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EGS4 in '94

A Decade of Enhancements*

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ORGANIZATION OF THE TUTORIAL

- Introduction:
  - General remarks about Monte Carlo codes.
  - Quick history behind EGS.
- Description of the EGS4 Code System:
  - How it is organized and physics within it.
  - Basic features of the code.
  - Mechanics of running EGS4.
- Benchmarks...... a necessity for credibility.
- *Additional features available after 1985.*

RECENT POPULARITY OF MONTE CARLO CODES

Electron-photon codes have become very popular:

- Five-fold increase in journal papers (1983-88).
- Several good books on electron-photon Monte Carlo.
- MC codes often tend to be used as *black boxes.*

EGS4 has played a very direct role:

- Several M.S. and Ph.D. theses based on the code.
- Seven workshops have now been given on EGS4.
- Six Best Paper awards in *Medical Physics* journal.

Why the sudden interest?

RECENT MONTE CARLO BOOKS ON RADIATION TRANSPORT

- I. Lux and L. Koblinger, MONTE CARLO PARTICLE TRANSPORT METHODS: NEUTRON AND PHOTON CALCULATIONS (CRC Press, 1991).
- R. L. Morin (Editor), MONTE CARLO SIMULATION IN THE RADIOLOGICAL SCIENCES (CRC Press, 1988). [Contributors: H.-P. Chan, K. Doi, J. E. Goin, R. L. Morin, R. Nath, D. E. Raeside, J. C. Widman and J. F. Williamson]
- T. M. Jenkins, W. R. Nelson, A. Rindi, A. E. Nahum and D. W. O. Rogers (Editors), MONTE CARLO TRANSPORT OF ELECTRONS AND PHOTONS (Plenum Press, 1988). [Contributors: P. Andreo, M. J. Berger, A. F. Bielajew, A. Del Guerra, B. Grosswendt, J. Halbleib, A. Ito, T. M. Jenkins, R. Mohan, A. E. Nahum, W. R. Nelson, D. W. O. Rogers, S. Seltzer and R. Wang]

Reasons for Increase in MC-code Popularity

- Analytic methods tend to be prohibitive.
- MC tends to be intuitive – appeals to experimentalists.
- Computers – faster and cheaper !!!

EGS4 Code in Particular

Powerful – Based on well-understood physics.

Versatile – General-purpose code.

Benchmarked – Extremely well-checked code.

Open Architecture – Many contributions by users.

User-friendly † – Reasonably well documented.

User-supported – Workshops, large user community.

Timely – A tool needed by medical physicists.

FREE !!! – Code readily available (*ftp*).

(† Maybe *"expert-friendly"* is a better description.)

Codes That Preceded EGS

Messel and Crawford code[1] – Australia (1958-1970).

- First to use computer for high-energy shower MC.
- Published excellent results – but code not available.

Zerby and Moran code[2] – ORNL (1962-1963).

- Motivated by the construction of SLAC.
- Excellent engineering calculations performed.
- Code not distributed outside ORNL.

Berger and Seltzer code[3] – NIST (1964-present).

- ETRAN – Excellent physics and MC techniques.
- User-friendly versions now available (ITS and MCNP).
- Unknown to the particle-physics community in 1966.

Nagel Code – University of Bonn (1963-1967)[4]

- Ph.D. dissertation (1964).
- Cylindrical geometry (only) — and hard coded!
- Only materials available were Pb and Cu.
- But...... readily available (*e.g.*, DESY, MIT, SLAC).
- Brought to SLAC around 1966 (by Nagel himself).

DEVELOPMENT OF EGS3
(SLAC-HEPL Collaboration)

SHOWER code (by Nagel) became *seed code* for EGS3.

- Energy range extended (0.1 MeV to few GeV).
- Any of 100 elements (compounds, mixtures).
- PEGS3 code – easy way to make input data for EGS3.
- More efficient sampling than in Nagel's code.
- New processes were added.

Popularity of EGS3 in late 1970's linked to HE physics.

- For reasons given previously (versatile, credible, *etc.*).
- But also, perfect timing...... *The November Revolution!*

DEVELOPMENT OF EGS4
(SLAC-KEK-NRCC Collaboration)

SLAC-KEK collaboration already underway in 1982:

- To fix bugs, extend flexibility, for HE accelerators.

Rogers (NRCC) using EGS3 rather extensively:

- Tremendous low-energy benchmarking effort.
- Medical physics applications, detector responses.
- Importance of electron step-size revealed (ESTEPE).
- Bielajew and Rogers fix (low-energy) bugs.

SLAC-265 report issued December 1985[5].

PRESTA released in 1986 by Bielajew and Rogers[6]:
Major advance in electron transport algorithms!

DESCRIPTION OF THE EGS4 CODE SYSTEM

- EGS – *analog* Monte Carlo program
  - Actual physical processes simulated as closely as possible.
  - Variance reduction techniques not "built-in".
  - Good for studying *fluctuations* (*e.g.*, particle detectors).
  - Disadvantage: *Very time consuming.*
- Can introduce importance sampling via `WT` parameter:
  `CALL SHOWER(IQ,E,X,Y,Z,U,V,W,IR,WT)`
  (normally `WT(NP)=1.0` by default in EGS4).
- PEGS code – created for efficiency reasons.

PEGS4 – PREPROCESSOR FOR EGS4

- PEGS uses theoretical & empirical formulae.
  - Compute σ's, branching ratios, scattering coefficients... *etc.*
  - Output is a 'table' $\Longrightarrow$ for **very fast** look-up by EGS.
- Run PEGS code before running EGS
  - But only *once* for each medium.
  - Save PEGS output on disk for subsequent use by EGS.
- PEGS4 has other uses:
  - Diagnostic tool.
  - Calculate and plot cross sections, *etc.*
  - Check sampling routines via bootstrap technique.

ELECTRON (±) PROCESSES IN EGS4

- Bremsstrahlung – $Z(Z+1)$.
  - $\theta_{\text{brem}} = mc^2/E$ (default).
  - Special θ_{brem}-sampling version available (macro).
- δ-ray production – Bhabha (e^+e^-) and Møller (e^-e^-).
- Collision loss – $dE/dx)_{\text{col}}$ (excitation/ionization)
  - Between discrete interactions.
  - Restricted $dE/dx)_{\text{col}}$ (*i.e.*, LET_Δ).
  - $dE/dx)_{\text{rad}}$ for soft x-rays (added to collision loss).
  - Density effect (Sternheimer-Berger-Seltzer).
- Multiple scattering – Molière model.
- Positron annihilation – in-flight/at-rest.

PHOTON PROCESSES IN EGS4

- Pair production – $Z(Z+1)$.
  - $\theta_{\text{pair}} = mc^2/E$ (default).
  - Special θ_{pair}-sampling version available (macro).
- Compton scattering (unbound).
- Coherent (Rayleigh) scattering.
- Photoelectric effect (excitation energy deposited locally).
  - Special *fluorescence* version available.
  - PE-angle sampling (macro) also available.

BASIC CAPABILITIES OF EGS4

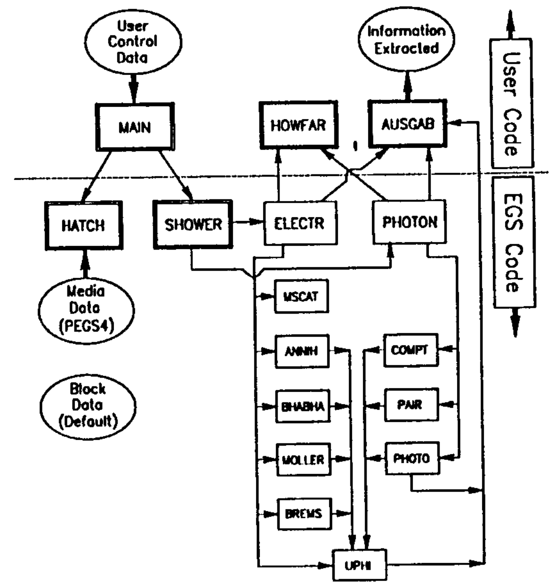
- ☐ Dynamic energy range – several TeV down to:
  - 1 keV (photons).
  - 10 keV (electrons).
- ☐ Geometry routines (SUBROUTINE HOWFAR) available .
- ☐ Combinatorial Geometry (MORSE-CG) User Codes.
- ☐ Transport in $\vec{E}$ and $\vec{B}$ fields.

- ☐ Weighting and biasing techniques:
  - Variance reduction and importance sampling.
  - Splitting, path-length biasing, Russian roulette.
  - Leading-particle biasing.
- ☐ Transport initiation (CALL SHOWER) with:
  - Energy spectrum (*e.g.*, synchrotron radiation).
  - Spatial and/or angular distribution.
  - Pi-zero decay.

Mechanics of Running an EGS4 Job

- ❑ User must create <u>User Code</u> consisting of:
  - **MAIN** program — '<u>driver</u>' code.
  - **HOWFAR** — <u>geometry</u> subprogram.
  - **AUSGAB** — <u>scoring</u> subprogram.
- ❑ In **MAIN** program:
  - `CALL HATCH` to read in media data created by PEGS4.
  - `CALL SHOWER` as many times as you want shower events.
- ❑ User Code follows specific set of rules:
  - Details (including an example) are in the User Manual.
  - Set of tutorial examples also provided.

Division between User-Interface and EGS4

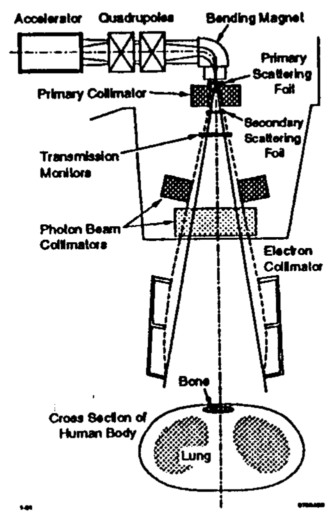


Experimental Benchmarks*

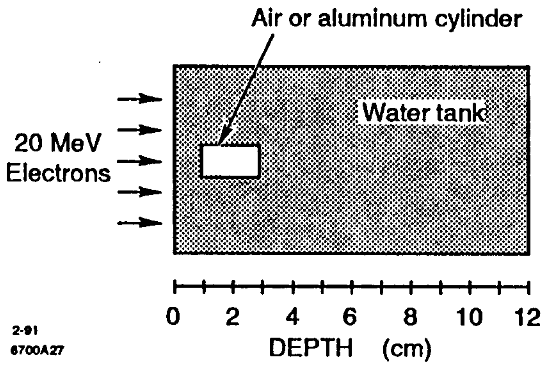
- ❑ Many successful comparisons in high-energy physics.
- ❑ Most precise benchmarks come from medical physics.
- ❑ Accurate patient dosimetry must account for:
  - Scattering from <u>machine</u> components.
  - Scattering from <u>inhomogeneities</u> within <u>human body</u> (*i.e.*, bones, lungs,... the <u>*interface effect*</u> problem).

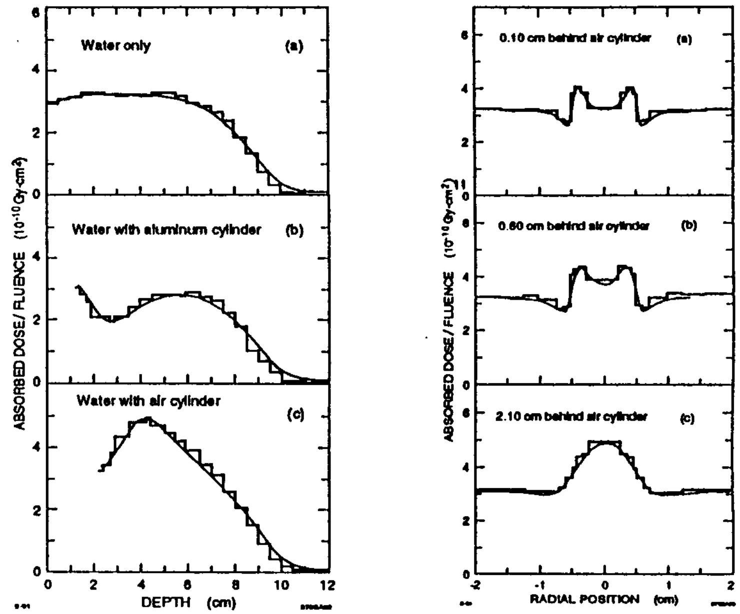
* For example, see Chapter 5 by Rogers and Bielajew in *The Dosimetry of Ionizing Radiation, Volume III*, K. R. Kase, B. E. Bjärngard and F. H. Attix (editors).

<u>Schematic of a typical clinical accelerator used for radiotherapy</u>



Heterogeneity benchmark experiment by Shortt *et al.* (1986)[46] using a monoenergetic point source of 20-MeV electrons. The dose per unit fluence was measured in a water tank containing both air and aluminum cylinders. Data was taken with a small solid-state detector and then normalized to a single point on the water-only curve. Experimental results (solid lines) are compared with EGS4 calculations (histograms).





IMPROVEMENTS TO EGS4 SINCE 1985

- This will be a brief description only.
- Interested readers should consult references in

  A. F. Bielajew, H. Hirayama, W. R. Nelson and D. W. O. Rogers, "History, Overview and Recent Improvements in EGS4", NRC-PIRS-0436 (1994)

- Most improvements/enhancements are
  - supplied with UNIX-version distribution, *or*
  - obtained directly from author(s).
- For the most part, all changes are *options* to EGS4:
  - must be "switched on" via flags, *and/or*
  - by including "macros" in User Codes.

Improvements/enhancements fall into three groups

I. Changes to *Physics Modeling* in EGS4

PRESTA, Angle Sampling (Brem,Pair,PE), Fluorescence, EM-Fields, Polarization, Doppler Broadening, Compton Binding, Single Scattering, Cross-Section Improvement.

II. Development of *Tools* and *Techniques*

Forced Interactions, Range Rejection, Bremsstrahlung Splitting, Long-Sequence Random-Number Generation, PEGS Tools, Graphics Tools.

III. *Systems* and other *Support*

New Platforms (UNIX,PC), Listserv, Anonymous-ftp Timing Benchmark Database, Courses, User Groups.

PRESTA

PARAMETER REDUCED ELECTRON STEP TRANSPORT ALGORITHM[6]

- Introduced shortly after release of EGS4 Code System.
- Motivated by Rogers' low-energy ESTEPE work (1984)[7].
- Almost completely new algorithm for electron transport.
- Implemented via macros and switches (IPLC, ILCA, IBCA).

PRESTA – Changes made in three principle areas:

Path-Length Correction (IPLC) – A refined method for calculating average curvature between multiple scattering sub-steps (Standard-EGS4 overestimates by up to a factor of 2).

Lateral-Correction Algorithm (ILCA) – Introduces extra lateral component, correlating it to the multiple scattering angle at end of sub-step (Standard-EGS4 ignores this, underestimates lateral diffusion).

Boundary-Crossing Algorithm (IBCA) – Causes sub-steps to be shorter in vicinity of boundaries (avoids transport artefacts near interfaces).

BREMSSTRAHLUNG AND PAIR PRODUCTION ANGULAR DISTRIBUTIONS

- ❑ In the Standard-EGS4:
  - Bremsstrahlung and pair energies are sampled.
  - Polar angles are fixed at m/E and m/k, respectively.
- ❑ This thick-target approximation assumes that multiple Coulomb *scattering* "washes out" *production* angles.
- ❑ The rationalization for this can be shown by equating

$$\theta_{\text{Brem}} = \theta_{MS}$$
$$m/E \approx 15\sqrt{t}/E$$

resulting in $t \approx 0.001$ r.l.

- ❑ Originally only expected to be a problem for thin-targets.
- ❑ However, thick-target studies revealed:
  - Angular-distribution artefacts near central axis.
  - Occuring at both radiotherapy (MeV) and diagnostic (keV) energies.
- ❑ Bremsstrahlung-angle sampling macro/switch (IBRDST) was developed by Bielajew, Mohan and Chui[8] in 1989.
- ❑ Pair-angle sampling macro/switch (IPRDST) was also developed by Bielajew[9] in 1991 (motivated in this case by a high-energy physics experiment at SLAC).

PHOTOELECTRIC ANGLE SAMPLING

- In the Standard-EGS4:
  - Photoelectron given same direction as incident photon
- PE-angle sampling macro/switch (IPHTER) developed by Bielajew and Rogers (1986)[10].
  - Based on relativistic theory by Sauter.
  - Their comparision with low-energy TLD experiments showed no major effect.
  - Importance of this option recently demonstrated by *backscattered synchrotron radiation* studies for the new Asymmetric B-Factory project at SLAC.

KAND L-SHELL FLUORESCENCE

- Standard-EGS4 does not create/transport fluorescent photons
- Substitute sampling routine SUBROUTINE PHOTO allows for generation of K_{α_1} and K_{β_1} fluorescent photons.
  - Originally developed by Nelson and Jenkins in 1985.
  - Now used as standard in UNIX and PC distributions.
  - Switch (IEDGFL) turns on fluorescence by geometry region.
  - Requires auxiliary subroutine EDGSET (extended by K. Weaver (UCSF) to include all 100 elements).
- Del Guerra *et al.* (1991)[11] have developed K and L-edge sampling scheme for compounds.

ELECTROMAGNETIC FIELD TRANSPORT

- SUBROUTINE ELECTR of Standard-EGS4:
  - Does *not* perform electron transport in $\vec{E}$ and $\vec{B}$ fields.
  - But... EGS4 contains *macros* and *templates* that allow the user to do this (call it hindsight!).
- A general theoretical treatment in

  A. F. Bielajew, "Electron Transport in $\vec{E}$ and $\vec{B}$ Fields", in Monte Carlo Transport of Electrons and Photons Below 50 MeV, (Plenum Press, 1988).

  describes how to accomplish this.

- Bielajew's EM-field treatise was preceded by a very innovative theoretical-experimental study:
  - Rawlinson, Bielajew, Munro and Galbraith (1984)[12].
  - Dose enhancement caused by *electric charge storage* in electron-irradiated phantoms.
  - Farrington Daniels award (best dosimetry paper in MP journal)!
- More recently Bielajew[13] has come up with another clever method for studying the benefits of employing strong longitudinal $\vec{B}$ fields to control the lateral spread of external electron (and photon) beams.

EGS_Windows_1/20 MeV Electrons in Water
Longitudinal B-Field (0 T) (slide #1 of 2)

EGS_Windows_1/20 MeV Electrons in Water
Longitudinal B-Field (20 T) (slide #2 of 2)

CROSS SECTION IMPROVEMENTS

- ☐ PEGS4 Modifications – *Collision* Stopping Power
  - Duane, Bielajew and Rogers (1989)[14] added PEGS4 option (EPSTFL) for inputing arbitrary density-effect corrections.
  - PC program (EPSTAR) by Seltzer (1988)[15] was used—to calculate density-effect corrections for arbitrary materials (ICRU-37)[16].
  - Relatively small changes to the collision stopping power... but crucial for stopping-power-ratio studies.

- ☐ PEGS4 Modifications – *Radiative* Stopping Power
  - Rogers *et al.* (1989)[17] added PEGS4 option (IAPRIM) to make radiative stopping powers ICRU-37-compliant.
  - Used Seltzer's PC program called EPSA[15].
  - Option provides a global renormalization of $\left(\frac{d\sigma}{dE}\right)_{\mathrm{brem}}$.
  - Noticeable changes in $\left(\frac{d\sigma}{dE}\right)_{\mathrm{brem}}$ below 50 MeV—experimentally verified by Faddegon, Ross and Rogers (1990,1991)[18].
  - Namito *et al.* (1990)[19] observed significant changes at low energies—*e.g.*, 80-keV x-rays from Au—setting IAPRIM=1 brought EGS4 into agreement with ETRAN.

Cross Section Improvements (cont.)

- Photon cross sections (< 50 MeV) in Standard-EGS4:
  - Based on 1970 Storm-Israel data package (DLC-15)[20].
  - ANSI (ENDF/B-VI) recommends DLC-136/PHOTX for point-kernel and S_n-transport calculations.
  - Sakamoto (1993)[21] introduced PHOTX into PEGS4.
  - Essentially, different PE cross sections in PHOTX.
  - Small effects observed for exposure buildup factors.

Cross Section Change Along Path of Electron

- The *"fictitious-interaction"* sampling scheme (Standard-EGS4).
  - Next interaction sampled from σ_{tot}^{i} at beginning of step.
  - Charged particles lose energy continuously between discrete interactions and σ_{tot} is different at the end of its path.
  - If σ_{tot} decreases as E decreases, can use sampling trick.
  - Invalid assumption at low-E—as E decreases σ_{Moller} rises and overtakes the decrease in σ_{brem} (Rogers, 1984)[7].
  - Ma and Nahum (1992)[22] created a linear-variation model.
  - Recommend its use for $E < 1$ MeV and Møller creation thresholds below 20 keV (few % effects).

More Accurate Trigonometric Functions

- Tracking algorithms make frequent use of sines and cosines.
- To gain computational speed, Standard-EGS4 uses a look-up table macro in lieu of standard FORTRAN sine/cosine functions.
- If accurate small-angle modeling is crucial—it is easy to revert back to a sine-by-function macro (at the cost of CPU time).
- Li and Rogers (1993)[23], calculating electron mass scattering factors, found shortcomings with default look-up table macro.
- Li, Rogers, and Ma (1994)[24] created new table look-up macro with small-angle accuracy as well as speed (as high as 45%).

Single Elastic Scattering

- Standard-EGS4 uses Molière multiple-scattering theory.
  - Employs small-angle form of screened Rutherford cross section (couched in small-angle formalism).
  - Contains approximations that make angular distributions unstable for short electron sub-steps.
- Recently Bielajew, Wang and Duane (1993)[25]:
  - Modified EGS4 to allow for single elastic scattering (using partial-wave cross sections by Berger and Wang).
  - Purpose – to study Molière theory.
- Subsequent study by Bielajew (1994)[26] has resolved small step-size difficulty of Molière.

Binding Effect in the Compton Interaction

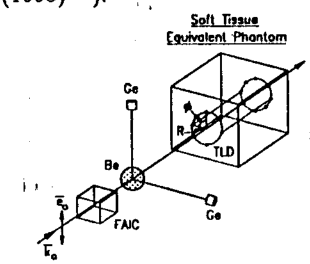
- Standard-EGS4 treats atomic electrons as "free" (electron binding important for $E_\gamma <$ few hundred keV).
- Electron binding manifests itself in three ways:
  - Reduction in total Compton-scattering cross section.
  - Modification of scattered photon angular distribution (*e.g.*, reduction in the forward direction).
  - Broadening of scattered photon energy spectrum.
- Including all three consistently is the best way to treat binding effect in Compton scattering.

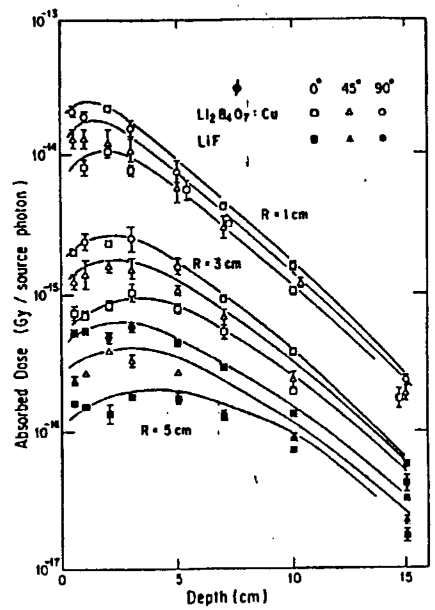
- Hirayama and Trubey (1988)[27] – First to include electron binding in Compton <u>cross section</u> for EGS4.
  - Calculated buildup factors for 40–200 keV x-rays.
  - Bound Compton modeling shown to have noticeable effect, especially at lower energies.
- Namito and Hirayama (1991)[28] and Samili and Dupeursinge (1991)[29] – First to also modify Compton <u>angular distribution</u> in EGS4 for electron binding.
  - Used same method implemented in ETRAN-based codes (SANDYL, MCNP, and ACCEPT of the ITS series).

Linear-Polarized Photon Scattering

- Number of synchrotron radiation facilities growing rapidly.
- Increasing need to include polarized photon scattering in MC codes.
- Standard-EGS4 considers all particles to be unpolarized.
- Namito, Ban and Hirayama (1993)[30] – First to implement linearly-polarized photon scattering into EGS4.
  - For both Compton and Rayleigh processes.
  - Calculations compared with series of benchmark experiments performed at KEK Photon Factory.

Absorbed dose measurement of a mono-energetic ($k_0 = 30$ keV) photon beam using TLDs in a soft tissue equivalent phantom. Intensity monitored by free-air ion chamber. Linear polarization ($P = 0.84$) monitored by Be scattering foil and Ge detectors. Symbols are measurements and lines are EGS4 calculations (Namito, Ban and Hirayama (1993)[30]).

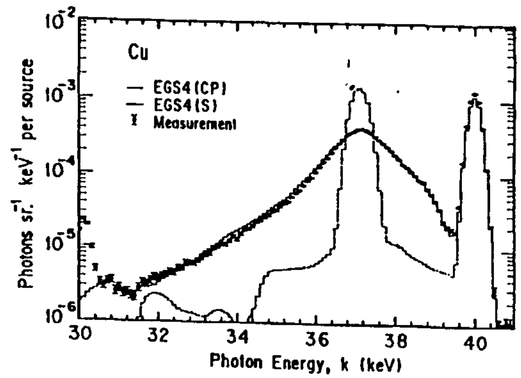


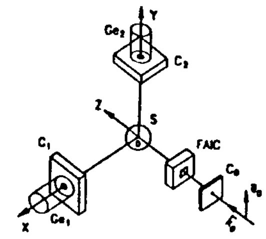


Compton Scattering with Doppler Broadening

- In addition to neglecting electron binding, Standard-EGS4 ignores motion of electrons in the atomic cloud.
- Compton-scattered photon spectrum is *broadened* by pre-collision motion of the electron.
- Namito, Ban and Hirayama (1994)[31] – First to include Doppler broadening with Compton scattering in EGS4.
- In fact... they simultaneously accounted for *electron binding, Doppler broadening*, and *linear polarization* in a complete and totally consistent way.
- Calculations were compared with another series of benchmark experiments performed at KEK Photon Factory.

Mono-energetic ($k_0 = 40$ keV) linearly-polarized ($P = 0.84$) photon beam scattered by sample (S). Scattered photons counted by Ge detectors located at $\theta = 90°$ relative to beam. Intensity monitored by free-air ion chamber. Collimators (C) define beam and opening angle of detectors. EGS4 calculation (histograms) include full Compton-binding effects plus linear polarization. EGS4(S)=without Doppler, EGS4(CP)=with Doppler (Namito, Ban and Hirayama (1994)[31]).





Forced Photon Interactions

- As stated earlier, Standard-EGS4 is an analog MC code.
  - Particles may pass through geometry without interacting!
  - For photons passing through *thin targets*—very wasteful.
- Rogers and Bielajew (1984)[32] have successfully used the technique of *forcing photon interactions* to eliminate this waste in some EGS4 applications.
- Rogers *et al.* (1985, 1994)[33,34] have also refined this technique by creating non-interacting *"fictitious photons"*, a method that is sometimes called *weighting-in-lieu-of-absorption*.
- Forced-interaction biasing and weighting is well described in

  A. F. Bielajew and D. W. O. Rogers, "Variance-Reduction Techniques", in Monte Carlo Transport of Electrons and Photons Below 50 MeV, (Plenum Press, 1988).

Range Rejection

- Range rejection – another variance-reduction technique
  - Electrons that simply cannot reach a region of interest are discarded "on the spot".
  - Approximations involved (see previous reference book).
- Rogers *et al.* (1994)[33] have refined the technique by using very accurate restricted range tables—obtained by integrating restricted stopping powers supplied by PEGS4.
- Range rejection can be quite powerful—as much as a factor of four has been gained in ion-chamber response calculations by Bielajew, Rogers and Nahum (1985)[35].

Bremsstrahlung Splitting

- Splitting – another variance-reduction technique
  - Set N photons in motion to improve statistics.
  - Give each photon a weight of $1/N$.
- Bremsstrahlung splitting (IBRSPL) has been developed for EGS4 by Bielajew, Mohan and Chui (1989)[8] (as part of brem-angle sampling macros discussed earlier).
- Faddegon, Ross and Rogers (1990,1991)[18] employed this technique at radiotherapy energies using $N = 5-30$.
- Namito *et al.* (1990)[19] used N-values as high as 300 to study 80-keV x-ray production from Au targets.

PEGS-Related Tools

- Interactive tool recently developed by Karr and Bielajew (1993)[36] to further automate the use of PEGS.
  - Called (PIF) – Prepare Input File for PEGS.
  - Includes ICRU-37 stopping powers (described earlier).
  - Maintains database – 100 elements/over 300 compounds.
- EXAMIN – NRCC User Code to understand PEGS output.
- Limitation currently imposed on operation of PEGS4:
  - Can only create *one* set of data at a time.
  - "Workaround" available (N. Hammond, EDS-Scion/U.K.).

Long-Sequence Random Number Generators

- Standard-EGS4 comes with two RNGs:
  - One specific to IBM mainframe architecture.
  - One based on same generator but coded for generic 32-bit 2's-complement integer arithmetic (*e.g.*, VAXs).
  - Sequence length (periodicity) of 2^{30} ($\sim 10^9$).
- Marsaglia *et al.* (1990)[37] long-period ($2^{144} \sim 10^{43}$) RNG now recommend for EGS4 (slightly slower than original RNG).
  - Machine independent/parallel-implementation adaptable.
  - Choose 10^9 independent sequences from initial conditions.
  - Currently distributed with UNIX version of EGS4.

Graphics Tools

- Several general-purpose packages for graphics output of particle tracks and geometries of EGS4 simulations:
  - SHOWGRAF from SLAC by Cowan and Nelson (1987)[38].
  - SHOW from NRCC by Mangin and Bielajew.
  - EGS_Windows_1 from NRCC by Wiebe and Bielajew (1991)[39].
  - EGS_Windows_2 from LBL by Chatterjee and Donahue.
  - EGS_Windows_3 from NRCC by Zurawski and Bielajew.
- Above packages have different functions and require specific hardware and software. See Bielajew (1993)[40] for details.
- Hirayama *et al.* are currently developing an EGS4-graphics utility specifically designed for the PC.

SHOWGRAF/SLAC 40-inch Bubble Chamber
Single 1-GeV Photon (20kG) (slide #1 of 4)

SHOWGRAF/SLAC 40-inch Bubble Chamber
Single 1-GeV Photon (20kG) – Closeup (slide #2 of 4)

EGS_Windows_1/Varian 2100C Accelerator (slide #3 of 4)
(Cover-page photo from SLAC Beam Line 23(1) (1993))

EGS_Windows_3/Varian 2100C Accelerator (slide #4 of 4)

MACHINE/SYSTEM DISTRIBUTIONS

- Originally, EGS4 was supported for only two machine types:
  - IBM/VM and VAX/VMS mainframes.
  - Example scripts (EXEC and .COM files) were provided.
  - Original distribution still available from SLAC or RSIC.
- Japanese-computer versions available from H. Hirayama (KEK).
- Around 1988 Walker *et al.* (1988,1990,1992)[41,42] volunteered to manage and distribute an IBM-PC version of EGS4.
- UNIX distributions:
  - Developed and maintained at NRCC by Bielajew (1990,1993)[43].
  - Includes most improvements/enhancements described here.

TIMING BENCHMARK DATABASE

- Best way to compare performance—*use one's own application*.
  - Standard timing benchmark code for radiotherapy created by Bielajew and Rogers (1992)[44].
  - For wide variety of computers—PCs to supercomputers.
  - Separate PC comparison (same code) by Walker *et al.* (1992)[42].
  - Latest combined results (by many contributors) maintained in *anonymous-ftp servers* (described below).
- Yasu *et al.* (1993)[45] compiled HE physics timing benchmarks.

LISTSERV AND ANONYMOUS-ftp SUPPORT

❑ *Listserv* – Electronic-mail discussion list (EGS4-L).

- Promote discussion within growing EGS-User Community.
- Users can post questions to this list that can be answered by the EGS-community-at-large.
- To subscribe, send an e-mail message to:

  `listserv@slac.stanford.edu` (Internet)

  saying: `SUBscribe EGS4-L` "Your full name"
- To post questions/comments/answers, send e-mail to:

  `egs4-l@slac.stanford.edu`
- Currently maintained at SLAC by R. Donahue (LBL).

❑ *Anonymous ftp*

- Distribution of UNIX version of EGS4 most conveniently done by *anonymous ftp*.
- Current sites: `nrcnet0.nrc.ca` [132.246.160.2]
  `academic.lbl.gov` [128.3.252.168]
- Anonymous ftp sites are dynamic — browse periodically.

  Contain EGS4 Codes System distribution, plus......

  ...graphics-support code.

  ...contributions from users.

  ...most recent timing benchmark studies.

  ...PostScript reprints of EGS-related papers and reports (including many mentioned in this tutorial).

EGS4 COURSES AND USER GROUPS

- Courses
  - We have given seven workshop-type courses (in Ottawa, Seattle, London and Capri).
  - Courses are limited to about 30 students and run "at cost".
  - The 8th course will be given March 6 – March 9, 1995 at the Lanzl Institute in Seattle, Washington.

- User Groups
  - EGS4 User's Meeting in Japan

    Recently finished fourth (annual) conference at KEK. Approximately 70 participants were from outside of KEK.
  - EGS4-User Group of France

    Has approximately 25 members and produces an EGS4 newletter. E. Sartori (OECD/NEA Data Bank, Issy-les-Moulineaux) distributes a PC version of EGS4 thoughout France.

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