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Photon Dose Calculation Based on Monte Carlo FSPB Model in Accurate Radiotherapy

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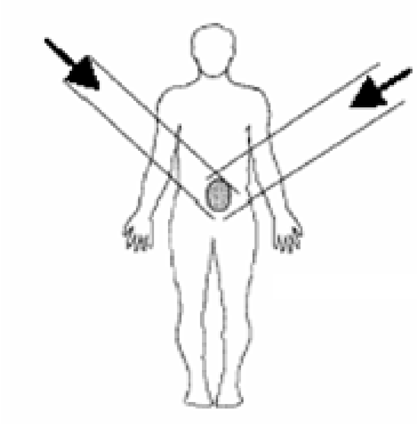
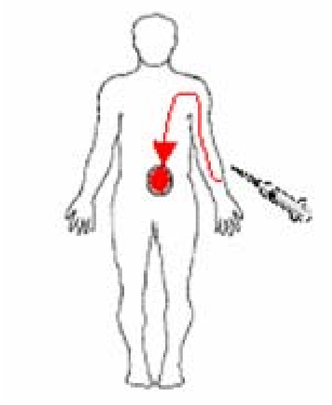
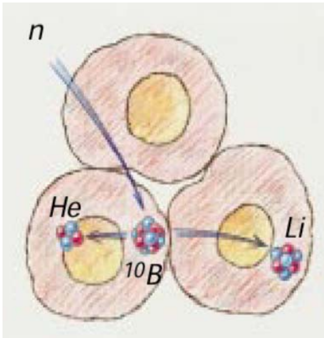
Objectives and Issues of Radiotherapy



External radiotherapy



Brachytherapy



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BNCT

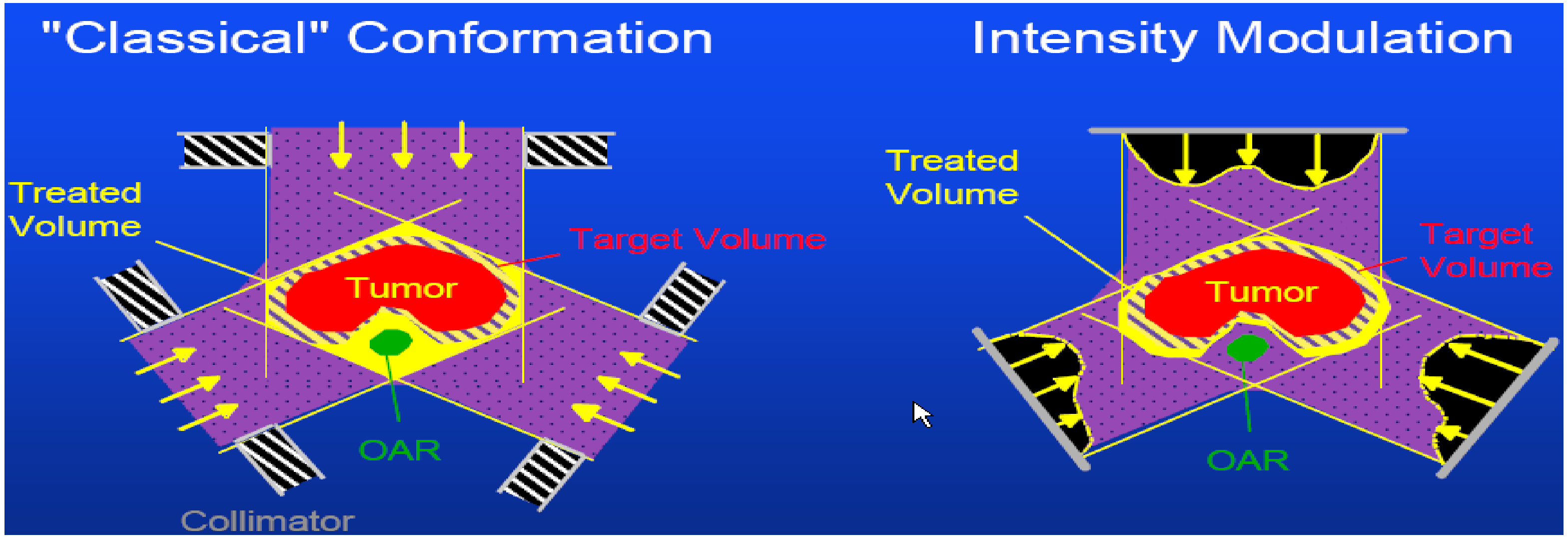
Objectives of Accurate Radiotherapy:

- Kill tumor cells to the utmost
- Protect the normal tissues and the organs at risk to the great extent

Main Issues:

- Normal tissue damaged in radiotherapy
- Great difference (material, structure, sensibility to radiation, etc.) of individuals
- Uncertainty of radiation biological effect

Development of Radiotherapy Technology

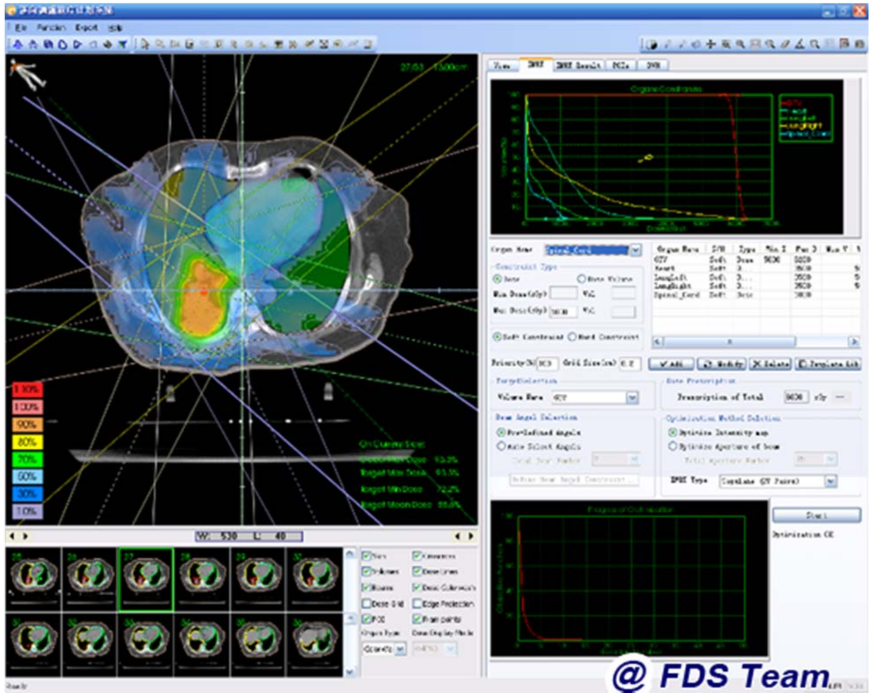


Development of Radiotherapy Technology:

3-d conformal radiotherapy=>intensity modulated radiotherapy **(IMRT)** => image guided radiotherapy **(IGRT)** => dose guided radiotherapy **(DGRT)**

TPS & ARTS

- With the help of the Treatment Planning System (**TPS**) , physicians and clinical doctors can efficiently create, choose and verify the treatment plan most suitable.
- Based on extensive researches on the scientific and technical issues of radiotherapy system, FDS Team has been working to develop series of accurate radiotherapy systems (**ARTS**).



Interface of ARTS-TPS

Accurate/Advanced Radiotherapy System（ARTS）

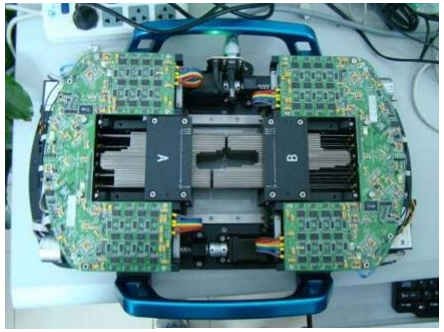
- **Treatment Planning System（TPS)**

  5D Human modeling, Hybrid dose calculation
  Multi-objective optimization inverse planning
  Multi-dimensional dynamic visualization

- **Plan Verification and Quality Assurance**

  Accurate positioning; Real-time dose reconstruction

- **Dynamic Multi-Leaf Collimator（DMLC）**



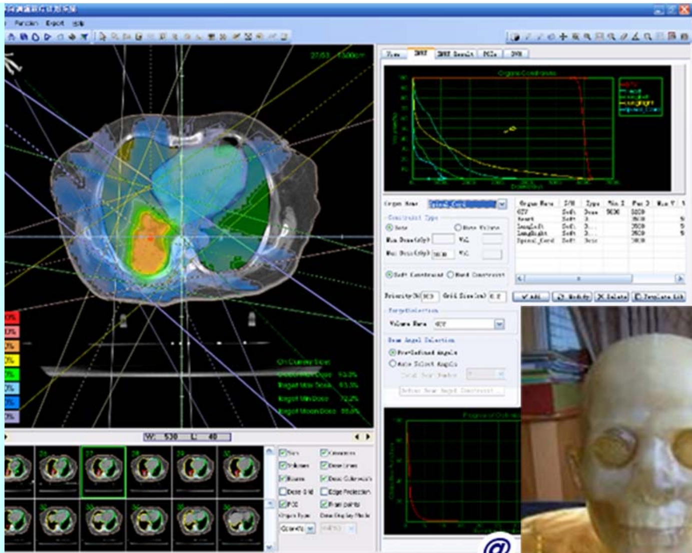
IMRT, IGRT and DGRT are supported. The phantom and clinical tests were passed.

Intensity Modulate Radiation Therapy of ARTS

(ARTS-IMRT)

Main function:

- Image import-- convenient and flexible
- Image fusion -- exact and fast
- Image sketch -- plentiful and practical
- 3D reconstruction -- fine and vivid
- Planning design -- rapid and effective
- Planning comparison --elegant and useful
- Planning assessment -- visual and reliable
- Reports output -- sample and overall



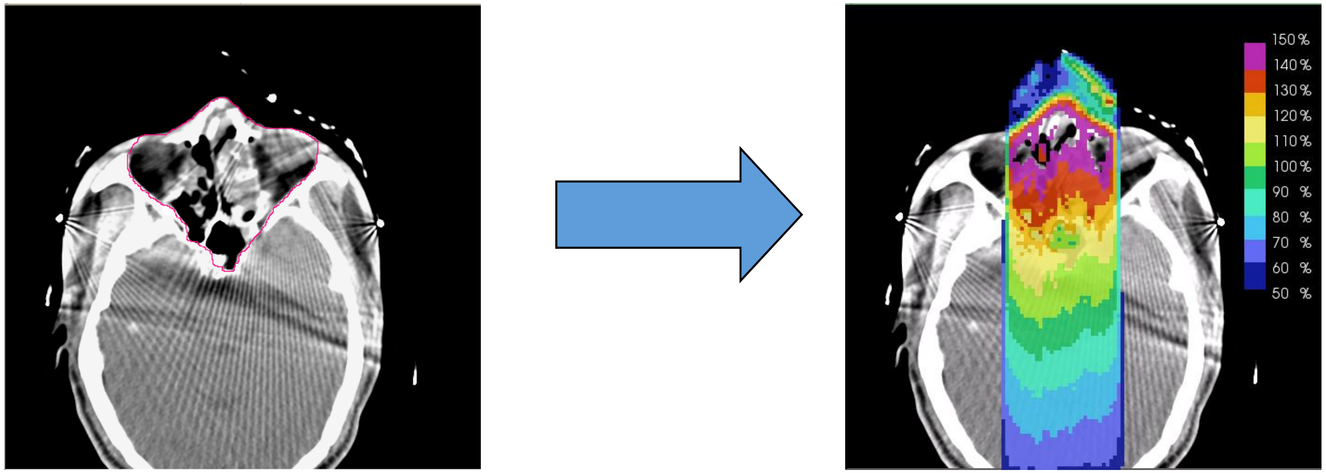
Assist function:

- Patients management
- Machine database
- Visualization in planning simulation

The ARTS-TPS has already been verified by lots of clinical experiment.

Dose Calculation

Dose calculation：



Dose calculation is one of the **core functions** in TPS.

International Commission on Radiation Units and Measurements (ICRU) NO.24 report points out that the error of the primary focus' radical dose should be lower than 5%, otherwise the primary focus tumors will be out of control.

Dose Calculation Method

- Conventional analytical dose calculation: Pencil Beam, Convolution Superimposition, etc.

  Feature:

  - Fast and accurate in homogenous phantom, yet inaccuracy in inhomogeneous phantom.

- Classical Monte Carlo: **MCNP, EGS, Geant4, PENELOPE,** etc.

  Feature:

  - Random algorithm, supposed to be the best accurate dose calculation engine among present methods, but time-consuming.

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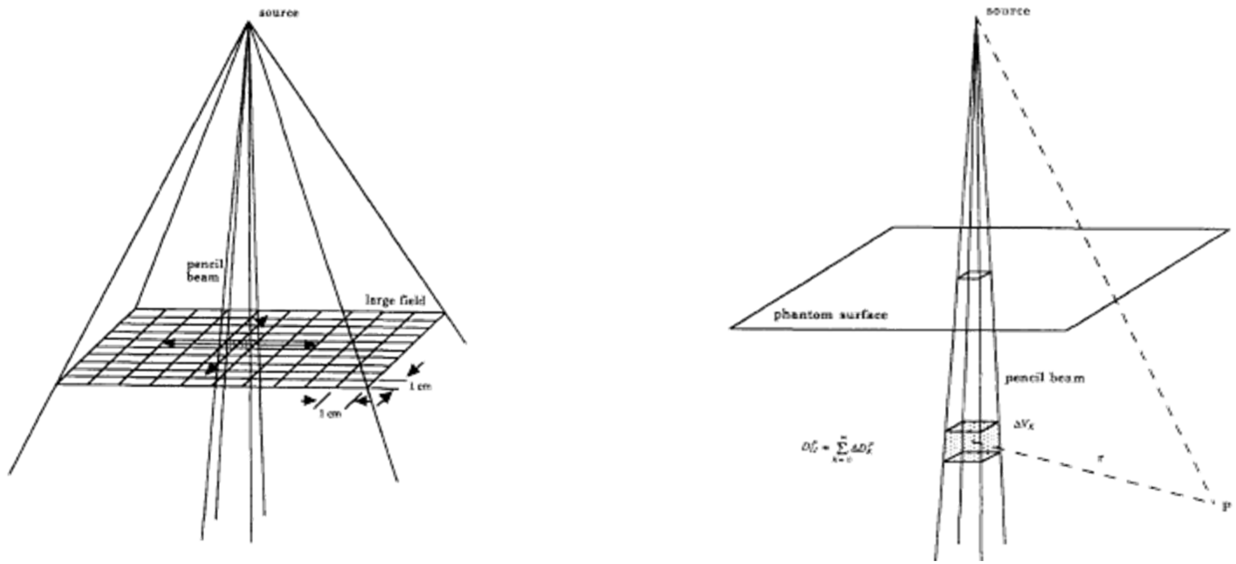
Finite-Size Pencil Beam Method

- **Finite-Size Pencil Beam method (FSPB for short): divide the clinical beam into small pencil beam, the dose of one point in patient is the sum of dose contributions of every pencil beam to the point.**



FSPB's Schematic Diagram

Pencil Beam Kernel Acquisition

- **Key Issues: the acquisition of pencil beam kernel**
- **Methods: Measurement or Monte Carlo (MC) Simulation**
- **Monte Carlo Finite Size Pencil Beam (MCFSPB):**

  a new pencil beam kernel model was developed based on the MC simulation and the technology of medical accelerator energy spectrum reconstruction

- **Advantages：**
  - ✓ **Accurate:** considering the energy spectra of practical medical accelerator (reconstruction technology)
  - ✓ **Small database:** by using symmetrical theory
  - ✓ **Fast:** during to small database and convolution algorithms

Analytical Method Based on Nonlinear programming model

$$Min \quad \sigma = \sqrt{\frac{1}{m-N}\sum_{j}^{m}\left[D'(z_j) - D(z_j)\right]^2}$$

$$\Phi(E) = cExp[-\ln^2(E/E_p)/4a^2]$$

$$D(z) = \int D(E,z)\Phi(E)dE$$

σ: Root Mean Square (RMS)

D(z): Percentage depth dose (PDD);

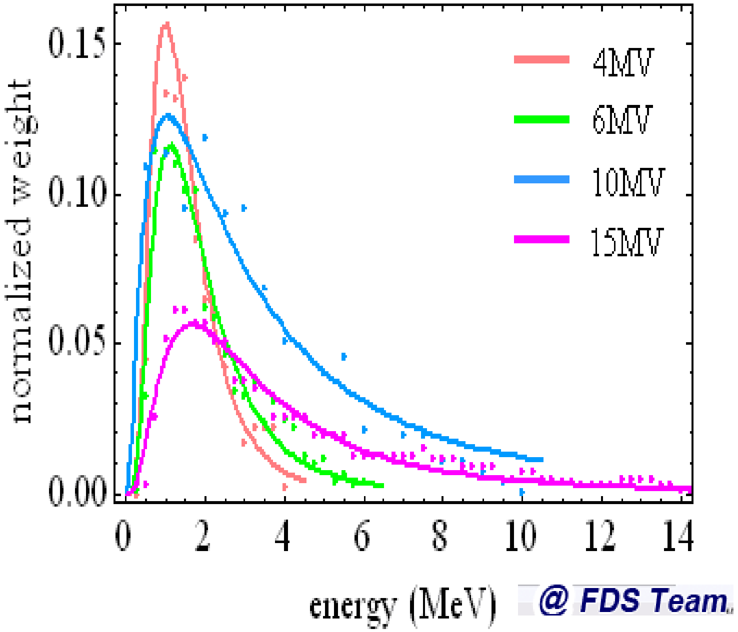
D(E,z): monoenergetic depth dose;

Φ(E): Energy spectrum;

***Ep*: peak value;**

***a* : peak width;**

***c*: normalization coefficient;**



Monte Carlo Finite Size Pencil Beam

- **FSPB:**

$$D(r) = \int_E \sum_S \Phi_E(s) \Pi(E, r, s) dE$$

- **MCFSPB:**

$$D(r) = \sum_S \Phi(s) \Pi(r, s)$$

- **With CF(*r*) which is the correct factor of the Batho inhomogeneous method**

$$D(r) = \sum_S \Phi(s) \Pi(r, s) \cdot CF(r)$$

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Comparison with Measured Data

Test Example

- Inhomogeneous phantom

Test Result

- Target dose variation less than 2% in the three-dimensional conformal plan
- Target dose variation less than 3% in the IMRT plan

AAPM Benchmark Test

No.55 Report of AAPM providing a set of complete dose data for the verification of the external photon beam algorithm, has been used to dose calculation accuracy test in TPS.

Type of test example

There are 27 examples in the No.55 Report, which can determine the machine energy, beam shape and size, source-skin distance change, wedge, block and tissue inhomogeneity as well as other factors that would affect the accuracy of dose calculation.

Field Size (cm)	Energy (MV)/SSD(cm)	Test Case	Depth (cm)	Off Axis Distance (cm)
5×5	4/80;18/100	vertical incidence, water phantom	1,3,5,10,15,20, 25,35	0,1,5
10×10	4/80;18/100	vertical incidence, water phantom	1,3,5,10,15,20, 25,35	0,3,9
25×25	4/80;18/100	vertical incidence, water phantom	1,3,5,10,15,20, 25,35	0,9,19
5×25	4/80;18/100	vertical incidence, water phantom	1,3,5,10,15,20, 25,35	0,1,5
25×5	4/80;18/100	vertical incidence, water phantom	1,3,5,10,15,20, 25,35	0,9,19
10×10	4/70;18/85	vertical incidence, water phantom	1,3,5,10,15,20, 25,35	0,2.5,7

AAPM Benchmark Test

Testing procedure

Make plans according to the situations shown in the previous table, comparing the calculation results of interested points with measured results from the report to verify the accuracy of the algorithm.

Testing result

Make a test on the 27 examples , points with the calculation error less than 3% are 98.x% in all calculated points.

Result analysis

MCFSPB dose calculation algorithm in ARTS can meet the demand of clinical TPS and can be put into practical use.

Summary

- A new pencil beam kernel model was developed based on the MC simulation and the technology of medical accelerator energy spectrum reconstruction.

- MCFSPB dose calculation algorithm in ARTS can meet the demand of clinical TPS and can be put into practical use.

- Some advanced functions, such as point energy deposition kernel dose calculation method and hybrid dose calculation engine of Monte Carlo and analytic , are under development.

The End

Thanks for your attention !

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Monte Carlo-based Finite Size Pencil Beam (MCFSPB)

Key Issues

- ✓ **How to obtain the pencil beam (direct measurement and Monte Carlo simulation, etc.)**

MCFSPB

- ✓ **Accurate:** considering the energy spectra of practical medical accelerator (reconstruction technology)
- ✓ **Small database:** by using symmetrical theory
- ✓ **Fast:** during to small database and convolution algorithms

(about 1minute, and less than 2%)