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DEVELOPMENT OF THE ACCURATE DOSE CALCULATION SYSTEM IMAGINE FOR REMOTELY AIDING RADIOTHERAPY

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Abstract

The dose calculation system IMAGINE is under developing for remotely aiding radiotherapy using photons and electrons . The system calculates the accurate dose distribution in a patient body rapidly utilizing precise models of the patient body and accelerator assembly incorporated with a Monte Carlo calculation. In the completed system, the dose calculation will be performed at the dose calculation center equipped with the ITBL high-performance computers, and the input and output data will be transferred through a network. The system is intended to support the quality assurance of the current radiotherapy widely carried out at present, and further to promote the prevalence of advanced therapy. The system is scheduled to be completed in 2006. Some prototypes of the modules constituting the system have been already constructed, and confirmed to work properly. These modules will be used to obtain basic data to decide the concrete design of the system.

1. Introduction

It is well known that the dominant cause of death of the public is various kinds of cancers, and about one-third of Japanese lose their lives by cancers. Radiotherapy has been considered to be an advantageous therapy method, and a great number of treatments using radiation are conducted every year. However, the contribution of radiotherapy to the whole cancer treatments in Japan is less than one half of that in USA[1)]. The main reason for the relatively low usage of radiotherapy is often attributed to the extreme shortage of medical staffs able to properly estimate the doses in radiotherapy. Commercial systems for radiotherapy planning have been widely used for dose evaluation and have played important roles. Nevertheless, it has been pointed out that under some specific conditions the commercial systems may not give sufficiently accurate doses. It was found that the approximation calculation employed in the commercial planning system cannot reconstruct the dose distribution properly when the density in the body varies rapidly because of the electron inequilibrium [2)]. ICRP recommends in report 50[3)] that the dose distribution in a patient body should be evaluated within an accuracy of 5%. Considering these situations, a system supporting radiotherapy on the basis of reliable dose evaluation is expected to work effectively in many aspects. We have started developing such a system. In this paper, the outline of this project and primary research results will be introduced.

2. Dose Calculation System

2.1 Outline of the system

The project started on November 2002 and is scheduled to continue for five years being funded by JST. Actually the project consists of two subjects: one is the development of the dose evaluation system for radiotherapy using photon and electron; another is the development of the simulation system for investigating the feasibility of therapy using X-ray induced protons. This paper describes the first subject. For obtaining accurate dose distribution in a patient body, the system utilizes a sophisticated human model constructed from CT images and a Monte Carlo calculation with the EGS4 code[4]. The system is planned to work on the ITBL (Information Technology Based Laboratory) computers consisting of 512 CPUs located at the Kankai Establishment, JAERI. Figure 1 gives the schematic design of the system. The data on CT images and treatment plan are transferred from a hospital to the dose calculation center, a voxel phantom is constructed immediately and the dose distribution in the patient body for the treatment is calculated in a short time; then, the calculated dose distribution is sent back to the hospital. The purposes of the system are: to provide benchmarks for the quality assurance and safety control of current radiotherapy; and to contribute to the promotion of the usage of advanced therapy.

2.2 Human body modeling

In this system a voxel phantom - the numerical human model where organs and tissues are defined as sets of small cuboid units called voxels - will be automatically constructed from CT data of a patient. In recent years, especially in radiation protection field, the voxel phantom has come to be used in many cases for dose calculation. Saito et al. developed voxels phantoms for Japanese male and female[5] shown in Figure 2. These phantoms could be the basic models for this project. However, usually it takes a long time to complete one voxel phantom, if diverse organs and tissues need to be segmented. In this project, a procedure will be developed to rapidly construct the voxel phantom that gives the least information needed for dose calculation with an accuracy of a few percent. To attain this accuracy, realistic modeling is necessary from viewpoints of geometry and elemental compositions; while only a few organs and tissues need to be segmented in this system because the information on organ and tissue doses are usually not indispensable. In the first step, we are planning to use 1x1x1 mm^3 voxels and to segment the phantom into five or six different media with different elemental compositions. The conditions to meet the necessary dose accuracy are being investigated. According to this preliminary study, the specification of the voxel phantom will be finally determined.

2.3 Transport calculation

Radiation transport calculation is performed in two different ways. First, the particle fluence entering a patient body is calculated modeling the accelerator assembly (target, collimators, filters etc.) precisely. The EGS4 user code BEAMnrc[6] developed at National Research Council Canada (NRCC) is available for this kind of simulation. We have started investigating the features of the incident photon fluence using the BEAMnrc code. Second, the dose distribution in a patient body is calculated using the voxel phantom described above. A prototype of the dose calculation code for radiotherapy incorporated with voxel phantoms has been already developed as a EGS4 user code[7] by modifying the external dose calculation code UCPIXEL[5,8] for radiation protection use. The code entitled UCRTP is going to be used in primary study. The fundamental features of radiation outside and inside the patient body are being investigated to determine the specifications required for the transport calculation codes and models for IMAGINE. Basically, we try to avoid as much as possible the usage of the approximations which might lead to degradation of dose accuracy. While, it is an essential requirement to reduce computational time significantly in order to obtain the dose distribution within a reasonably short time. Super parallel computing on the ITBL computers will be fully utilized to fasten the computational time; moreover, algorism to reduce computational time without degradation of accuracy will be investigated. In a practical use, the reliable incident fluence specific to each treatment system and each treatment condition will be determined once. Then, the same fluence data will be used commonly for all radiotherapy under the same irradiation conditions.

3. Application to advanced therapy

The IMAGINE system is also planned to apply to the advanced radiotherapy of intensity modulated radiation therapy (IMRT)[9] and CT radiotherapy (CTRx)[10]. IMRT can concentrate doses at the tumor target by forcing a variety of beams with diver shapes and intensities created by multi-leaf collimators to enter a patient body from different directions. Consequently, it is extremely troublesome and time consuming to evaluate the dose distributions and make a treatment plan on the basis of the evaluated doses. For performing this procedure efficiently, it is essential that the variation in photon fulence due to multi-leaf collimators can be accurately simulated in a short time. We are investigating how it can be approximated without significant reduction of the accuracy. Basic data for examining the characteristics of the collimated beams will be obtained changing the conditions variously with full Monte Carlo simulations and experiments. CTRx is a new radiotherapy method utilizing a high-energy CT machine. In this therapy, X rays from the X-ray tube for tomography are also used for radiotherapy, and the irradiation is performed checking the target position in the CT images. This enable us to follow the movement of the target; for example, the one according to breathing. Further, it has been shown that using low energy X rays can make the dose distribution in the tumor uniform compared with cases using high-energy photons from accelerators. However, this therapy needs to estimate the dose in real time to repeat the irradiation while confirming the accumulated dose. The characteristics of the low-energy photons could be utilized to reduce the computational time. The IMAGINE system is expected to be used efficiently in the advanced therapy, and the investigation has started for applying the system specifically to each therapy.

4. Examples of Transport Calculation Results

Some trial calculations tons have been performed to investigate the fundamental features of the radiation behavior inside and outside a body. Figure 3 shows the accelerator model used for the trial calculation of photon fluence. An example of photon energy spectrum from the accelerator calculated by the BEAMnrc code system is shown in Figure 4. The calculated energy spectrum due to 16 MeV electron incident on the target indicates a reasonable shape. To obtain accurate photon fluence from the calculation, the detailed information is essential concerning the accelerator assembly such as shapes, dimensions and compositions. We are gathering the information on several commercial accelerators typically used in the present treatments, the models of them being constructed step by step. The performance of the BEAMnrc code on the ITBL computers has been also investigated. The speed-up due to parallel computing has been found to be almost linear to the number of processor elements as shown in Figure 5. In this trail calculation, the speed-up rate decreased for the calculation with 64 processor elements. This is considered due to the statistical fluctuation resulting from the comparably small total histories for the test case. In an actual case considering greater histories, the speed-up characteristic would be expected to be better. The percentage depth dose in a water phantom consisting of 2x2x2 mm^3 voxels was calculated by the prototype of dose calculation module (Figure 6). The statistical accuracy within 1% was attained by twenty-six million histories of photons.

5. Conclusions

The project team organized by the members with different backgrounds is constructing the dose calculation system IMAGINE intended to support the radiotherapy using photons and electrons. Most of the basic techniques necessary for the system have been cultivated by the members so far, and primary investigation is being carried out using these techniques. The system will be completed in 2006. However, to make the system practically useful, the discussion concerning the framework of the system operation is also very important as well as the technical investigation. We would appreciate receiving comments widely from doctors, medical staffs engaged in radiotherapy, and anyone interested in the system.

Acknowledgment

We would like to express our thanks for all the people supporting this project directly and indirectly. Without their help, the project never succeeds.

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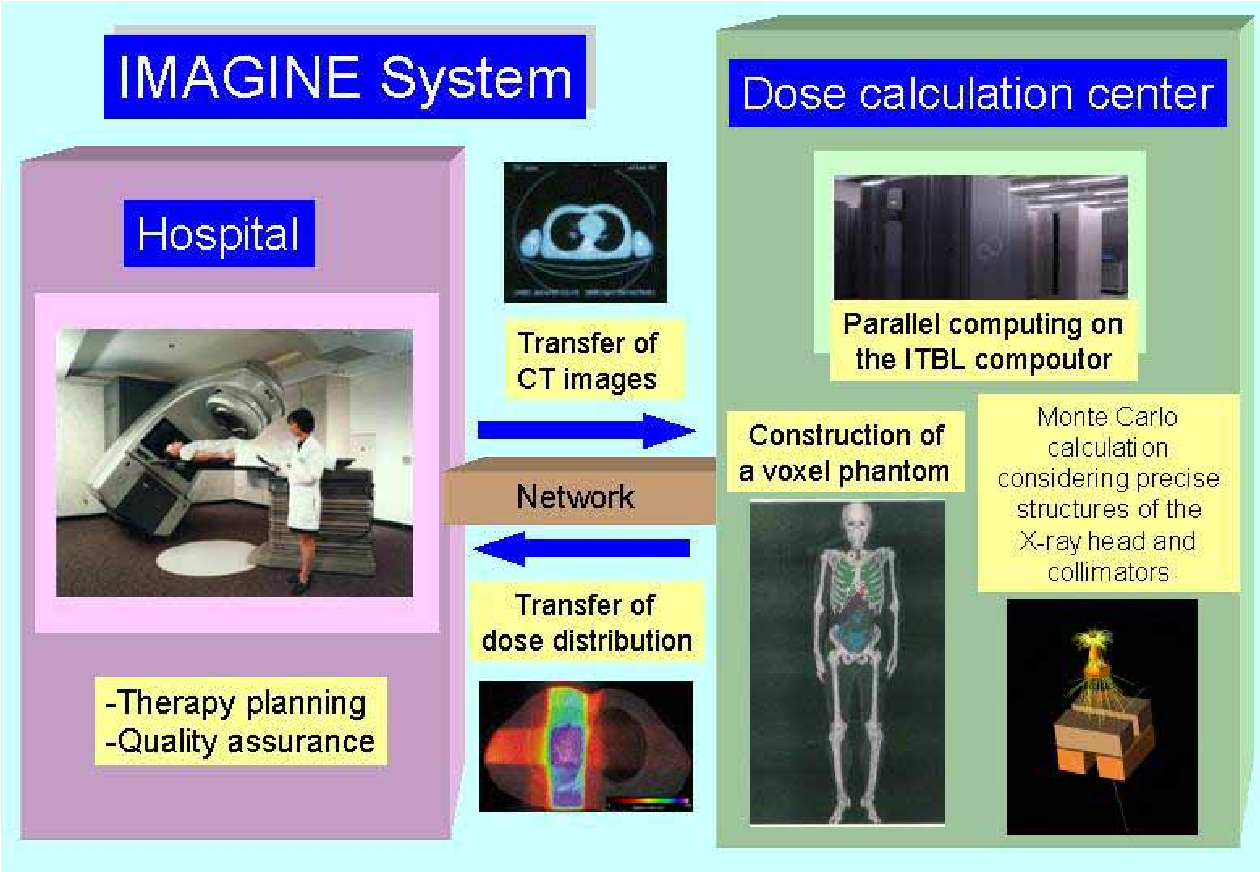

Figure 1 Schematic design of the IMAGINE system.

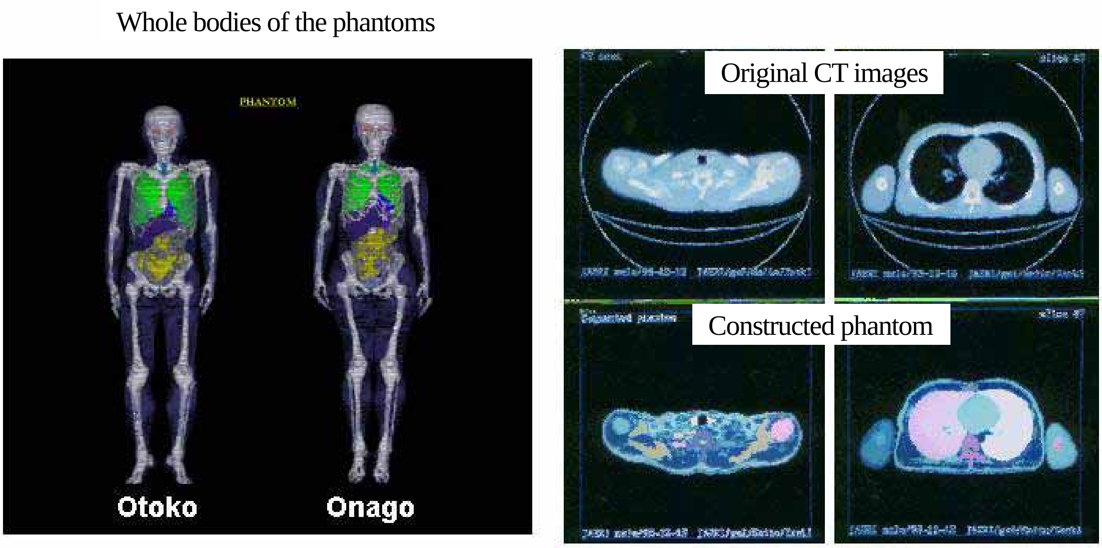

Figure 2 Voxel phantoms developed at JAERI for radiation protection use.

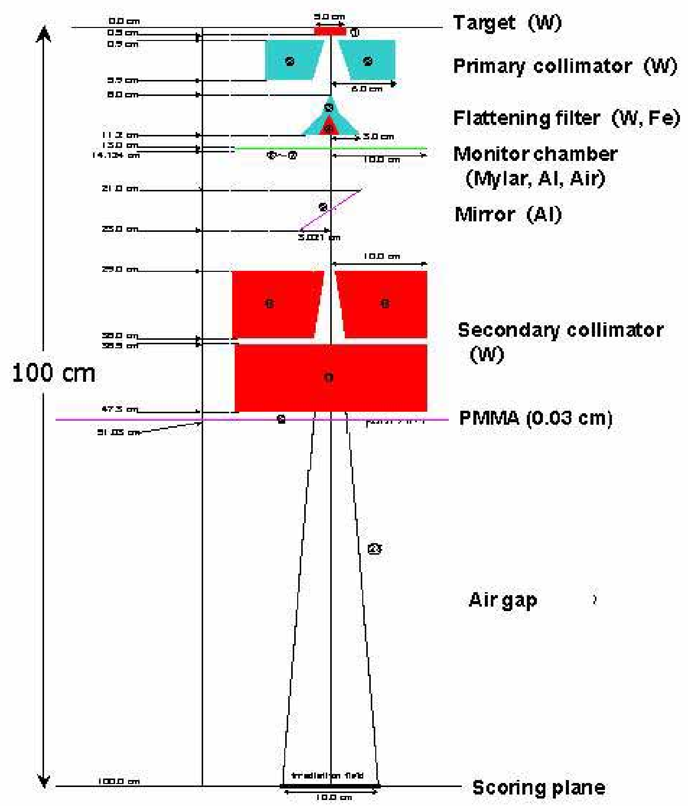

Figure 3　Accelerator model used for the trial calculation.

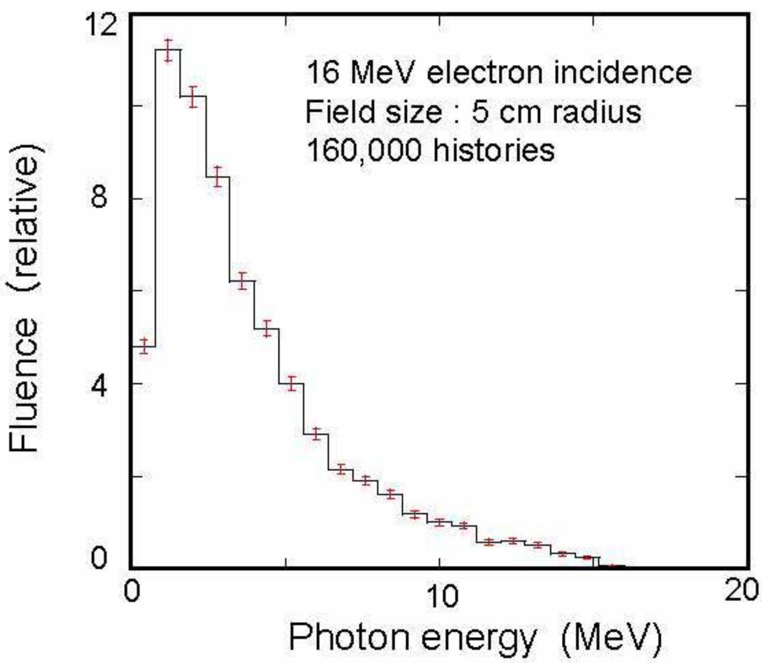

Figure 4　Photon energy spectrum calculated using the accelerator model in Figure 3.

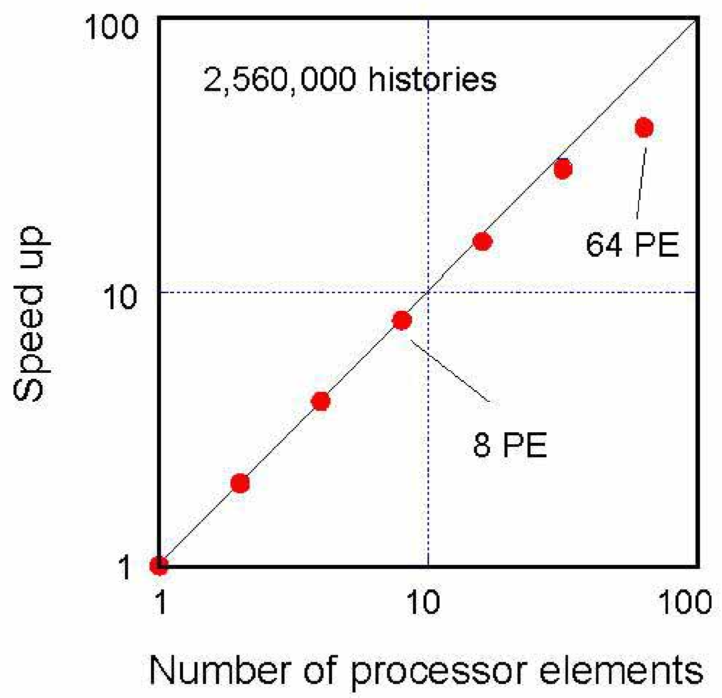

Figure 5　Speed-up of the irradiation fluence calculation due to parallel computing.

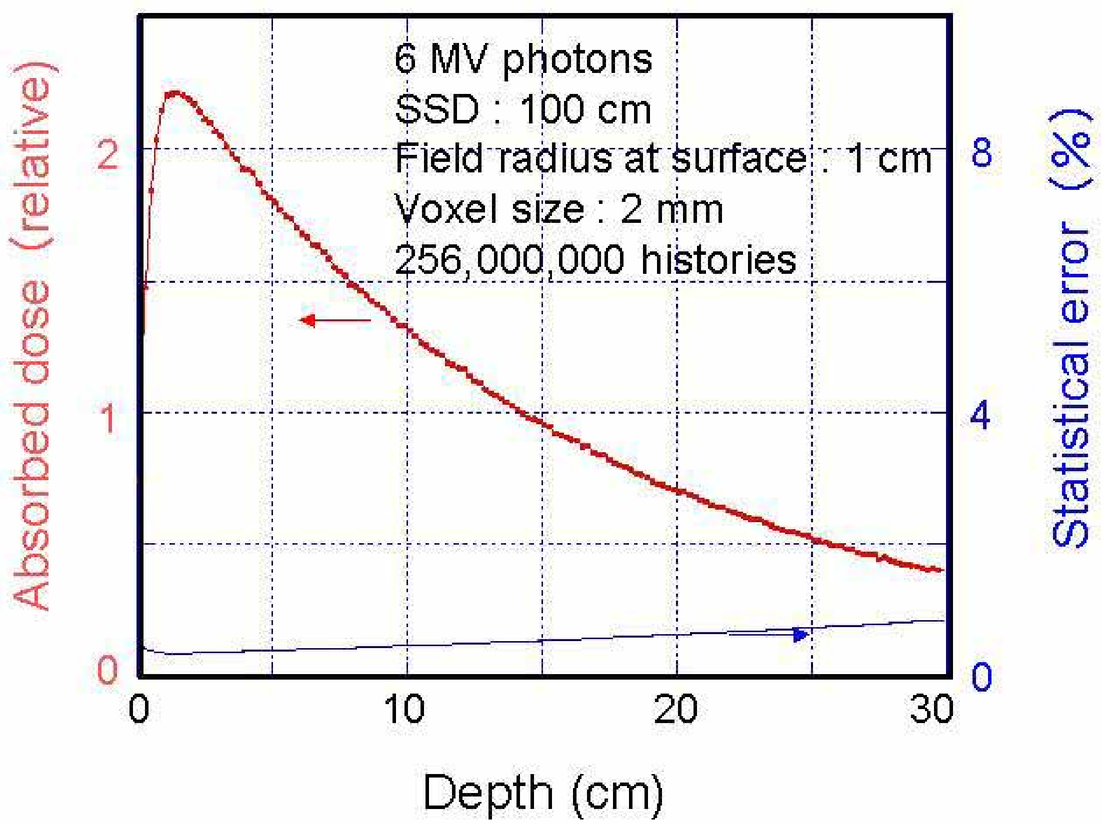

Figure 6　Dose distribution in a water phantom calculated by the prototype of the dose calculation module.