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EGS4 in '94

A Decade of Enhancements*

W. R. NELSON

Radiation Physics Department
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309, USA

A. F. BIELAJEW AND D. W. O. ROGERS

Institute for National Measurement Standards
National Research Council of Canada
Ottawa, K1A 0R6, Canada

H. HIRAYAMA

National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

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W. R. Nelson
Stanford Linear Accelerator Center, Stanford, CA 94309, USA

A. F. Bielajew and D. W. O. Rogers
National Research Council, Ottawa, K1A 0R6, Canada

H. Hirayama
KEK, Oho-machi, Tsukuba-gun, 305 Japan

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

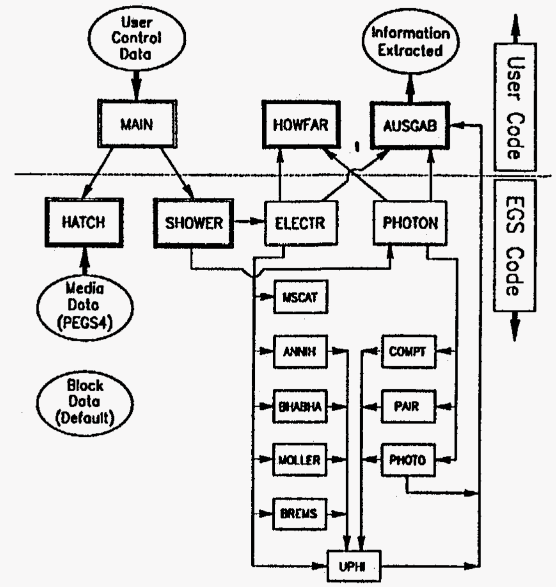
- ❑ Dynamic energy range – several TeV down to:
  - 1 keV (photons).
  - 10 keV (electrons).
- ❑ Geometry routines (SUBROUTINE HOWFAR) available .
- ❑ Combinatorial Geometry (MORSE-CG) User Codes.
- ❑ Transport in $\vec{E}$ and $\vec{B}$ fields.

- ❑ 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 **User Code** 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

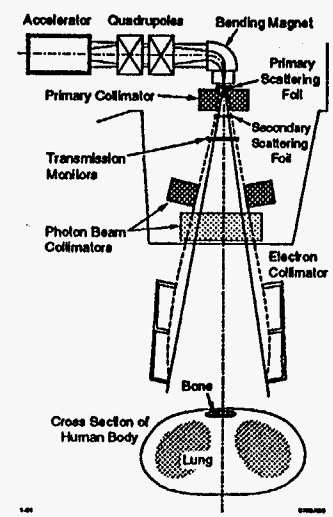


Experimental Benchmarks*

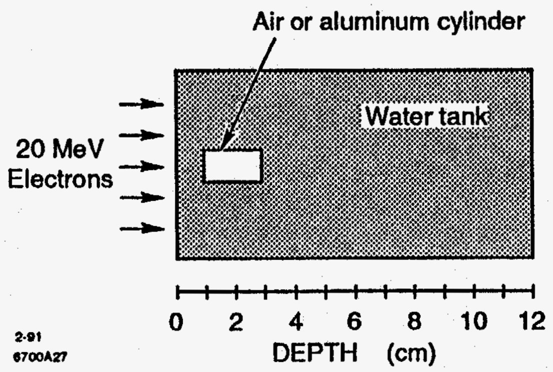
- ❑ Many successful comparisons in high-energy physics.
- ❑ Most precise benchmarks come from medical physics.
- ❑ Accurate patient dosimetry must account for:
  - Scattering from <u>machine</u> components.
  - Scattering from <u>inhomogeneities</u> within <u>human body</u> (*i.e.*, bones, lungs,...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

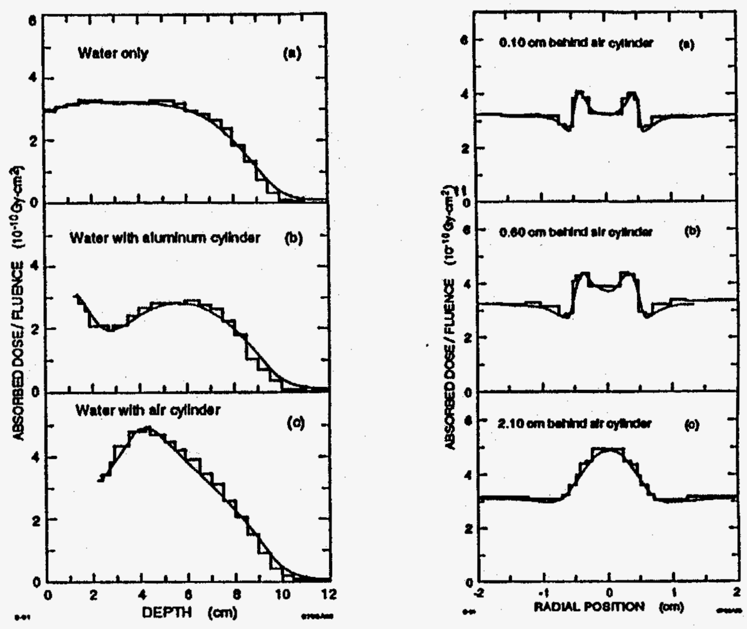
* For example, see Chapter 5 by Rogers and Bielajew in *The Dosimetry of Ionizing Radiation, Volume III*, K. R. Kase, B. E. Bjärngard and F. H. Attix (editors).

Schematic of a typical clinical accelerator used for radiotherapy



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 $\frac{d\sigma}{dE})_{\mathrm{brem}}$.
  - Noticeable changes in $\frac{d\sigma}{dE})_{\mathrm{brem}}$ 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} 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

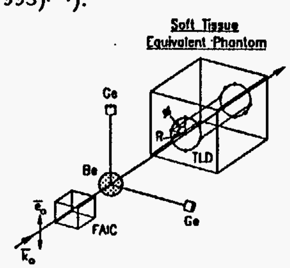
- Standard-EGS4 treats atomic electrons as "free" (electron binding important for $E_\gamma <$ few hundred keV).
- Electron binding manifests itself in three ways:
  - Reduction in total Compton-scattering cross section.
  - Modification of scattered photon angular distribution (*e.g.*, reduction in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

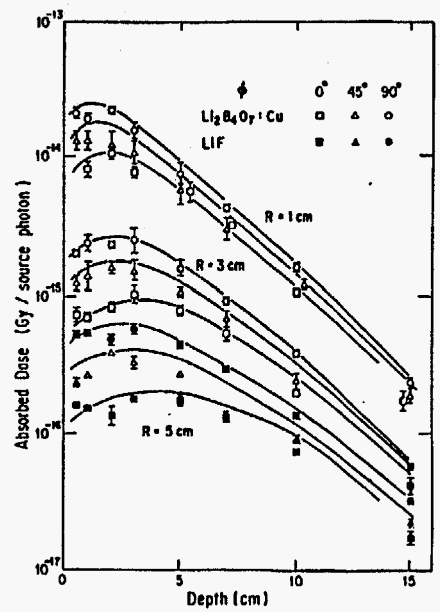
- Hirayama and Trubey (1988)[27] – First to include electron binding in Compton cross section for EGS4.
  - Calculated buildup factors for 40–200 keV x-rays.
  - Bound Compton modeling shown to have noticeable effect, especially at lower energies.
- Namito and Hirayama (1991)[28] and Samili and Dupeursinge (1991)[29] – First to also modify Compton angular distribution 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]).

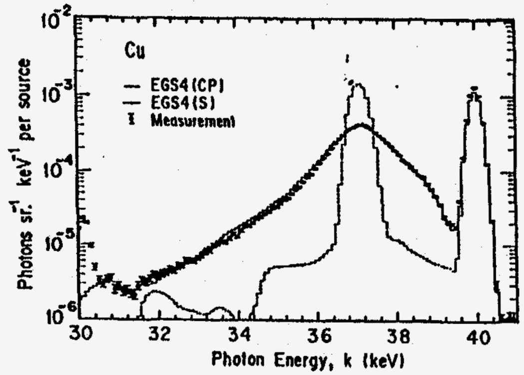


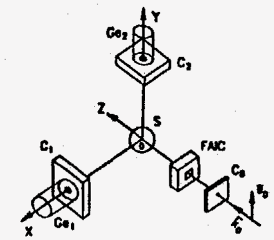


Compton Scattering with Doppler Broadening

- 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 bench-mark 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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