A status report on the EGSnrc and BEAMnrc Monte Carlo packages

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IRRMA6 MacMaster June 22, 2005

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Overview

- an introduction to EGSnrc and overview of recent upgrades
  - port to Windows: MultiPlatform release (Kawrakow et al)
  - CSnrc (Buckley)
  - Multi-Geometry package (Yegin)
    - brachydose code
- an introduction to BEAMnrc and overview of recent upgrades
  - directional brem splitting
  - history by history statistics

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The people involved

Iwan Kawrakow

Palani Selvam

Ernesto Mainegra-Hing Lesley Buckley

Gultekin Yegin

Leo Heistek Blake Walters

A brief history of EGS

EGS3 - 1970s

Ford (a grad student) and Ralph Nelson developed the code for high energy particle physics at SLAC

EGS4 - 1980s

Nelson and Hirayama developed EGS4 for particle physics applications at SLAC in collaboration with Rogers of NRC working on low-energy benchmarking for medical physics applications.

PRESTA -1986

Bielajew working with Rogers at NRC improved the transport of low-energy electrons with the PRESTA algorithm as add-on package.

User-codes late 80s, early 90s

DOSRZ, CAVRZ, SPRRZ, FLURZ developed by Rogers and Bielajew. In 2002 Mainegra-Hing developed a GUI for EGSnrc versions

A brief history of EGS (cont)

Low-energy transport-1990s

Hirayama, Namito and Ban at KEK developed EGS4 add-on macros which extended EGS4 low-energy photon physics.

Kawrakow at NRC developed an integrated approach to these same things and implemented them as part of EGSnrc in 2000.

Multiple scattering and electron transport-1990s

Kawrakow and Bielajew developed a new theory of multiple scattering which removed the restrictions of the Moliere theory used prior. Kawrakow implemented a new electron transport algorithm which started from some work done with Bielajew. This is basis of EGSnrc.

A brief history of EGS (cont)

EGSnrc 2000

EGSnrc released, incorporating a multitude of enhancements.

EGSnrcMP (multi-platform) 2003

Kawrakow et al develop a new environment which means EGSnrc works on Windows & Unix/Linux systems. There are GUIs for most operations.

Multi-geometry package - 2003

Yegin develops a general purpose geometry package which retains efficiency with EGSnrc

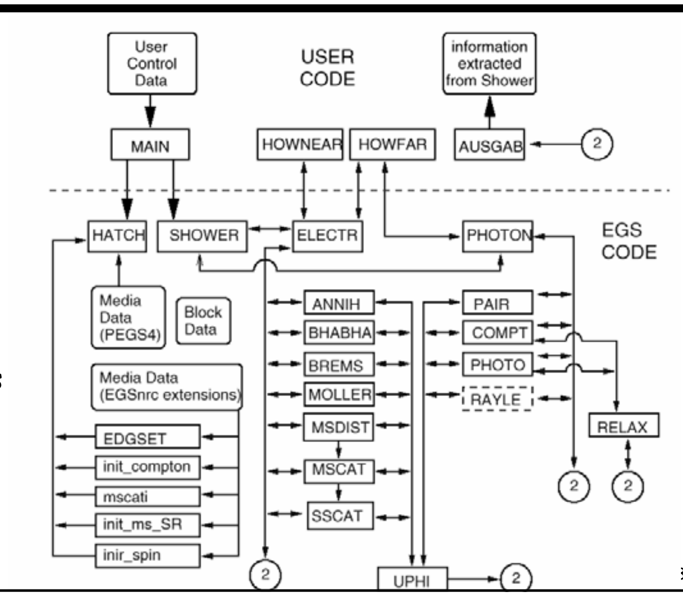
egspp: the EGSnrc C++ class library -2005

Kawrakow extended EGSnrc to work from C++ user codes and added a C++ package for geometry and source routines

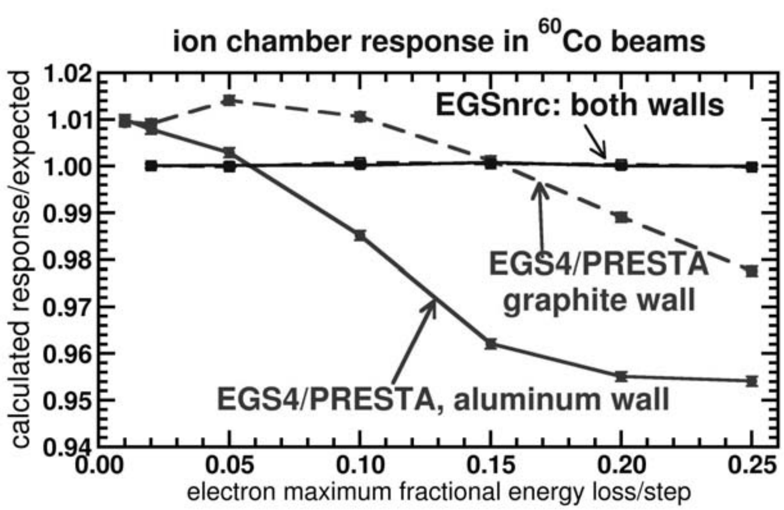
EGSnrc structure (2000)

Code accurate to 0.1% relative to its cross-sections & geometry

Kawrakow, Med Phys 27 (2000) 485-498
Kawrakow and Rogers, NRC Report PIRS-701,2000,



The toughest test: simulated ion chamber response vs result using Fano's theorem



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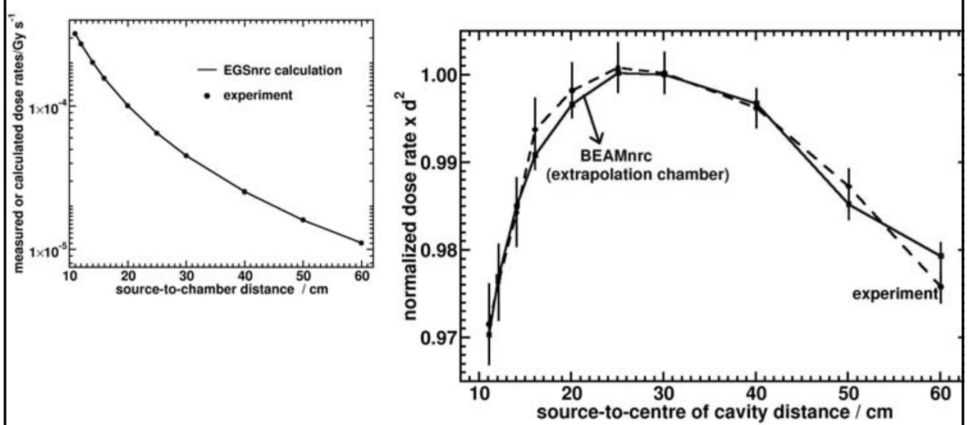
Extrapolation chamber response vs d from $^{90}Sr/^{90}Y$ beta source



Selvam et al, in press Med Phys

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What is efficiency?

$$\epsilon = \frac{1}{\sigma^2 T}$$

T: computing time

σ^2: variance on quantity of interest

- sum of uncertainty^2
  - -fluence in 1x1cm^2 regions in beam
  - -dose on central axis or profile

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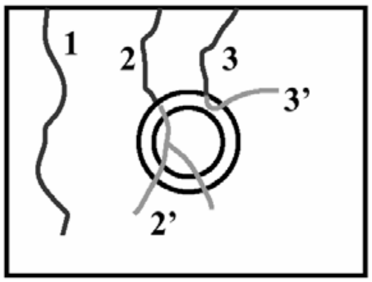
What is correlated sampling?

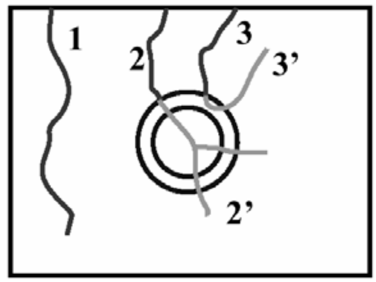
Of use when there are two or more similar geometries in which one wants the ratio of doses

eg: electrodes, TLDs, wall effects, dosimeters in phantom, etc,

Originally developed by Ma and Nahum for EGS4



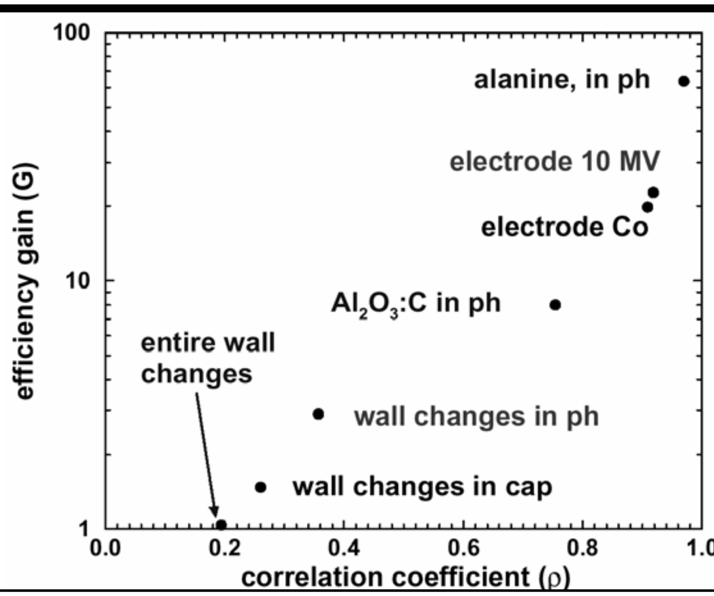
geometry 1



geometry 2

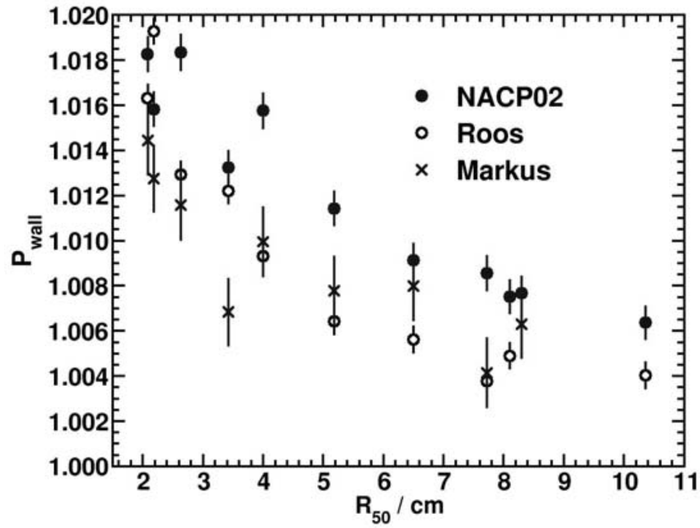
efficiency gain vs correlation

Buckley et al, Med Phys **31** (2004) 3425



P_{wall} correction for wall effects of clinical plane-parallel chambers in e^- beams

P_{wall} is considered 1.00 in all current protocols for clinical dosimetry



Buckley et al in preparation

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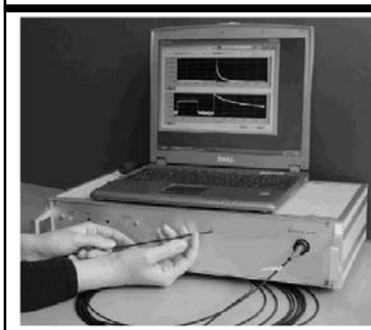
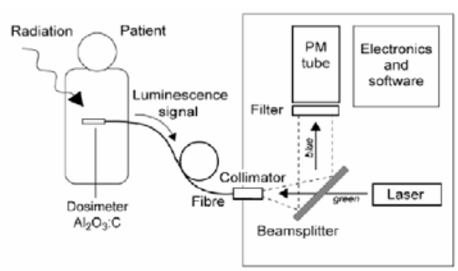
Optically stimulated luminescence (OSL) Al_2O_3:C in radiation dosimetry





- OSL uses a light source to stimulate luminescence
- small size detector (1 mm^3 or 2 mm^3)
- sensitive over a wide range of dose & dose rates
- can measure both dose and dose rate in real time

figures from Aznar et al: PMB 49(2004)1655

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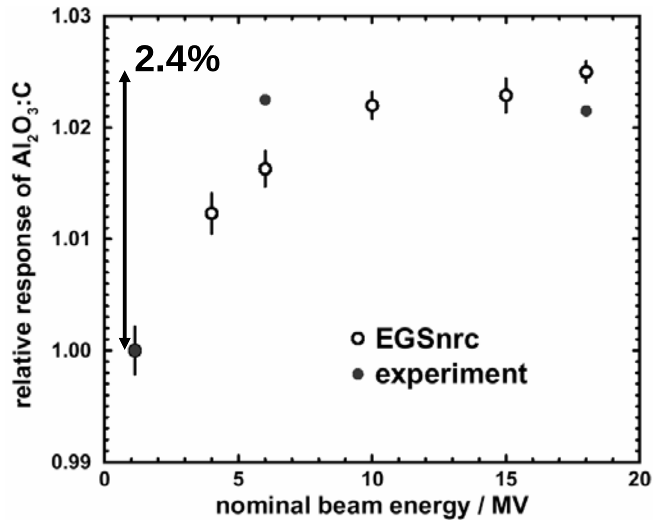
OSL calculations vs measurement

Results normalized at ^{60}Co

Preliminary experimental uncertainty estimate is on the order of 1.5%

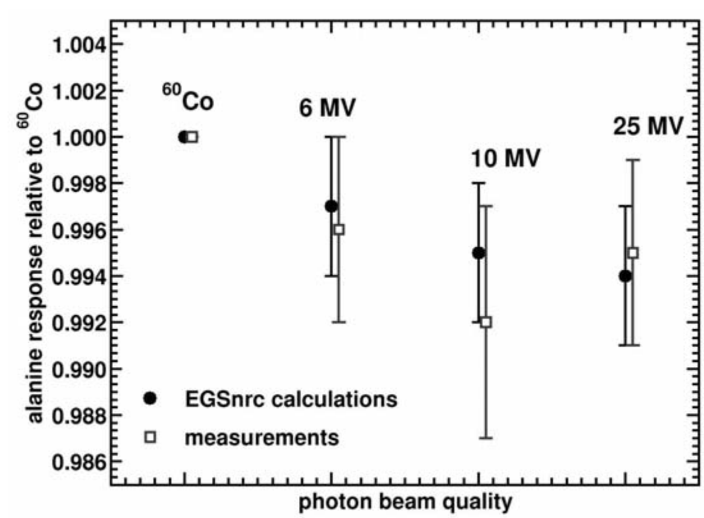


Expt: Aznar et al: extension of PMB 49(2004)1655

Alanine response in accelerator photon beams

alanine pellets measured against primary standards

calculations EGSnrc

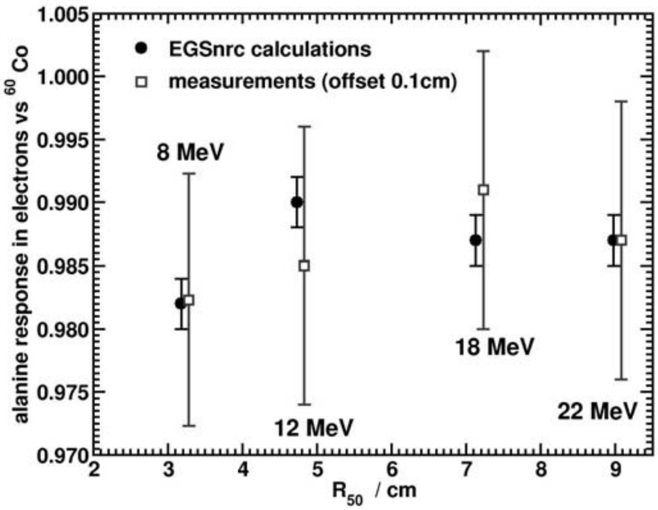


Zeng et al Phys Med Biol 49 (2004) 257 -- 270

Alanine response in accelerator electron beams

alanine pellets measured against TG-51 at d_{ref}

calculations EGSnrc

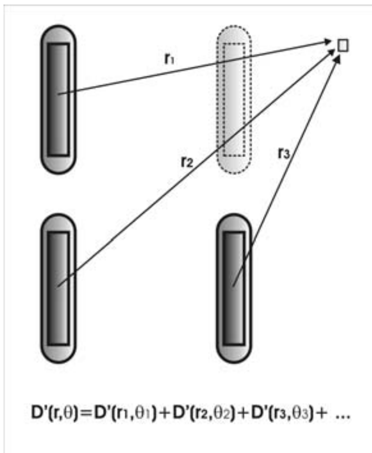


Zeng et al Phys Med Biol 50 (2005) 1119 - 1129

Monte Carlo for brachytherapy

- Gultekin Yegin of Turkey has developed the multi-geometry technique for EGSnrc (NIMB **211** (2003) 331-338)
- we applied it to multiple seeds in a phantom
- using tracklength scoring improves efficiency by a factor 20
- complete calculation, 125 seeds in 1 mm^3 voxels takes 12 min for 2% stats on a 2.4MHz P-IV
- code called brachydose
- ***What is the effect of inter-seed shielding?***

Inter-seed effects in brachytherapy



Standard planning systems ignore self-shielding

Only a few papers have investigated inter-seed effects.

In those papers, a small number of seeds are used in fixed configurations

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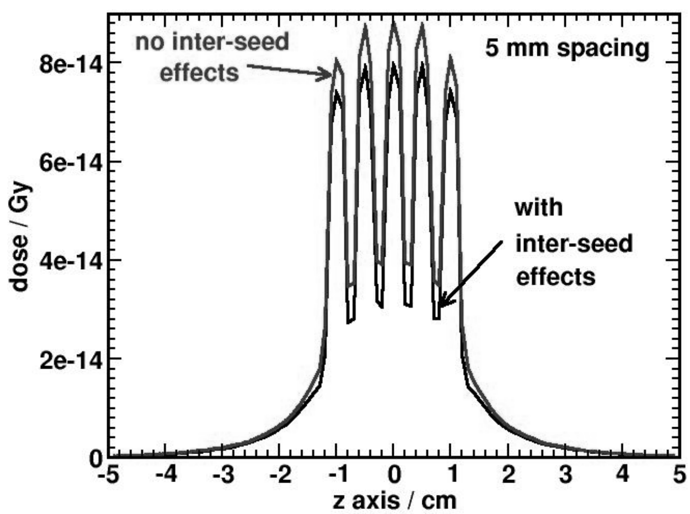
central axis dose for 5mm spacing



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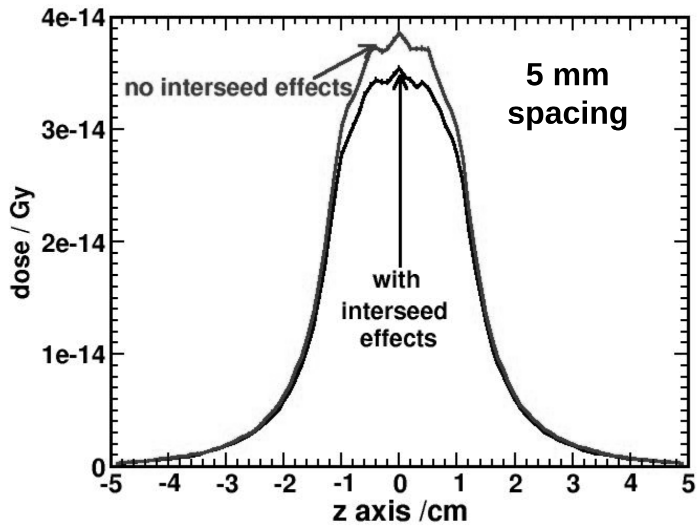
Dose on a line close to central axis



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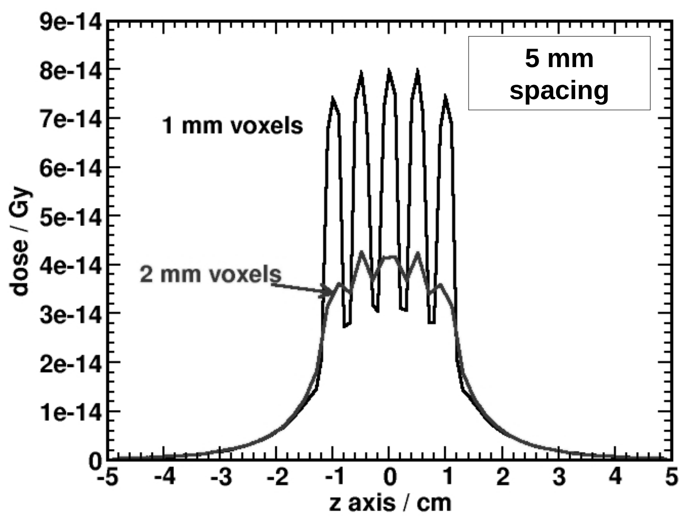
Influence of voxel size



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BEAM code

- general purpose code to simulate radiotherapy beams
  - accelerators -electrons & photons
  - ^{60}Co units
  - x-ray units

- Part of the OMEGA project with Rock Mackie's UW group
  many others involved

Dave Rogers Blake Walters Charlie Ma
Bruce Faddegon Jiansu Wei George Ding
Geoff Zhang Joanne Treurniet Michel Proulx
Daryoush Sheikh-Bagheri Iwan Kawrakow

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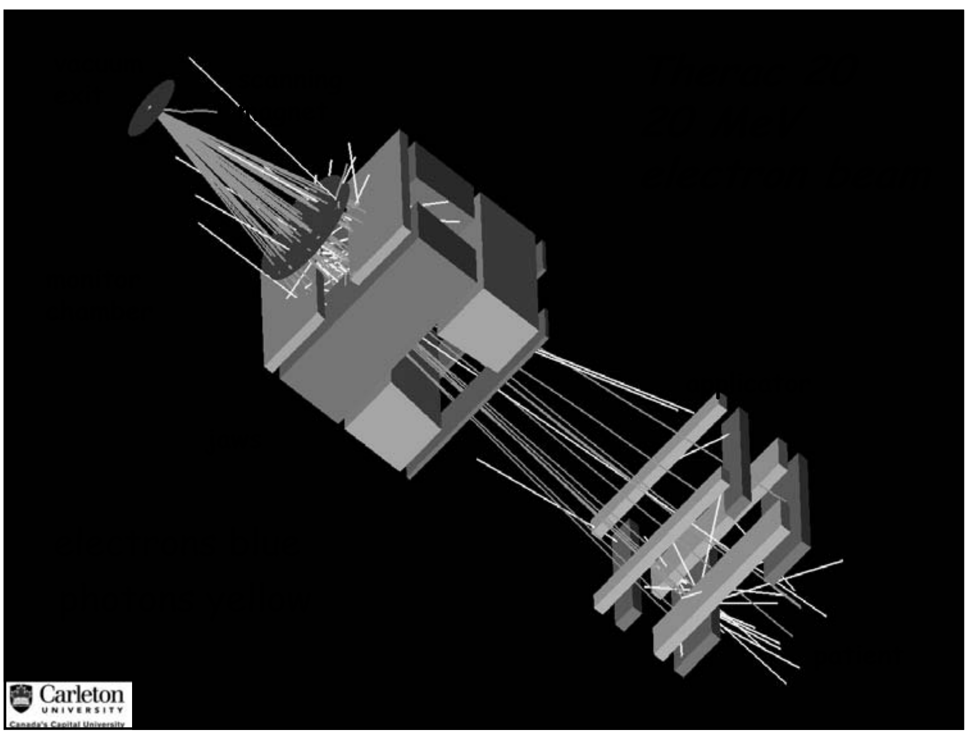

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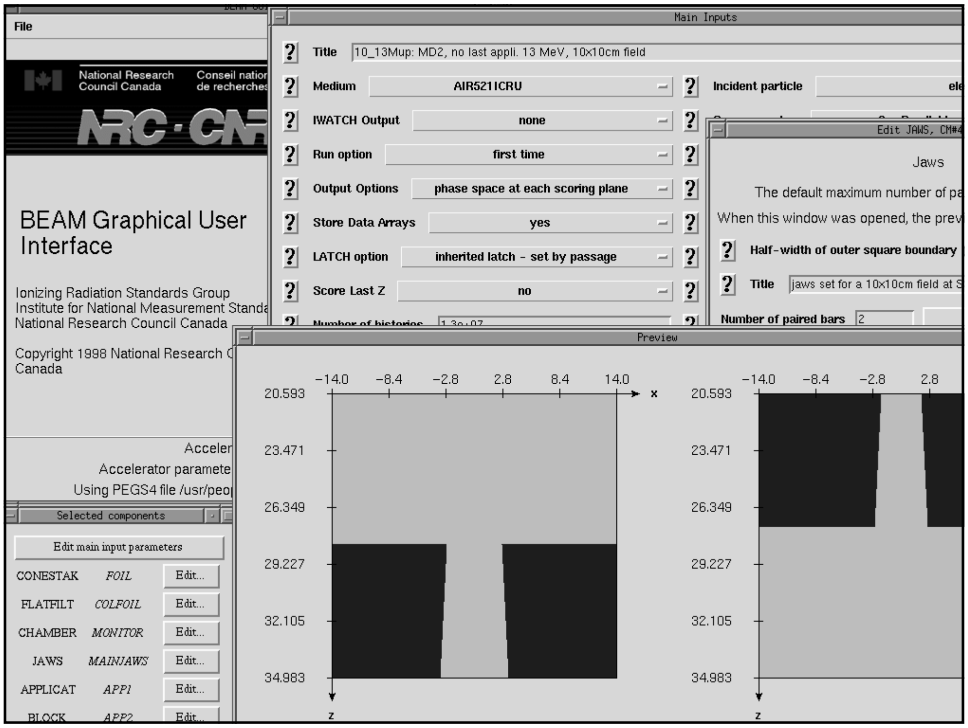
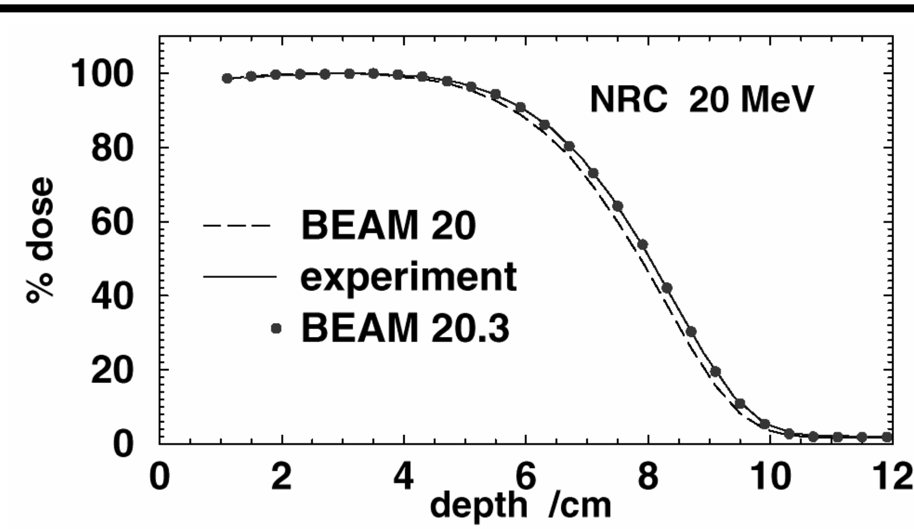
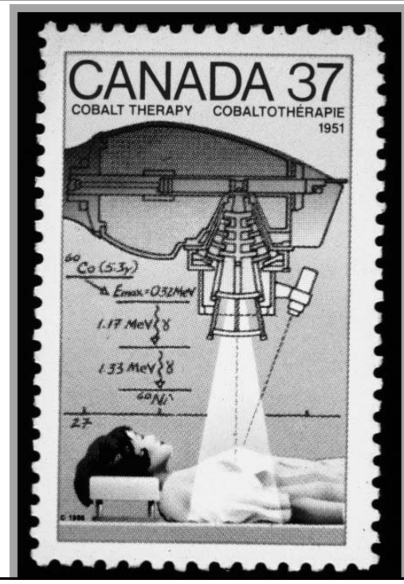


20 MeV NRC depth-dose



+similar studies for photon beams

^{60}Co therapy unit



Issued
June 17,
1988

Thanks to
Jerry Battista

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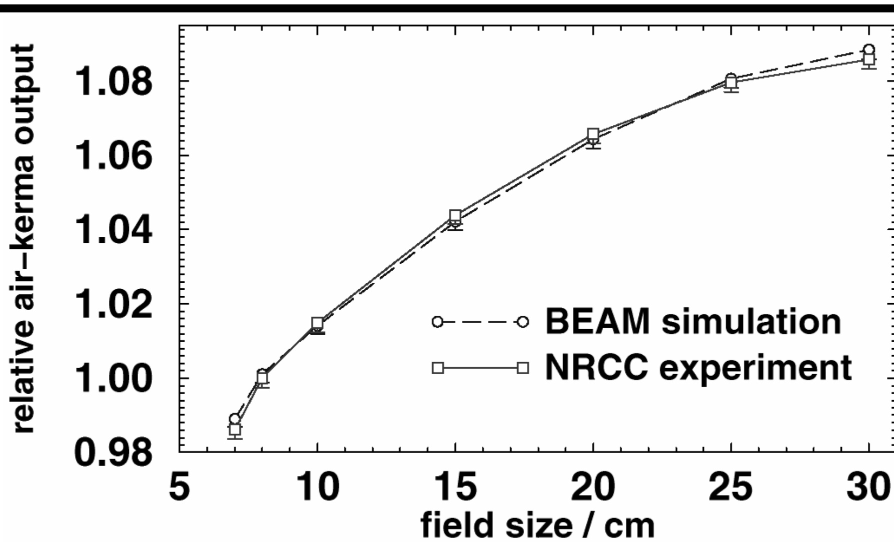
^{60}Co output variation vs expt



Mora et al Med Phys 26(1999) 2494

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Uses of BEAM

- accelerator design
- study physics of beams
- dosimetry studies
- beam characterization
  - 1st step to treatment planning
- commissioning accelerators
- dose distributions from irradiators

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Efficiency problems to overcome for photon accelerators

- majority of time is spent following electrons
-most photons are absorbed in the primary collimator

-calculations can be very time consuming (note: with no variance reduction BEAMnrc runs about 6 times faster than MCNP, PENELOPE or GEANT4)

Past approaches within BEAM
-uniform brem splitting
-selective brem splitting
-Russian Roulette

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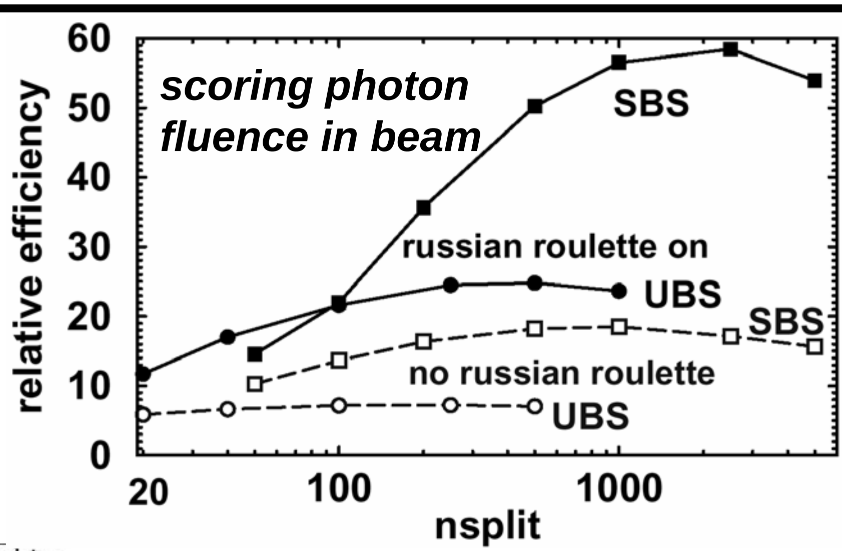
Selective Brem Splitting (SBS)



Directional Brem Splitting (DBS)

-goal: all particles in field when reach phase space have same weight

Procedure

i) brem from all fat electrons split nsplit times

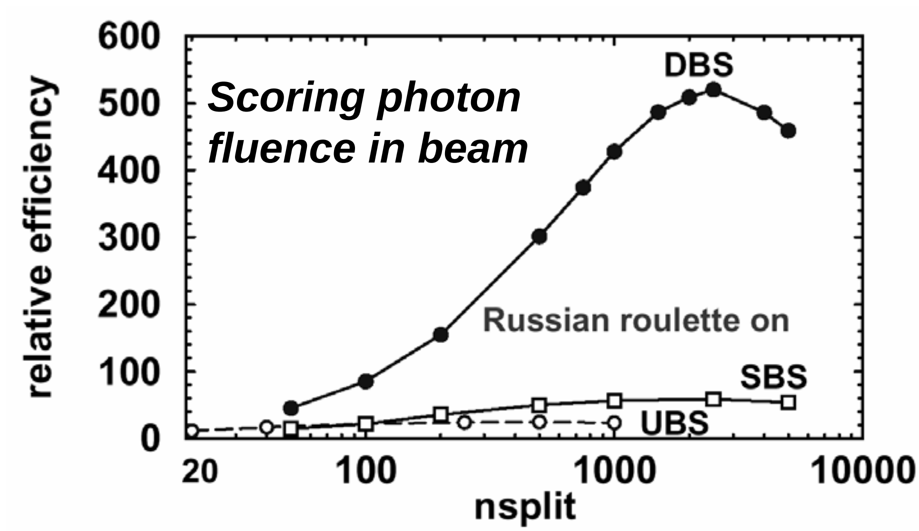
ii) if photon aimed at field of interest, keep it, otherwise Russian roulette it:

if it survives, weight is 1 (i.e. fat)

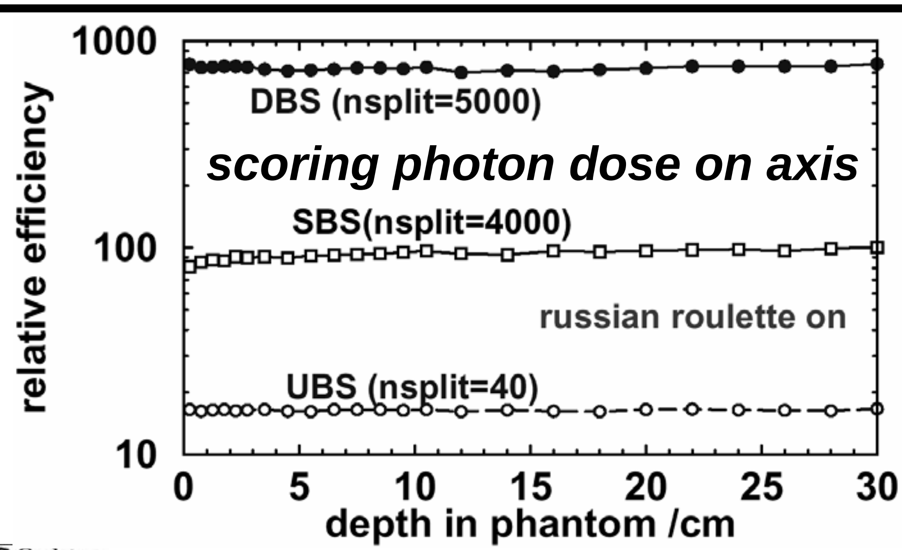
iii) if using only leading term of Koch-Motz angular dist'n for brem: `do_smart_brems` and similar tricks for other interactions (Kawrakow clever coding!)

Kawrakow et al Med Phys 31 (2004)2883-2898

Directional Brem Splitting



Directional Brem Splitting



Electron problem

-efficiency gain for electrons is only 2

Basis of the solution

-electrons are, almost entirely, from flattening filter and below

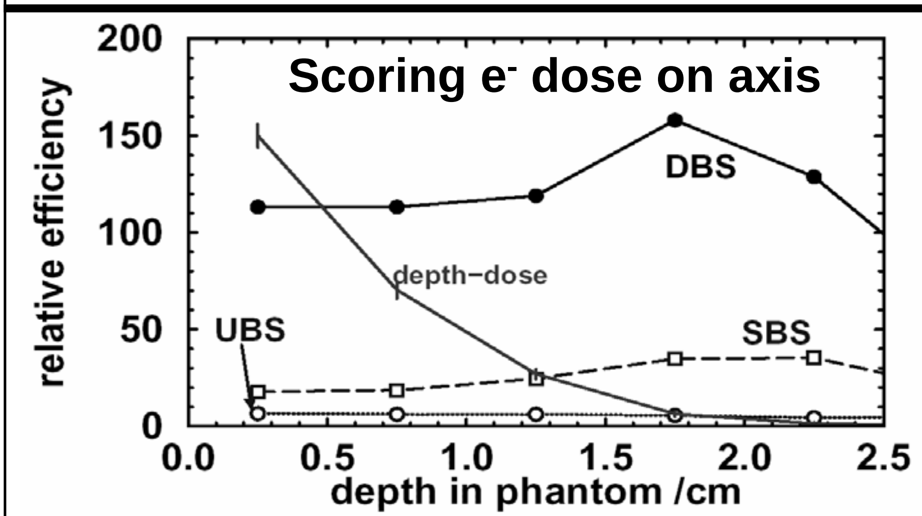
-major gains are from efficient treatment of electrons in primary collimator

-so introduce 2 planes near flattening filter base

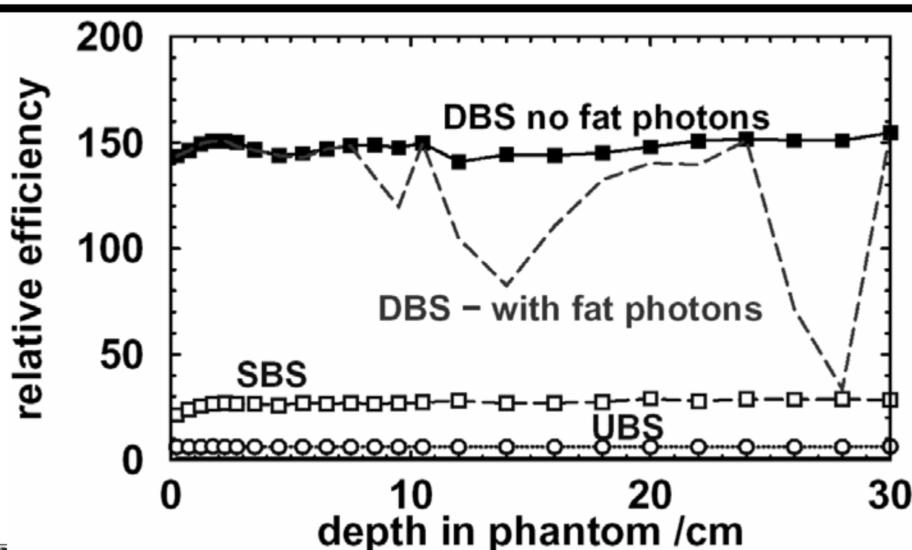
- a splitting plane: split all fat particles

-Russian roulette plane: below this turn off RR and split fat photon interactions

Efficiency increase for e^-



Efficiency: total dose



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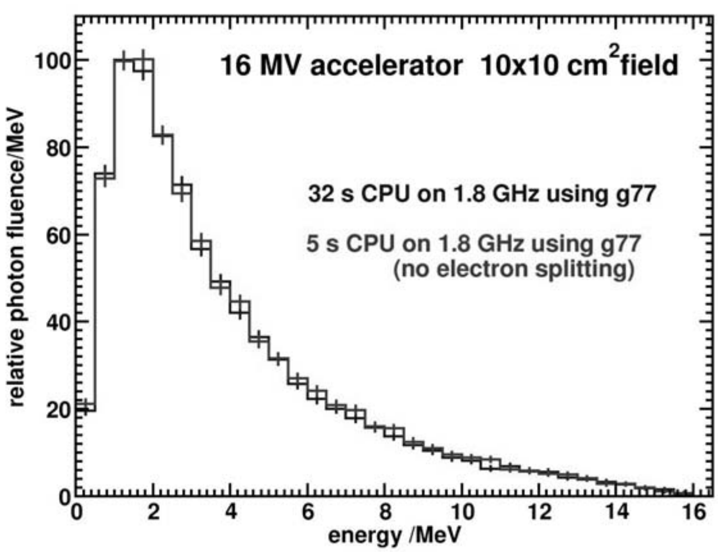
DBS in action



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New statistical package

Batch method

-Break the cal'n into N batches and determine uncertainty by distribution of results for batches

-large uncertainty in the uncertainty

History by history method

batches = #histories

-much better estimate

-``trick" of Salvat allows for efficient calculation

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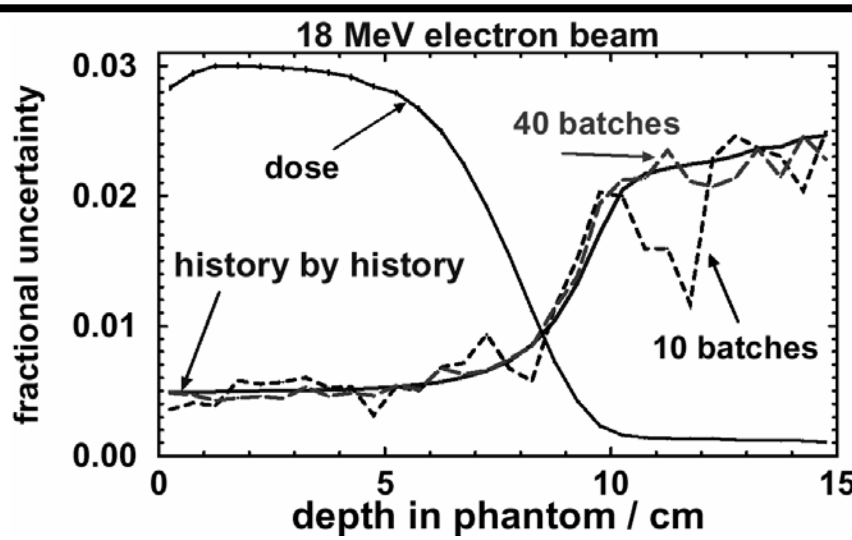
History by history technique



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Walters et al Med Phys 29(2002) 2745

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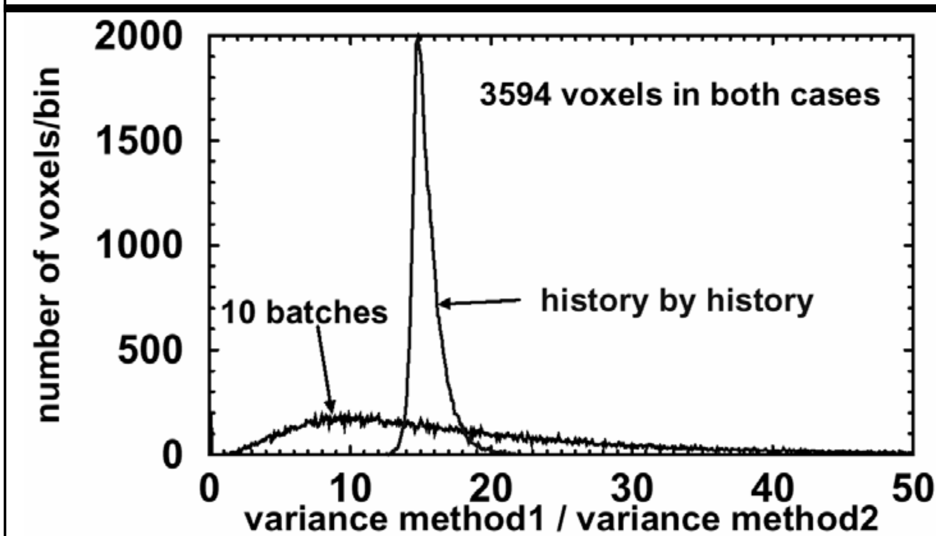
Advantage of history by history



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Dose calculations in a brachytherapy phantom: from Gultekin Yegin

Conclusions

- EGSnrc and BEAMnrc codes are powerful tools for many radiation physics problems
- Both are freely available on the web for non-commercial applications
  - both have extensive documentation
- courses are run about 1/yr for BEAM (next in Oct 2005) and about 1/2yr for EGSnrc

www.physics.carleton.ca/~drogers/BEAM/course/brochure.html

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Thanks to

- many, many colleagues who have helped develop the BEAM/EGS codes discussed: Kawrakow, Walters, Mainegra-Hing, Nelson, Ding, Faddegon, Ma, Zhang, Mackie, Bielajew, Sheikh-Bagheri, Proulx + many users reporting bugs (sometimes patches!)
- Gultekin Yegin for slides and collaborating on brachydose
- Lesley Buckley for her data on correlated sampling
- Jerry Battista for good slide of the stamp

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