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12. Structure and Operation of the EGS4 Code System†

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12.1 INTRODUCTION

The EGS** system of computer codes is a general purpose package for the Monte Carlo simulation of the coupled transport of electrons and photons in an arbitrary geometry for particles with energies above a few keV up to several TeV. The current version is the EGS4 Code System by Nelson, Hirayama and Rogers[1], which is more commonly referred to as EGS4.

With the introduction of EGS4, we created a new manual (SLAC-265) that retained much, but not all, of the previous documentation for the EGS3 Code System[2]. In particular, we omitted the history prior to EGS3 and, since many of the EGS3 benchmark comparisons had been published elsewhere[3-5] and SLAC-265 was already rather large, we did not duplicate the effort in the EGS4 manual. However, since the EGS3 documentation (SLAC-210) will soon be out of print, it seems appropriate to include some of this information here.

In the sections that follow, the history leading up to the release of EGS4 will be presented, together with a relatively short description of the EGS4 Code System itself. This will then be followed by a series of benchmark comparisons with experiments and with Monte Carlo results of others. Additional comparisons are also presented in Chapter 13.

12.1.1 History Prior to EGS3

Messel and Crawford code – Australia (1958-1970).
The first use of an electronic digital computer in simulating high-energy cascades by Monte Carlo methods was reported by Butcher and Messel[6,7], and independently by Varfolomeev and Svetlolobov[8]. These two groups collaborated in a much publicized work[9] that eventually led to an extensive set of tables describing the shower distribution functions—the so-called "shower book"[10].

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** Electron-Gamma Shower

Chapter 12 (Pages 287-305) in "Monte Carlo Transport of Electrons and Protons," T.M. Jenkins, W.R. Nelson, and A. Rindi, Editors Plenum Publishing Co. 1988

Zerby and Moran code – ORNL (1962-1963).
Around the same time period, Zerby and Moran at the Oak Ridge National Laboratory developed a high-energy electromagnetic cascade program based on the Monte Carlo method[11–13]. This ORNL code was motivated by the construction of the Stanford Linear Accelerator Center (SLAC) and by the many physics and engineering problems that were anticipated as a result of high-energy electron beams showering in various devices and structures at that facility. This code has been used by Alsmiller and others[14–18] for a number of studies since its development. Even though the results of Zerby and Moran calculations were used extensively during the initial design of SLAC, the code was not readily available outside ORNL, nor was it maintained, so that today most of the ORNL studies requiring electron-photon transport make use of EGS.

Nagel code – Bonn University (1963-1967).
Also during the early 1960's, H. H. Nagel wrote his Ph.D. thesis at Bonn University on electron-photon Monte Carlo[19–21], and several versions of his code have appeared since then[22–25], including one that eventually became EGS3. Nagel's original FORTRAN IV program, which we shall simply refer to as SHOWER (not to be confused with `SUBROUTINE SHOWER` of the EGS Code System), represented a very practical tool for the experimental physicist during the middle 1960's—and it was free for the asking!

However, SHOWER was still rather limited in its application. One could initiate radiation transport with energies only up to 1 GeV, and then only for monoenergetic electrons. Except for annihilation, positrons and electrons were treated alike and were followed until they reached a cutoff energy of 1.5 MeV (total energy) and photons were followed down to 0.25 MeV. But this still represented cutoff energies that were, at the time, as low as or lower than those used by ORNL or the Australians. Probably the most limiting constraint of SHOWER, however, was its built-in geometry—one was obliged to use a single cylinder of Pb. To make matters worse, the code was not very modular and a fair amount of effort on the part of the user was involved in order to do even rather simple things, such as a bremsstrahlung spectrum as input. There was nothing wrong with the physics or the Monte Carlo schemes. The simple fact was that SHOWER was both unwieldly and limited in scope.

During the period starting around 1967 up to about 1974, the SHOWER program was modified by Nelson and colleagues at Stanford, who were attempting to make it faster, as well as more useful. However, efforts by R. L. Ford at the High Energy Physics Laboratory (HEPL), where a group led by R. Hofstadter and E. Hughes was continuing their development of large NaI(Tl) Total Absorption Shower Counters (TASC's), soon led to the growing conviction among everyone concerned that a generalized code was really necessary.

12.1.2 The Development of EGS3

The EGS Code System (Version 3) was a joint effort, undertaken over the period 1972-1978 by R. L. Ford and W. R. Nelson. The sole purpose of the collaboration was to revamp completely the work started by Nagel, but to do it in such a way that further enhancements could easily be made as time progressed—in today's words, to create a program that was *versatile*, *upward-compatible*, and very *user-friendly*.

When EGS3 was formally introduced in 1978[2], it was designed to simulate EM cascades in various geometries and at energies up to a few thousand GeV and down to cutoff kinetic energies of 0.1 MeV (photons) and 1 MeV (electrons/positrons). By means of the PEGS* auxiliary code, radiation transport was made available in any of 100 elements, or any compound or mixture of these elements. In addition to providing more efficient sampling schemes, EGS3 also included some processes that were not part of the original SHOWER program. To lend credibility to our efforts, a fairly extensive set of benchmark comparisons, representing a wide range of applications, were included in the EGS3 manual (SLAC-210). The most important benchmarks, however, have been performed by the multitude of users of the code itself.

Upon reflection, probably the single most important event that made EGS an everyday word in high-energy physics was the discovery of the J/ψ particle in the Fall of 1974. EGS3 was originally intended to be a tool for high-energy health physicists and accelerator designers, but the "November Revolution", as it is now referred to in the particle physics world, led to a dramatic increase in the use of storage rings and the need for sophisticated EM calorimetry. It is safe to say that EGS3 has played a role in the design of many, if not most, of the electromagnetic shower counters since then.

12.1.3 EGS4 – A Code Greatly Influenced by Medical Physics

Since the introduction of EGS3, there has been a growing need to extend the lower energy limits—*i.e.*, down to 1 and 10 keV for photons and electrons, respectively. Essentially, EGS3 has become more and more popular as a general low-energy electron-photon transport code that can be used for a variety of problems in addition to those normally associated with EM cascade showers. While there was a collaborative effort being undertaken by Nelson (SLAC) and Hirayama (KEK) to extend the flexibility of EGS in general, particularly for use around high-energy accelerators, there was also an important low-energy benchmarking effort being done by Rogers, Bielajew, and colleagues at the NRC in Canada. The efforts of these three laboratories was pooled and the EGS4 Code System became the result[1] .

Although EGS is still very heavily used in particle physics, it is interesting to note that of the 260 EGS4 Distribution Tape requests received by the SLAC Radiation Physics Group during 1986, well over half went to hospitals or to organizations involved in medical physics and dosimetry research. The fact that this book is based on a course on electron-photon Monte Carlo is further demonstration of the current strong interest in this field of research.

12.2 GENERAL DESCRIPTION OF EGS4 (AND PEGS4)

EGS is basically an *analog* Monte Carlo program. That is to say, each and every particle is followed until it reaches its final destiny, usually an energy limit (cutoff) or a discard boundary. Due to the statistical nature of the Monte Carlo method, the accuracy of the results will depend on the number of histories run. Generally, the statistical uncertainties are proportional to the inverse square root of the number of histories[26]. Thus, to cut uncertainties in half, it is necessary to run four times as many histories. Also, for given cutoff energies, the computer time for a shower history is slightly more than linear in the energy of the incident particle. The point to be made here is that

* Preprocessor for EGS

analog Monte Carlo calculations can be very time consuming. It is for this reason that the computational task of the EGS4 Code System is divided into two parts. First, a preprocessor code (PEGS4) uses theoretical (and sometimes empirical) formulas to compute the various physical quantities needed, and prepares them in a form for fast numerical evaluation. Then another code (EGS4) uses these data, along with user supplied data and routines, to perform the actual simulation.

12.2.1 PEGS4 as a Development Tool

To aid in debugging and to help those interested in studying the various interactions, the EGS4 Code System was expanded beyond the minimum coding necessary to simulate radiation transport. With this in mind, PEGS4 was written in a modular form with over 95 subprograms. These include functions to evaluate physical quantities which are either needed by PEGS4, or are of interest for other reasons. Other routines necessary for operation of EGS4 include the fitting routines and the routine to write the data for a given material onto a data set. Included among the PEGS4 subprograms not needed for the operation of EGS4 itself are routines to plot the functions on the lineprinter or a graphics device, and a routine to compare (on a lineprinter plot) the theoretical final-state density functions with sampled final-state distributions. The latter may be created most easily by means of UCTESTSR*, which is provided on the EGS4 Distribution Tape.

12.2.2 PEGS4 as a Preprocessor for EGS4

As we have stated, the prime use of PEGS4 is to produce material data sets for subsequent use by EGS4 itself. The main program of PEGS4 calls some once-only initialization routines and then enters an option loop. After reading in the option that is desired, a `NAMELIST` read establishes other parameters which may be needed. The action requested is then performed and control returns to the beginning of the loop. This continues until the control input has been exhausted. Options exist for plotting and examining the cross sections themselves, but the most important options are: `ELEM`, `COMP`, `MIXT`, and `ENER`. The first three tell PEGS that an element, compound, or mixture, respectively, is being requested. Additional data are then supplied by the user in order to establish the medium in question.

The `ENER` option is even simpler—it defines the range of energies, both upper and lower (*i.e.*, cutoffs), which are to be used by PEGS4 when it creates the data for EGS4. The amount of data that the user supplies to PEGS4 is actually quite small (less than about 10 cards), and examples for a variety of material situations are given in SLAC-265 (Appendix 3).

12.2.3 General Implementation of EGS4

The EGS4 code itself consists of two *user-callable* subroutines, `HATCH` and `SHOWER`, which in turn call the other subroutines in the EGS4 code, some of which call two *user-written* subroutines, `HOWFAR` and `AUSGAB`. The latter determine the geometry and output (scoring), respectively. The user communicates with EGS4 by means of various `COMMON` variables. To use EGS4, the user must write a `MAIN` program and the subroutines `HOWFAR`

* User Code for Testing Sampling Routines

and AUSGAB. Usually, MAIN will perform any initialization needed for the geometry routine, HOWFAR, and set the values of certain EGS4 COMMON variables which specify such things as names of the media to be used, the desired cutoff energies, and the unit of distance (*e.g.*, centimeters, radiation lengths, etc.). MAIN then calls the HATCH subroutine, which "hatches" EGS by doing once-only initialization and by reading from the data sets prepared by PEGS for the materials requested.

This initialization completed, MAIN may then call SHOWER when desired. Each call to SHOWER results in the generation of one EGS history. The arguments to SHOWER specify the parameters of the incident particle. Therefore, the user has the freedom to use any source distribution desired.

12.2.4 Mortran3 Macros and EGS User Codes

The flow of control and data when a user-written program is using the EGS4 code is illustrated in Fig. 12.1.

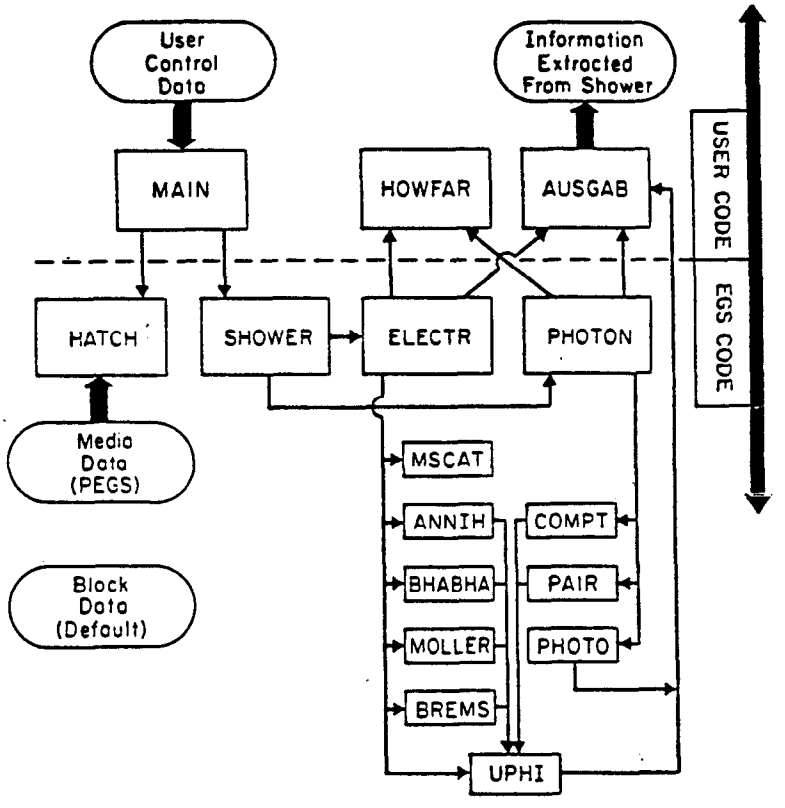

Figure 12.1. Flow control with user using EGS4.

The detailed information needed to write such user programs, commonly referred to as User Codes, is given in the EGS4 User Manual (SLAC-265, Appendix 2). As an introduction, however, the reader might find it more useful to study first the series of short tutorials provided in Chapter 3 of SLAC-265.

The entire EGS4 Code System is written in a structured language called Mortran3, a FORTRAN-like language that has been developed at SLAC by Cook[27], and which contains a *macro-facility* that is very useful. EGS4 contains many macros (*i.e.*, definitions), most of which are quite simple once they are understood. Buried within EGS4 are *patterns* (also called *templates*), which are no more than strings that get replaced by other strings. Stated explicitly, the Mortran string processor searches throughout EGS4 (and the User Code) for a specified pattern. If a match is found, the *template part* gets replaced by the *replacement part*. It is not our intention to discuss Mortran3 in any detail at this time, but it seems appropriate to demonstrate the power of the Mortran macro-facility by means of a simple example.

Let us assume that the user wants to change the way charged particles are transported by EGS. This is really quite easy to do at the User Code level (*i.e.*, above the dashed line in Fig. 12.1). The macro pattern

```
$CHARGED-TRANSPORT;
```

has been specifically located within `SUBROUTINE ELECTR` so that during the so-called "Mortran-step", just prior to the usual FORTRAN compilation, a search and replacement can be done. Located within a file called EGS4MAC MORTRAN* (provided on the EGS4 Distribution Tape) is a macro

```
REPLACE {$CHARGED-TRANSPORT;}
   WITH {X(NP)=X(NP)+U(NP)*VSTEP;
         Y(NP)=Y(NP)+V(NP)*VSTEP;
         Z(NP)=Z(NP)+W(NP)*VSTEP;} ,
```

which is the default replacement that is used with EGS4—*i.e.*, a simple linear translation along the direction of motion (`U,V,W`) by the scale factor `VSTEP` (the step length).

The important point is that the user can *override* the above macro by placing one of his choice within the User Code. For example,

```
REPLACE {$CHARGED-TRANSPORT;} WITH {CALL MYTRAN};
```

would be invoked first and the default macro (in EGS4MAC MORTRAN) would never find a pattern to replace. Of course, the user must now supply `SUBROUTINE MYTRAN` or an error message will occur during the FORTRAN compilation. Alternatively, the replacement part (`CALL MYTRAN`) could be the entire subroutine itself. Placing code directly *in-line* can sometimes help speed up a code rather dramatically.

To summarize, Mortran macros provide the user with an easy and effective way to change the EGS4 code (*i.e.*, below the dashed line in Fig. 12.1) without having to actually edit EGS4 itself. The disadvantage of this approach is that one must take the time to learn something new. The benefits can be significant, however, and the more sophisticated EGS user generally takes advantage of them.

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* EGS4MAC.MOR in VAX/VMS notation.

12.3 SOME BENCHMARK COMPARISONS

12.3.1 Conversion Efficiency of Lead for 30-200 MeV Photons

An experiment to measure the conversion efficiency for 44, 94, and 177 MeV photons incident on lead was performed by Darriulat *et al*[28] at CERN. By tagging the photons, the mean energy was determined to an accuracy of ±4 MeV. The photon beam, with an area less than 15 × 15 cm², struck a lead plate of desired thickness (1 to 20 mm) and area (20 × 20 cm²). Immediately following the lead was a large plastic scintillation detector, 28 × 40 cm² in area and 5-mm thick. An event was counted as a conversion if more than 60 keV was deposited in the scintillator for each incoming photon.

To calculate the conversion efficiency with EGS4, the geometry layout shown in Fig. 12.2 was used, consisting of four regions separated by three semi-infinite planes.

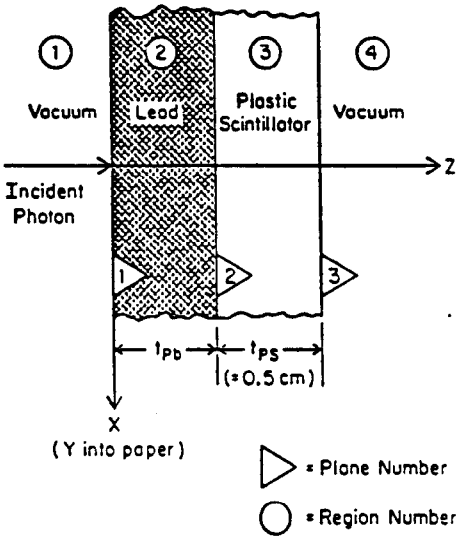

Figure 12.2. Geometry layout used in HOWFAR for simulation of the conversion efficiency experiment.

Polystyrene, with a density of 1.032 g/cm³ and consisting of hydrogen and carbon with an atomic ratio H/C=1.10, was used as the medium for plastic scintillator in region 3. The density of lead was taken to be 11.34 g/cm³. PEGS4 was used to create the necessary material data with cutoff energies of 0.1 MeV and 1.5 MeV (total energy) for photons and electrons, respectively.

The HOWFAR subprogram portion of the User Code* utilized the macro form of three auxiliary geometry subroutines, PLAN2P, PLANE1 and CHGTR**. The AUSGAB (scoring and/or outputting) subroutine was set up to sum the energy deposition in the plastic (region 3) for each photon. Upon completion of a photon shower initiated by a CALL SHOWER statement in the MAIN driver program, a conversion event was scored, provided that the energy sum in the plastic exceeded 0.060 MeV as dictated by the discrimination level established in the experiment.

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* The EGS4 User Code: UCCONEF1

** These subprograms are described both in SLAC-265 and in Chapter 17.

The results of the calculation are compared with the experimental data in Fig. 12.3. The agreement is extremely good over the entire lead thickness range for the two energies shown.

In the text describing the experimental results, Darriulat *et al* point out that the energy distribution in the scintillator showed characteristic peaks corresponding to the production of one, two, or three secondary electrons that are produced in the lead and lose energy as they pass through the scintillator. To check out this observation, the total energy deposition in the scintillator per incident photon was histogrammed, and typical results are shown in Fig. 12.4. Two of the three electron peaks are indeed prominent and are located where one would expect them to be based on a stopping power of ~ 2 MeV-cm^2/g. This experiment is well-defined and easily simulated. One can conclude that EGS4 can predict photon conversion efficiencies rather well, at least in the energy range 30-200 MeV and for geometries similar to the one described here.

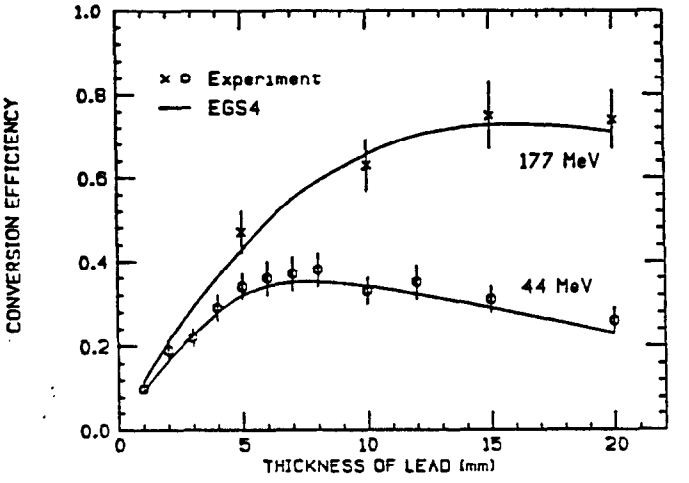

Figure 12.3 Absolute comparison of EGS4 simulation with a conversion efficiency experiment by Darriulat *et al*[28].

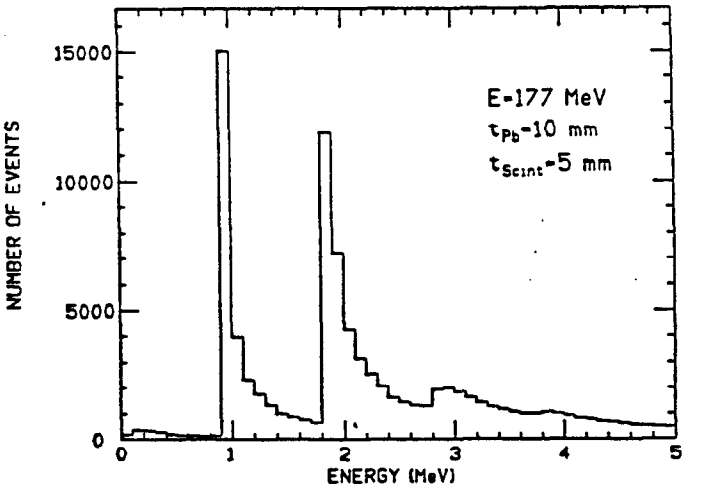

Figure 12.4. Energy distribution in the scintillator (EGS4 calculation).

12.3.2 Large, Modularized NaI(Tl) Detector Experiment

The application of large, modularized NaI(Tl) detectors to physics experiments, particularly those involving photon spectroscopy around high-energy electron-positron storage rings, has increased considerably during the last decade. An report by Ford *et al*[29] describes an experiment that was performed at SLAC to measure, among other things, the energy resolution of a typical detector array consisting of 19 NaI(Tl) hexagonal modules. Although each module itself cannot be expected to provide good energy resolution at high photon or electron energies—due to the transverse spread of energy in the EM shower (*i.e.*, leakage)—this problem is overcome in a detector made up of an array of such modules.

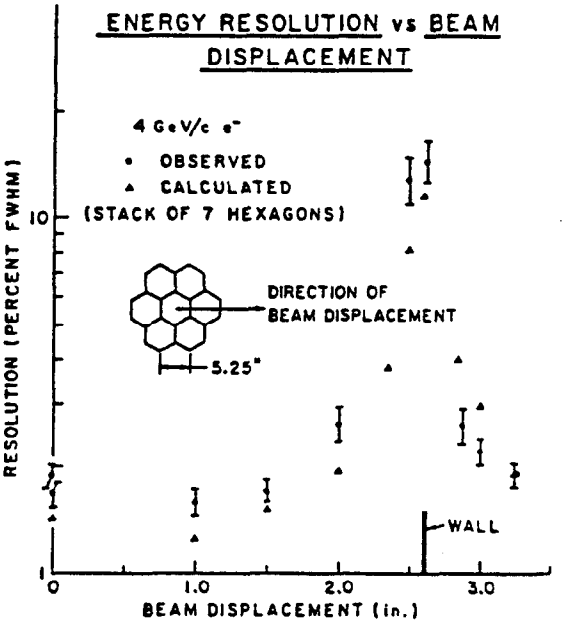

Figure 12.5. Comparison between the observed and calculated (EGS3) resolution at 4 GeV/c as a function of the displacement of the 0.25 × 0.25 in.^{2} beam (from Ford *et al*[29]).

Each hexagon was encapsulated in a stainless steel container with a wall thickness of 0.51 mm. The individual crystals were optically coupled at one end to a 0.5-inch thick glass window, through which the crystal volume was viewed by a 3-inch diameter photomultiplier tube. The stainless steel walls cause undesirable effects when the beam trajectory approaches closely or intercepts them, as illustrated in Fig. 12.5. In this figure, the variation of the energy resolution at 4 GeV/c for an array of 7 modules is shown as a function of the displacement of the trajectory from the axis. No significant loss in the resolution is experienced until the trajectory approaches within about 0.5 inch of the nearest wall. The agreement with the measurements is quite good.

The calculated and observed response of the modular array of 19 hexagons to 0.1 to 4 GeV/c electrons incident along the axis of the central module is summarized in Fig. 12.6. This figure shows not only the energy resolution obtained when the energies deposited in all 19 crystals are summed, but also those obtained when only the energies

in the central 7 modules or in the central module alone are used. The agreement is observed to be very good. EGS takes into account both the energy leakage fluctuations from the detector volume and fluctuations due to energy absorption in the stainless steel walls surrounding each crystal module. Also shown in Fig. 12.6 is the EGS simulation of 19 crystals without walls—*i.e.*, the best resolution possible with such a system.

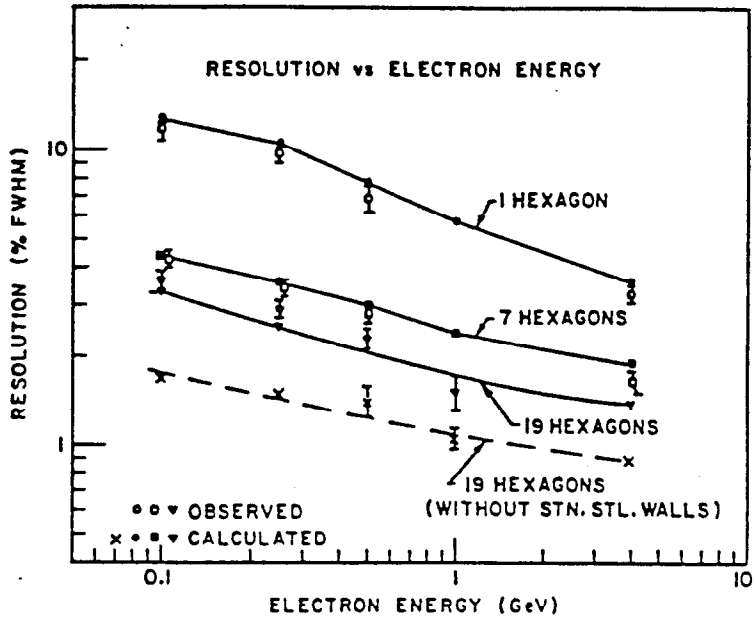

Figure 12.6. Comparison between the observed and calculated (EGS3) resolution for detectors consisting of 1, 7, or 19 hexagons (from Ford *et al*[29]).

12.3.3 Longitudinal and Radial Showers in Water and Aluminum at 1 GeV

An experiment was performed by Crannell *et al*[30] to measure the three-dimensional distribution of energy deposition for 1-GeV showers in water and aluminum. The water target consisted of a steel tank containing 8000 liters of distilled water. The incident beam, less than 1 mm in diameter, entered the water through a 0.13-mm thick aluminum window centered on the square end of the tank ($122 \times 122 \times 460$ cm^3). The aluminum target, on the other hand, consisted of plates varying in thickness from 0.64 to 2.5 cm, pressed together to form a solid target ($61 \times 61 \times 180$ cm^3).

Differential, as well as integral, energy deposition data obtained from this experiment afford a good benchmark comparison, particularly since

i) a reasonably good comparison has been made using the Zerby and Moran code[11–13,16], and

ii) Crannell indicates in the paper that the Nagel code (*i.e.*, SHOWER) does not give radial distributions in agreement with the experiment (note: since EGS descends from SHOWER, we are obligated to make this comparison).

The User Code for this calculation* makes use of \$CYLNDR and \$PLAN2P, geometry macros contained within the EGS4MAC MORTRAN file on the EGS4 Distribution Tape. Another useful subprogram, ECNSV1, provides a convenient way to keep track of where and how energy is deposited in each cylindrical shell-slab region.

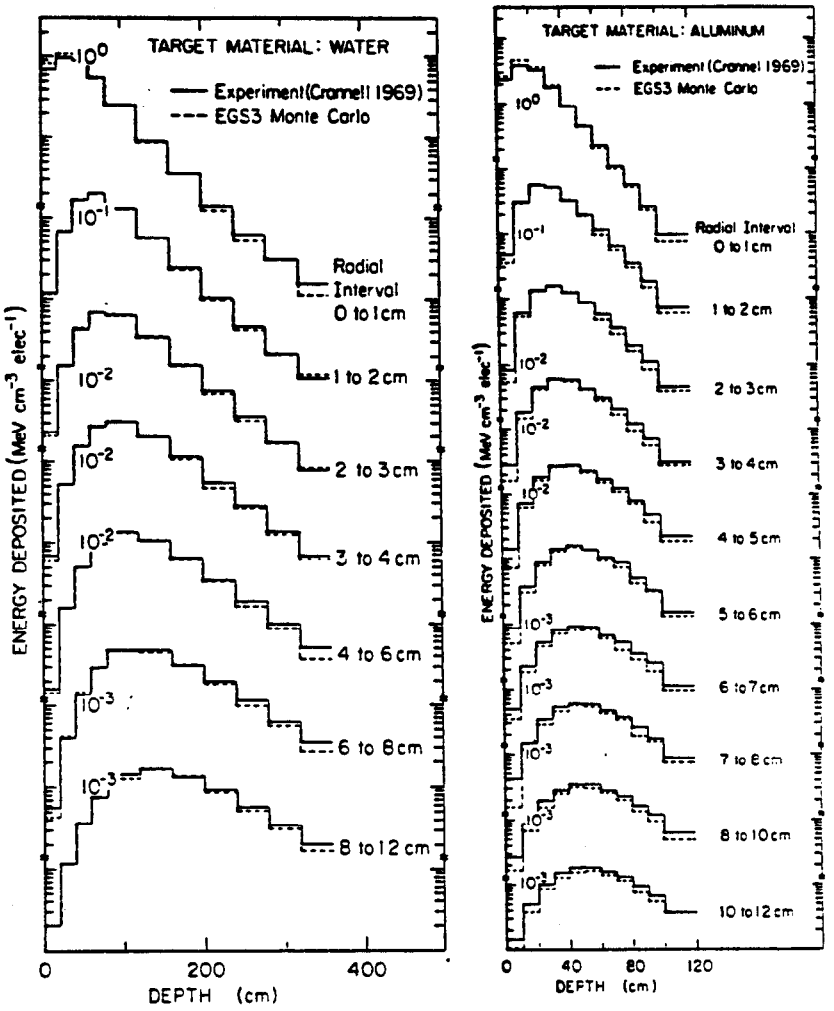

Figure 12.7. Comparison of EGS with the Crannell *et al*[30] shower experiment in water and aluminum at 1 GeV.

A comparison of the Crannell data with EGS3 is given in Fig. 12.7. The agreement is extremely good everywhere for the water case and reasonably good for the aluminum experiment. The slight discrepancy at large radii in the aluminum comparison is possibly attributed to a a mismatch between detector and absorber. CaF_2(Eu) was used as a scintillation detector in the aluminum experiment, whereas anthracene which is a much better match, was used in the water case. Crannell goes into considerable discussion on this in the paper, and the reader is referred to this reference. The calculations have also been repeated using EGS4[31], and similar results were obtained.

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* UCH2OAL

12.3.4 Track-Length Calculations

Track-length calculations are most easily done with EGS by summing the length of the step, TVSTEP, in SUBROUTINE AUSGAB each time a transport (IARG=0) takes place. In the case of photon track lengths, the calculation is simplified because the photon does not lose energy during transport between events. Charged particles, on the other hand, lose energy during the step, and the method of scoring is correspondingly more complicated. The comparisons made below were done using the EGS3 code. However, the same results have also been obtained using EGS4.

Differential photon track length.
Alsmiller[32] has used the Zerby and Moran code[11-13] to calculate the differential photon track length for the specific case of 18-GeV electrons incident on a cylindrical copper target having a radius of 11.5 cm and a thickness of 24.5 cm. The results are compared with similar data obtained using EGS3, as shown in Fig. 12.8 where ageement between the codes is quite apparent. Also shown is a solid line corresponding to the track-length formula of Clement[33].

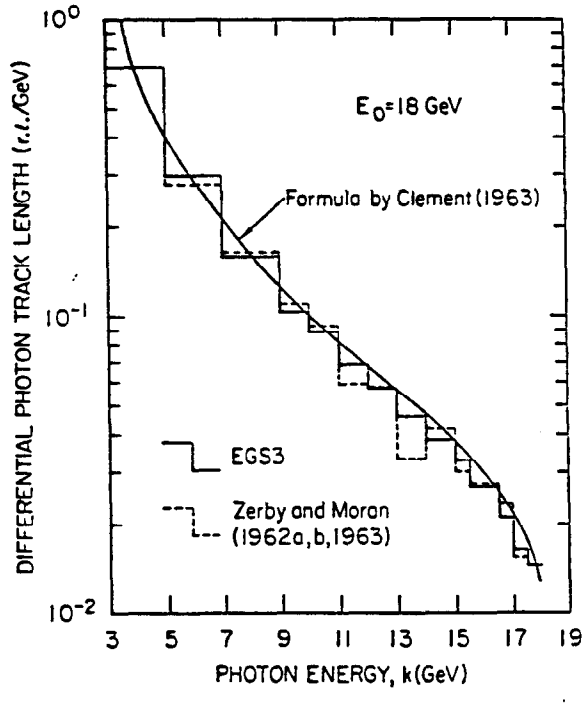

Figure 12.8. Differential photon track length. Comparison of EGS with Monte Carlo results using the Zerby and Moran code.

Differential electron track length.
In order to score the charged particle track length in SUBROUTINE AUSGAB properly, account must be taken of the continuous energy loss along the track. By determining the energy of the particle at the beginning and the end of the track, the total track length can be fractionated, sorted, and summed in histogram bins corresponding to energy (an example of a track-length scoring algorithm is given in SLAC-210[2]).

Figure 12.9 compares the charged particle track length, as calculated by EGS3, with that of Zerby and Moran[11-13] for three electron beams (50, 200, and 700 MeV) incident on a 100 cm thick, semi-infinite slab of copper. Cutoff energies of 10 MeV were used in both Monte Carlo simulations, which agree quite well with each other. The same results have also been obtained with EGS4.

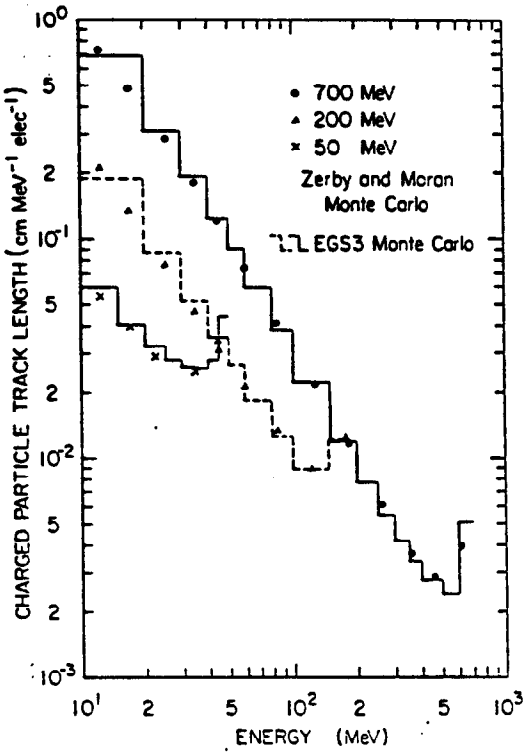

Figure 12.9. Differential electron track length. Comparison of EGS with Monte Carlo results using the Zerby and Moran code.

12.4 SUMMARY OF EGS4 CAPABILITIES AND FEATURES

The following is a summary of the main features of the EGS4 Code System, including statements about the physics that has been put into it and what can realistically be simulated.

- The radiation transport of electrons (+ or −) or photons can be simulated in any element, compound, or mixture. That is, the data-preparation package PEGS4 creates data to be used by EGS4, using cross-section tables for elements 1 through 100.

- Both photons and charged particles are transported in random rather than in discrete steps.

- The dynamic range of charged particle kinetic energies goes from a few tens of keV up to a few thousand GeV. Conceivably, the upper limit can be extended higher, but the validity of the physics remains to be checked.

- The dynamic range of photon energies lies between 1 keV and several thousand GeV (see above statement).

- The following physics processes are taken into account by the EGS4 Code System:

  - Bremsstrahlung production (excluding the Elwert correction at low energies).

  - Positron annihilation in flight and at rest (the annihilation quanta are followed to completion).

  - Molière multiple scattering (*i.e.*, Coulomb scattering from nuclei). The reduced angle is sampled from a continuous (rather than discrete) distribution. This is done for arbitrary step sizes, selected randomly, provided that they are not so large or so small as to invalidate the theory.

  - Møller (e^-e^-) and Bhabha (e^+e^-) scattering. Exact rather than asymptotic formulae are used.

  - Continuous energy loss applied to charged particle tracks between discrete interactions.

    - Total stopping power consists of soft bremsstrahlung and collision loss terms.

    - Collision loss determined by the (restricted) Bethe-Bloch stopping power with Sternheimer treatment of the density effect.

  - Pair production.

  - Compton scattering.

  - Coherent (Rayleigh) scattering may be modelled using an independent-atoms approximation (non-default option in EGS4). by means of an option.

  - Photoelectric effect.

    - Neither fluorescent photons nor Auger electrons are produced or transported in the default version of `SUBROUTINE PHOTO`.

    - Other *user-written* versions of `PHOTO` can be created, however, that allow for the production and transport of K- and L-edge photons [see, for example, the discussion of the EGS4 User Code called UCEDGE in Chapter 4 of SLAC-265)].

- PEGS4 is a stand-alone data preprocessing code consisting of 12 subroutines and 85 functions. The output is in a form for direct use by EGS4.
  - PEGS4 constructs piecewise-linear fits over a large number of energy intervals of the cross-section and branching-ratio data.
  - In general, the user need only use PEGS4 *once* to obtain the media data files required by EGS4.
  - PEGS4 control input uses the `NAMELIST` read facility of the FORTRAN language (in Mortran3 form).
  - In addition to the options needed to produce data for EGS4, PEGS4 contains options to plot any of the physical quantities used by EGS4, as well as to compare sampled distributions (produced by the UCTESTSR User Code) with theoretical spectra.
- EGS4 is a package of subroutines plus block data with a flexible user interface.
  - This allows for greater flexibility without requiring one to be overly familiar with the internal details of the code.
  - Together with the macro facility capabilities of the Mortran3 language, this reduces the likelihood that user edits will introduce bugs into the code.
  - Flow diagrams for the 13 subroutines of EGS4 are given in Appendix I of SLAC-265.
  - EGS4 uses material cross-section and branching-ratio data created and fit by the companion code, PEGS4.
- The geometry for any given problem is specified by a *user-written* subroutine called `HOWFAR` which, in turn, can make use of auxiliary subprograms.
  - Auxiliary geometry routines for planes, cylinders, cones, spheres, etc., are provided with the EGS4 Code System for those who do not wish to write their own.
  - Macro versions of these routines are also provided in the set of defining macros (*i.e.*, in the EGS4MAC file) which, if used, generally result in a faster running simulation.
  - The MORSE-CG Combinatorial Geometry package can be incorporated into `HOWFAR` (*e.g.*, see the UCSAMPCG file on the EGS4 Distribution Tape). However, experience indicates that a much slower simulation generally results (of the order of at least a factor of four).
  - Transport can take place in a magnetic field by writing a specially designed `HOWFAR` subprogram (*e.g.*, see Section 4.2 of SLAC-265[1]). Transport in both electric and magnetic fields can be simulated in a more general manner (*e.g.*, see Chapter 19) by making use of Mortran3 macro templates that have been appropriately placed for that purpose in `SUBROUTINE ELECTR`.

- The user scores and outputs information in the *user-written* subroutine called AUSGAB.
  - Auxiliary SUBROUTINE ECNSV1 is provided in order to keep track of energy for conservation (or other) purposes.
  - Auxiliary SUBROUTINE NTALLY is provided in order to keep track of the number of times energy has been scored into the ECNSV1 arrays (*i.e.*, an *event counter*).
  - Auxiliary SUBROUTINE WATCH is provided in order to allow an event-by-event or step-by-step tracking of the simulation.
- EGS4 allows for the implementation of *importance sampling* and other variance-reduction techniques—*e.g.*, splitting, path-length biasing, Russian roulette, leading-particle biasing, etc.
- Initiation of the radiation transport:
  - An option exists for initiating a shower with two photons from π^0 decay (*i.e.*, use IQI=2 in the CALL SHOWER statement).
  - The user has the choice of initiating the transport by means of a monoenergetic particle, or by sampling from a known distribution (*e.g.*, a synchrotron-radiation spectrum).
  - Transport can also be initiated from sources that have spatial and/or angular distributions.

12.5 EGS4 GRAPHICS CAPABILITIES

EGS4 has been coupled* with the SLAC Unified Graphics System (UGS77)[34] to provide a means for displaying particle tracks on UGS77-supported devices[35] . This is done by inserting CALL SHOWPL statements at appropriate places in the EGS4 User Code, attaching an auxiliary subprogram package (SHOWGRAF), and creating SUBROUTINE HOWPL to *match* HOWFAR. SHOWGRAF may be used to create shower displays directly on an interactive IBM-5080 color terminal, supporting three-dimensional rotations, translations, and zoom features, and providing illustration of particle types and energies by color and/or intensity.

Alternatively, SHOWGRAF can produce graphics output data which are subsequently operated on by a post-processor system (EGS4PL)[36] for display on two-dimensional devices supported by UGS77. Options exist within EGS4PL that allow for two-dimensional translations and zoom, for creating line structure to indicate particle types and energies, and for turning off particle types altogether. Examples of shower pictures created with the SHOWGRAF package are provided in Figs. 28.2-4, Figs. 28.13-14, and Figs. 28.28.15-16 of Chapter 28.

EGS4PL currently runs under IBM VM/SP and VAX VMS operating systems.

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* This is a recent addition not found in the EGS4 manual.

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