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COLLEGE ON MEDICAL PHYSICS
AND
WORKSHOP ON
NUCLEAR DATA FOR SCIENCE AND TECHNOLOGY:
MEDICAL APPLICATIONS
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"The EGS4 System for Radiation Transport"

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OUTLINE

- History of the EGS4 system
- An overview of the EGS4 system
- Basic aspects of the M-C radiation transport
- Techniques for scoring quantities of interest
- Variance reduction techniques
- Implementation of the EGS4 system
- Some important EGS4 parameters
- The EGS4 user codes (the BEAM system)

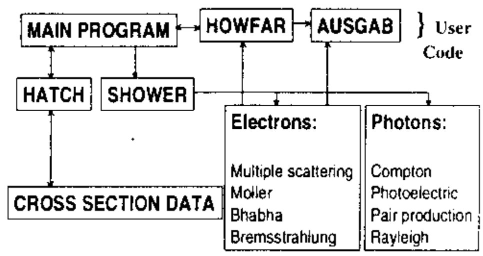
An Overview of the EGS4 system

The EGS4 system is a Monte Carlo computer simulation program package.

- PEGS4 is a standalone program to generate material cross-section and other data used for particle transport
- Other subroutines (SHOWER, etc.) can be called from a user-written program (a user code) to simulate the transport of the radiation particles
- A user code takes care of the simulation geometry, scoring quantities and data analysis

ELECTRON GAMMA SHOWER

(Stanford Linear Accelerator Center)



Basic aspects of the EGS4 Monte Carlo radiation transport

- Particle transport

$$N_\lambda = S/\lambda_{ave},\ N_\lambda = -\ln R,\ S = -\lambda_{ave} \ln R$$

- Particle interaction

$$F(k) = (\sigma_1+\sigma_2+\ldots\sigma_k)/\sigma_t,\ F(k)<R<F(k)$$

Random Number Generators

The linear congruential random number generators (LCRNG): $I_{n+1} = a(I_n + c)$ modulus 2^k

- a is the "multiplier", c is the "increment" and k is the number of bits in the integers of the computer

The multiplicative congruential random number generators (MCRNG): $I_{n+1} = a\, I_n$ modulus 2^k

- The RNG used in EGS4 is a = 663608941 and k = 32 with a sequence length of about 10^9

Scoring quantities of interest

The absorbed dose = $\Sigma E/m$

- E_i is the energy deposited by the particle i in a voxel and m is the mass of the voxel

The particle fluence = $\Sigma s/V$

- s_i is the track lenths of the particle i in a voxel and V is the volume of the voxel

Tagging a history using *LATCH*

Variance reduction techniques

The efficiency of a Monte Carlo calculation can be estimated by

$$\varepsilon = 1/(\sigma^2 T)$$

where T is the computation time to obtain a variance estimate σ^2

Photon interaction forcing

Force to interact in a phantom

$$N_\lambda = -\ln\{1-R[1-e^{-M_\lambda}]\}$$

M_λ is the thickness of the phantom in number of mean free paths

The new weighting factor: $W' = W\{1-e^{-M_\lambda}\}$

Force to interact in a region of a phantom

$$N_\lambda = M_{\lambda 1} - \ln\{1-R[1-e^{(M_{\lambda 1}-M_{\lambda 2})}]\}$$

$M_{\lambda 1}$ is the number of mean free paths to the near boundary of the region and $M_{\lambda 2}$ to the far boundary of the region.

The new weighting factor: $W' = W\{e^{-M_{\lambda 1}} - e^{-M_{\lambda 2}}\}$

Exponential Transform

Bias the sampling procedure to interact in the regions of interest

$$N_\lambda = -\beta \ln R$$

$$\beta = 1/(1-C\cos\theta)$$

C is defined by the user, θ the photon angle wrt the direction of interest

The new weighting factor: $W' = W\beta\, e^{-N_\lambda C\cos\theta}$

$C < 0$: smaller N_λ for surface problem

$0 < C < 1$: larger N_λ for shielding problem

Electron Range rejection

Range rejection:

- Discard an electron if its residual range is smaller the distance to the nearest boundary

Region Rejection:

- Discard an electron if its energy is smaller than the energy cutoff (ECUT) for a region, which is "far" away from the region of interest.

Correlated Sampling

Sharing same particle tracks:

- same geometry for several simulations

Sharing same random number sequence:

- different geometry for several simulations

Repeating particle tracks:

- several tracks for the same simulation (displacement, rotation, stretching)

Implementation of EGS4

Generate the PEGS4 data

- Use consistent data for the simulation

Write the main program

- Input beam and geometry data
- Call HATCH to obtain cross-section data
- Call SHOWER to generate histories
- Write HOWFAR to handle geometry and boundary crossing
- Write AUSGAB to score quantities of interest
- Analyze results and output

Some Important EGS4 Parameters

AE, AP

- Threshold energy for δ-ray and bremsstrahlung generation

ECUT, PCUT

- Energy cutoffs for electron and photon transport

ESTEPE

- Maximum fractional energy loss per electron step

TMAX

- Upper limit on electron step size (in cm)

Some EGS4 User Codes

DOSRZ

- dose calculation in cylindrical-planar geometry

FLURZ

- fluence calculation in cylindrical-planar geometry

CAVRZ

- dose calculation in cylindrical-planar geometry

DOSIMETER

- dose calculation in cylindrical-planar/rectangular geometry

The OMEGA/BEAM system

The BEAM script

- to build and compile EGS4 user codes for linac simulation

The BEAM proper and Component Modules

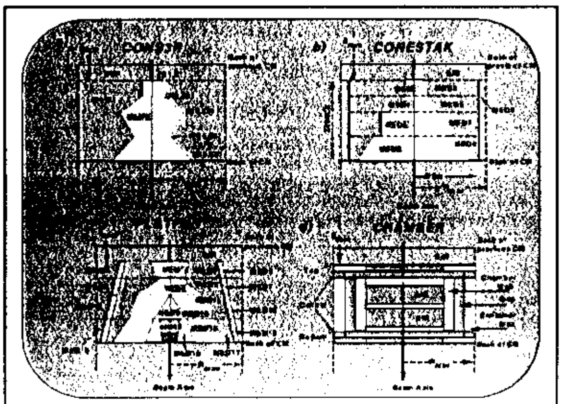
- building blocks to form EGS4 user codes

DOSXYZ

- dose calculation in a 3D rectilinear geometry (CT phantom)

BEAMDP, STATDOSE, beam_gui, xyz_gui

- utility software for data in/output and analysis



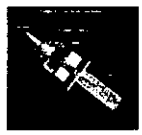
OMEGA BEAM SYSTEM

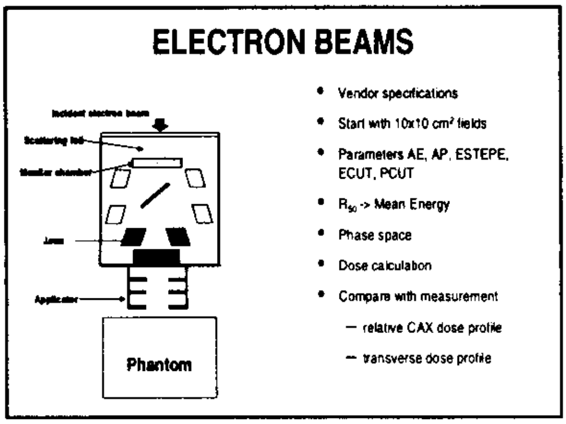
NRC Canada, University of Wisconsin, Madison

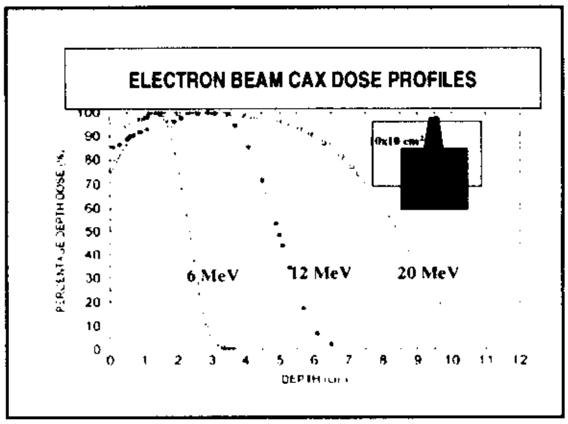

VARIAN

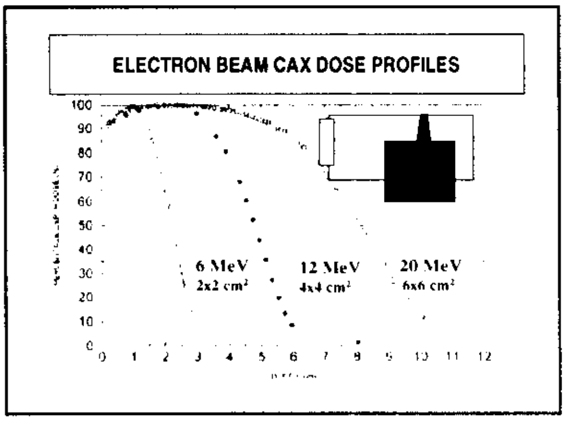

THERAC

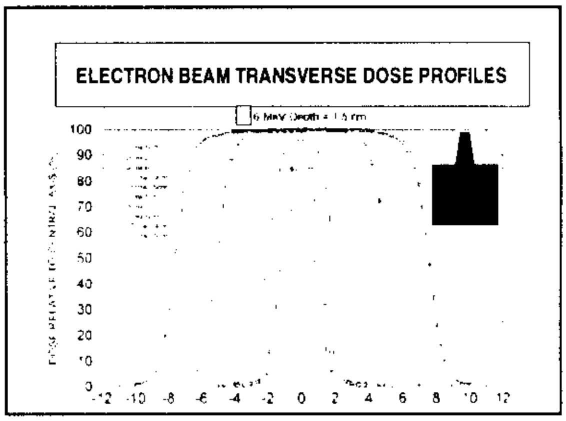

SCANDITRONIX

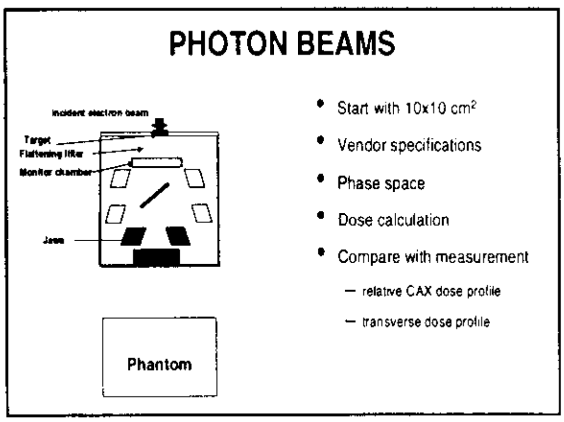

PHILIPS

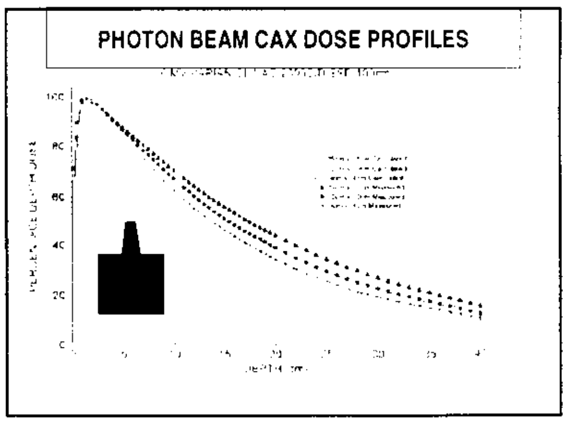

ELECTRON BEAMS
Vendor specifications
Start with 10x10 cm² fields
Parameters AE, AP, ESTEPE, ECUT, PCUT
R50 -> Mean Energy
Phase space
Dose calculation
Compare with measurement
– relative CAX dose profile
– transverse dose profile
Phantom

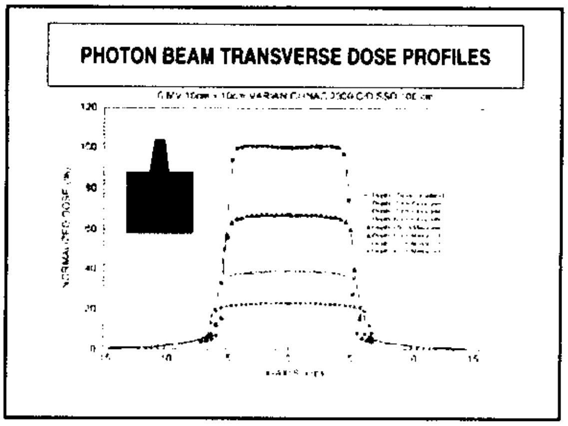

ELECTRON BEAM CAX DOSE PROFILES
6 MeV
12 MeV
20 MeV

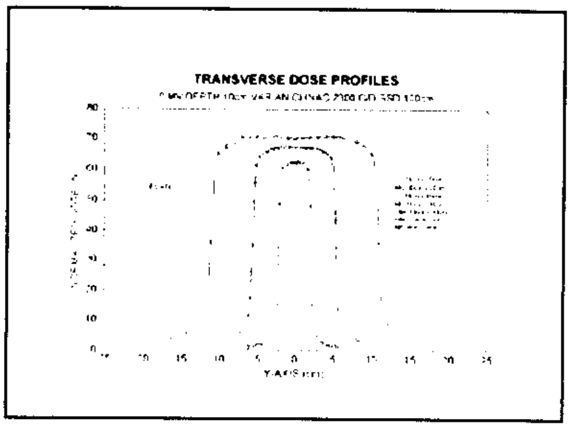

ELECTRON BEAM CAX DOSE PROFILES
6 MeV
2x2 cm²
12 MeV
4x4 cm²
20 MeV
6x6 cm²

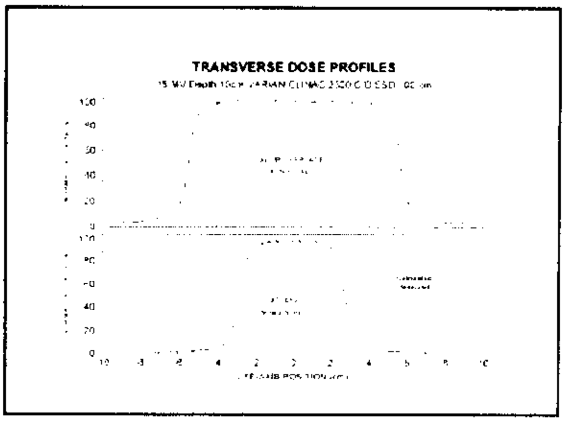

ELECTRON BEAM TRANSVERSE DOSE PROFILES

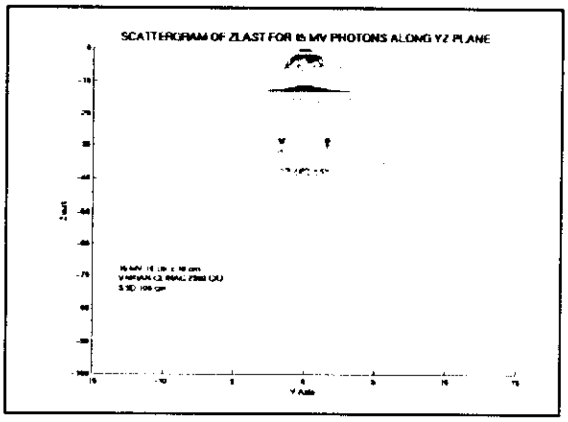

PHOTON BEAMS
Start with 10x10 cm²
Vendor specifications
Phase space
Dose calculation
Compare with measurement
– relative CAX dose profile
– transverse dose profile
Phantom


PHOTON BEAM CAX DOSE PROFILES









Web Site on EGS4 system

EGS Web page

- http://ehssun.lbl.gov/egs/egs.html

EGS4 download site

- Unix: http://www.irs.inms.nrc.ca/inms/irs/EGS4/get_egs4.html
  C: http://www.ncnc.org/nova/
- Mac: http://ehssun.lbl.gov/egs/epub/aap/yn28jut97.html
- PC: ftp://ehssun1.lbl.gov/public/egs/std/egs4pc.zip

BEAM home page

- http://www.irs.inms.nrc.ca/inms/irs/BEAM/beamhome.html