times for full 3D dose distributions. 2D arrays, on the other hand, are efficient but have often the disadvantage that resolution is limited given limitations on the amount of signals that can be read-out. Distributed radiosensitive agents in films, scintillating plates, gels or plastics provide a high resolution but the former two require laborious readout procedures while the latter two require optical or magnetic resonance interrogation with tomographic reconstruction. For scanned ion beams, an additional constraint is that dose scanning methods are not an option in terms of efficiency since for every dose point the entire scan sequence has to be delivered. 2D arrays or 3D dosimetry methods are often the only practical option. A particular requirement of scanned ion beams is the measurement and verification of spot positions. Deformation of the profile due to inhomogeneities of the 2D detectors used can result in an erroneous determination of the centre of the spot.

For light ion beams, a specific issue encountered is that the radiosensitivity of many physical or chemical detectors is dependent on the energy of the charged particle passing the detector volume. It is thus essential that this energy dependence is well-understood and corrected for. One of the contributing factors is the difference in energy absorption between the detector material and the phantom material (water or tissue) but in most cases the energy dependence is predominantly related to the ionisation density which, for a given type of projectile, increases with decreasing particle energy. In solid state detectors that are based on the creation of electron-hole pairs, such as silicon diodes, mosfets, diamonds and luminescence detectors, an increased ionisation density modifies the probability of recombination and consequently also the dose response. Other processes involving the mobility of electron-hole pairs may also be affected by ionisation density. In chemical dosimeters such as Fricke gels, polymer gels and radiochromic films or plastics, the increased ionisation density changes the yield of primary species diffusing out of the ion tracks resulting in a modified dose-sensitivity and for many of those, also the probability of termination reactions increases with increasing ionisation density resulting in a loss of signal. Even for detectors that are generally considered to exhibit little energy dependence such as ionisation chambers and calorimeters, the effect may not be negligible for ion beams. For ionisation chambers, the mean energy required to produce an ion pair is energy dependent resulting in a small quenching of 1-2% of the Bragg peak, while for calorimeters, the primary instruments for the unit of absorbed dose, the physicochemical heat defects due to the formation of lattice defects or chemical reactions are energy dependent for ion beams.

An overview of 3D dosimetry technologies for scattered and scanned ion beams will be presented and signal quenching mechanisms and sources of response non-uniformities will be discussed. In conclusion, energy dependence of any 3D dosimeter should be considered and corrected for as well as any non-uniformity in the detector's dose response.

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