Dosimetry of β-emitting Radioactive Implants ◇

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Brachytherapy is a special kind of radiotherapy where radioactive sources are used to deliver a high radiation dose at a short distance locally to the tumor with rapid dose fall-off in the surrounding tissue. Within the RadBioMat-project radioactive implants are developed for this purpose using the pure β-emitter ^{32}P with a mean electron energy E_{mean}= 0.7 MeV. The total range of 0.7 MeV electrons is only about 4 mm and the deposited dose of a ^{32}P line source falls off from 0 to 1 mm distance in tissue by about 80%. Dose distribution measurements have to be made therefore with a space resolution of 1 mm or better which is at the limit of todays dosimetry both in measurement and simulation.

To measure dose distributions with this precision a detector setup with 4 stepper motors has been built using a scintillation detector system with 0.8 mm^3 sensitive volume (Type 60006, Optidos, PTW Freiburg). We also tested a recently developed detector diode with 2.5 μm active thickness (Dosimetriediode E) which was kindly left by PTW Freiburg for tests in our energy range below 2 MeV. Detector and radiation source are mounted inside a small water pool ("water phantom") to simulate tissue equivalent conditions (Fig. 1). An alignment telescope was used to measure the actual distance between detector and source as 0.1 mm change results in a dose difference of more than 10%. On the other hand dose distributions should be known better than 5% in radiation therapy.

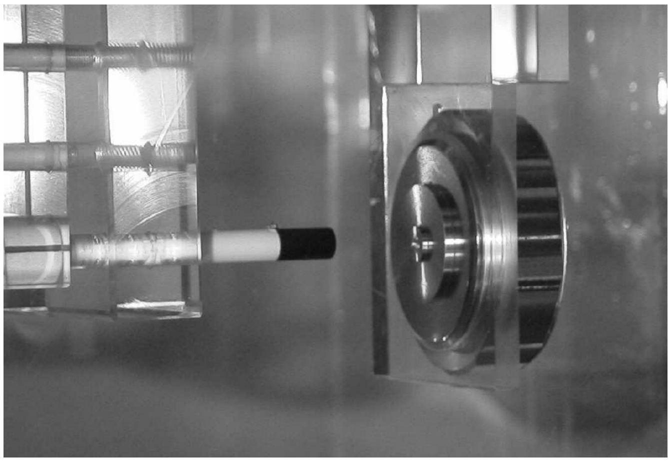

Fig. 1: Scintillation detector in front of a ^{90}Sr calibration source, both in a Plexiglas fixture inside the water phantom. Note the sensitive detector volume is only about 5% of the black colored volume.

Dose distribution of a 3 mm wide ^{90}Sr calibration source is shown in Fig. 2. Measurements using photon and electron beams of different energies were made at the therapy accelerator of the Clinic for Radiation Therapy of the University Hospital (TUM). Comparing the results of the scintillation and the diode detector with a calibrated ionization chamber, first a clear energy dependence of the diode below 2 MeV electron energy is seen and secondly a systematic error of the scintillation detector (but still within the errors given by the manufacturer).

Dose deposited by ionizing radiation in tissue as well as in detector materials can be simulated by Monte-Carlo programs. Recently, GEANT4 was extended to energies as low as 250 eV for medical applications and entered the group of well established dose simulation programs like MCNP or EGSnrc. It has the advantage of very flexible modular programming using C++.

We tested this program by comparing it with EGS and found a perfect agreement of both programs. Using it for simulations with 1 mm depth resolution makes a pixel size of 0.01 mm necessary and accordingly a step size of 1 μm for energy loss processes. This could be easily handled on our cluster system with 48 AMD microprocessors within reasonable time. As no direct comparison can be made between measurement (output is dose in Gy) and simulation (input is activity in Bq), our new liquid scintillation system (TriCarb, Perkin Elmer) was used to measure the activity of the radioactive samples and link dose and activity. After the dose distribution measurements the implants were dissolved in liquids (in collaboration with the Institute for Radiochemistry, TUM) and their total activity measured. To improve the accuracy a cross check was made with a calibrated ^{32}P solution. The systematic deviation of the scintillation detector was confirmed and could be explained in simulations with the special calibration geometry of the detector.

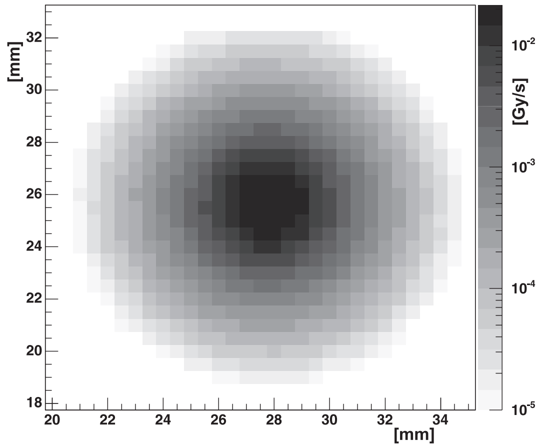

Fig. 2: Dose distribution in a plane 1 mm in front of a ^{90}Sr calibration source, measured with the scintillation detector inside the water phantom.

Our detector setup BETADOS is now routinely in use to measure the β-activity and dose homogeneity of ^{32}P implanted sources for cell irradiation experiments which are produced in close collaboration with the Research Center Karlsruhe (Dr. Klaus Schlösser).

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