DISTRIBUTION OF PROTON ABSRORBED DOSE IN HUMAN EYE SIMULATED BY SRNA-2KG COMPUTER CODE

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Abstract

Rapid increasing of performances of personal computers and development of codes for proton transport based on Monte Carlo methods will allow, very soon, introduction of the computer planning proton therapy, as a normal activity in regular hospital procedures. Description of SRNA code, used for such applications, and results of calculated distributions of proton-absorbed dose in human eye, are shown in paper.

1. Introduction

It was already shown, in few last decades, that computer codes based on Monte Carlo techniques are powerful tools for simulations of transport of nuclear particles. Large number of physicists involved in nuclear medicine and radiotherapy believe that in near future application of these computer tools will be only a routine in a dose estimation during radiotherapy planning [1]. Monte Carlo technique could be used for simulation of all proton interactions with material in three dimensions (3D) with requested statistical accuracy. It was the basic motive for development of a general computer code - SRNA for proton transport based on these techniques [2] with applications in following main fields: (1) proton therapy; (2) design of ADS targets; (3) production of radioisotopes for medical applications; (4) simulation of dispensers and devices for proton beam characterisation, e.g. multi-layers Faraday's cap [3]; (5) simulation of generation of positron emitters, and (6) dosimetry and radiation protection of accelerator installations. SRNA code simulates various sources of protons and targets in 3D for interactions with protons with energies from 100 keV to 250 MeV. SRNA-2KG and SRNA-3KG [5] are general versions of the code, while SRNA-VOX is a version developed for proton therapy planning using data about anatomy of patient, obtained from computer tomography (CT). All versions of SRNA code are supported by independent SRNADAT module that prepares transition probabilities used in simulation of proton transport. The codes are written in FORTRAN77 for Windows and Linux operation systems.

2. Model and SRNA computer code

Simulation of proton transport by Monte Carlo techniques is based on theory of multi-scattering of charged particles [6, 7], loss of proton energy in fluctuations [8] and a model of decay of compound nucleus, based on cross sections for inelastic nuclear reactions [9]. Proton trajectory is divided in large number of small space steps, for which sampling of probable events is made using inverse probability distributions prepared in advance in a separate module, SRNADAT, for all materials of targets and for all proton energies. Energy deposited in a target is calculated as difference of proton energy before and after ionisation, accounting fluctuation. Proton deflection angle after interaction is determined by sampling from inverse Moliere distribution. International data for proton deposited energy in ionisation and verified internationally recognised routines for numerical integration of functions are used. Proton inelastic interaction is very rare event, but it is treated specially in the SRNA code because proton could be lost from a beam trajectory completely or create secondary protons. In decay of compound nucleus, created in the event, neutrons, protons, deuterons, tritons, alpha particles and photons could be emitted. The code calculates particles' emission probabilities by integration of respective differential cross sections [9]. Energy deposited by proton is increased for energies of other particles and recoiled nucleus. Stages of generated neutrons and photons are recorded in databases for their subsequent transport by other computer codes, e.g. MCNP or FOTELP [4].

3. Code verification in numerical experiments

Determination of proton beam characteristics in various media are limited by existing detectors [3], except in water, where still a small number of data is available for protons with energies up to 250 MeV, or higher. For validation and verification of SRNA code, a series of inter-comparison numerical experiments is made, comparing results of SRNA code with PETRA code [10] and GEANT code [11].

Since PETRA is 1D code for proton energy up to 250 MeV, and GEANT is primary high-energy code, with version GEANT4 applicable to radiotherapy, the codes inter-comparison is made in 1D model of water phantom. Results are given in Figures 1-4 showing very good agreement. A study group from Harvard University has shown that the best test for any Monte Carlo based computer code for proton transport is a case of proton transport through multi-layer Faraday's cap [3]. Result of SRNA code for this test is given in Figure 5.

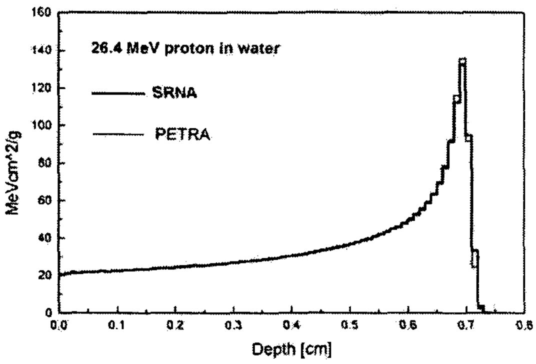

Fig. 1 Dose depth distribution in water phantom, 26.4 MeV protons (SRNA and PETRA)

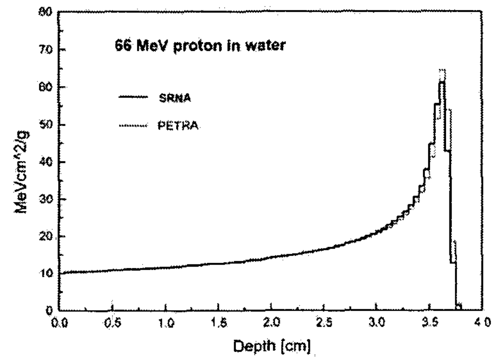

Fig. 2 Dose depth distribution in water phantom, 66 MeV protons (SRNA and PETRA)

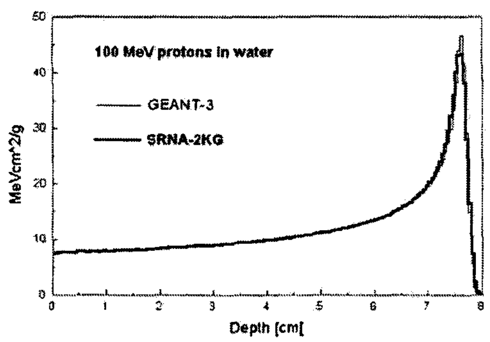

Fig. 3 Dose depth distribution in water phantom, 100 MeV protons (SRNA and GEANT3)

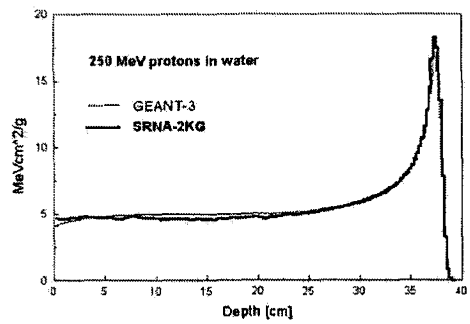

Fig. 4 Dose depth distribution in water phantom, 250 MeV protons (SRNA and GEANT3)

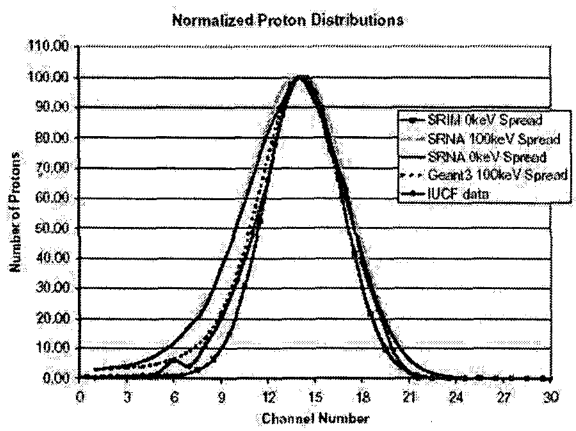

Fig. 5 Measured and calculated energy distribution of 205 MeV proton beam at Indiana University accelerator [3]

4. Proton dose distribution in human eye

Proton therapy is based on fact that the largest part of proton energy is deposited in media (tissue) at the end of proton range, e.g., near Bragg peak (Figs. 1 - 4). Efficiency of this therapy is about 90%. Position of a tumour in a human eye requires application of 50 MeV proton beam, obtained easily in small accelerators.

OECD NEA has supported inter-comparison of computation tools in radiation dosimetry through project QUADOS (Quality Assurance of Computational Tools for Dosimetry). Within the project, benchmark case – problem no. P3 is set up for calculation of distribution of proton deposited dose in the model of human eye – the water phantom that comprises plastic compensator and water sphere (Fig. 6).

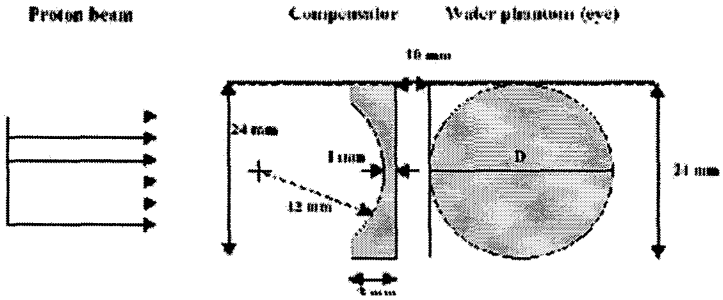

Fig. 6 QUADOS model of human eye

Benchmark case P3 requires code results for two sub-cases: (1) 50 MeV proton beam with diameter 15 mm, and (2) same diameter proton beam with given energy spectrum in range from 40 MeV to 50 MeV. Tasks for the code are determination of: (1) proton deposited dose distribution in eye along beam axis and (2) 2D distribution of proton absorbed dose in equatorial plane along the beam axis.

SRNA code is modified to use predefined voxels (0.5 x 0.5 x 0.5 mm^3) in the phantom geometry, that was described by planes, cylinders and spheres. Within voxels proton transport was simulated and deposited energy (MeV/kg) was recorded. The code is run for one million protons in a beam to obtain statistical error (1σ) better of 1.5 % above 20 % of maximal dose. Results of SRNA code are shown in Figures 7 – 10.

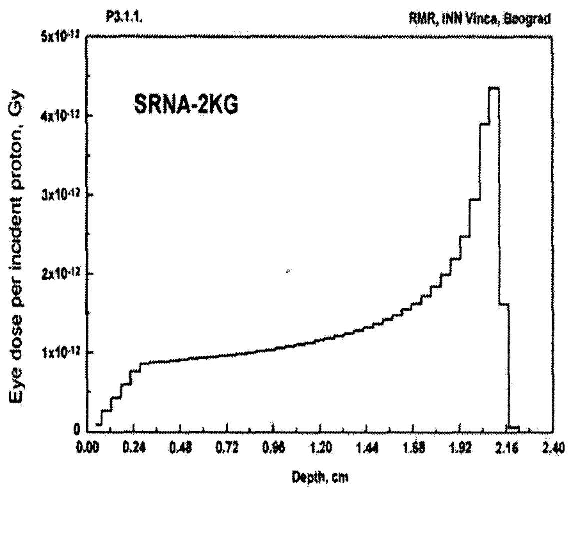

Fig. 7 Distribution of absorbed dose of 50 MeV protons in eye along beam axis

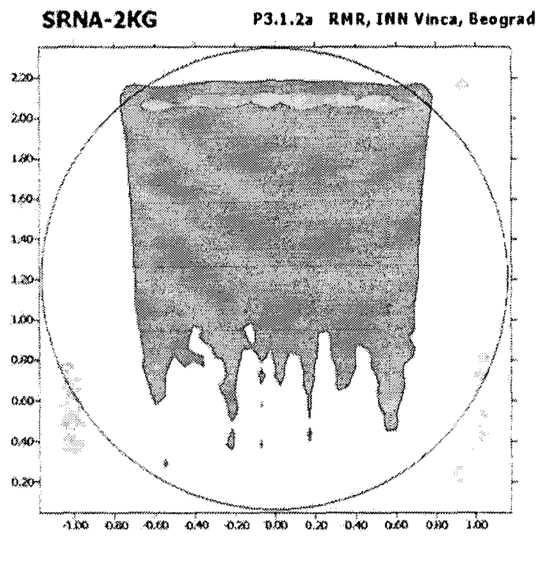

Fig. 8 Distribution of absorbed dose of 50 MeV protons in equatorial plane of eye

Data for deposited proton energy in voxels in equatorial plane of human eye (water sphere) and spline numerical techniques were used to construct 2D figure showing the proton absorbed dose.

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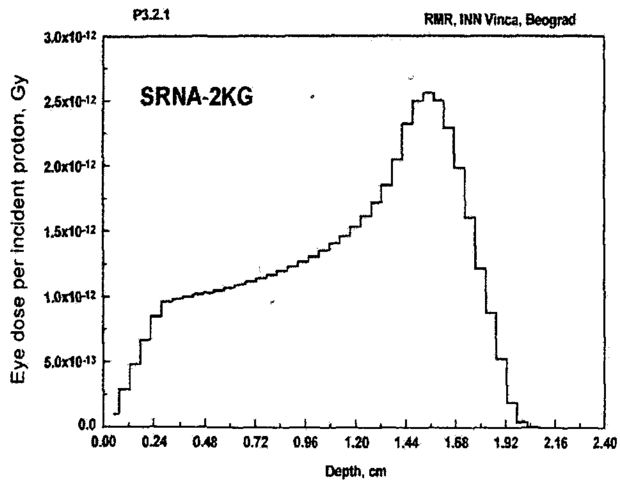

Figure 9: Distribution of absorbed dose of 40 MeV protons in eye along beam axis

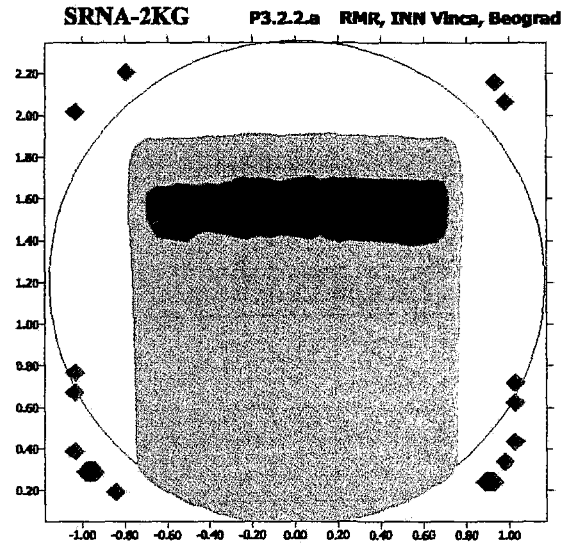

Figure 10: Distribution of absorbed dose of 40 MeV in equatorial plane of eye

5. Conclusion

Results obtained by Monte Carlo based computer code SRNA for proton transport in various inter-comparison numerical experiments show that the code is prepared for including in an information system, to be designed for the computer planning proton therapy in near future.

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