A Basic Monte Carlo Course (Electron Gamma Shower)

Speaker: Dr. Joel Y.C Cheung
Date: 5th Mar 2016, 10:00-13:00
Venue: Room Y302, PolyU, HK

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Monte Carlo – A Statistical Calculation, problem solving

2

Probability of drawing 6 ?

1) Perform an actual experiment !

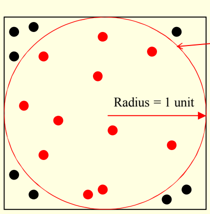
2) Using the Monte Carlo technique!

3

Monte Carlo - π Calculation

4

Calculation of π using the Monte Carlo method



$$x^2 + y^2 = 1$$

History run = 19

$$\pi = \text{Area of the square} \times \frac{\text{no: of red dots}}{\text{no: of black and red dots}}$$

$$= 4 \times \frac{11}{19} = 2.32$$

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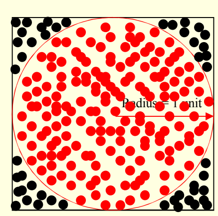
Calculation of π using the Monte Carlo method – cont.



History run = ~200

$$\pi = \text{Area of the square} \times \frac{\text{no: of red dots}}{\text{no: of black and red dots}}$$

$$= 4 \times \frac{150}{200} = 3.0$$

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Monte Carlo – Sales Forecast

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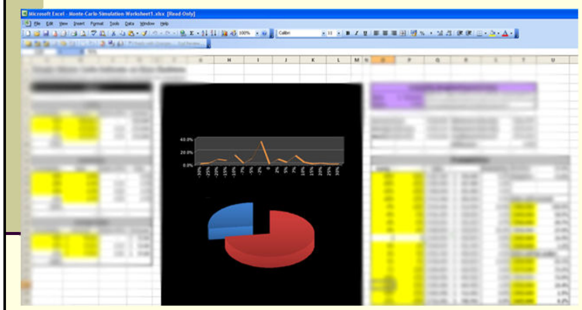
Sales Forecast Monte Carlo Simulation



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Monte Carlo in Radiation Physics

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Monte Carlo in Radiation Physics

- Monte Carlo modeling of particle transport problems in medical and radiation physics gives more advantages than other techniques.
- Experiments can be done without setting up the physical situation, and results of some "impossible" experiments can be obtained.
- e.g. scoring the numbers of created particles or calculating the relative OPFs of narrow beams.

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Determine by Random Numbers ?

Photon or Charge Particle

<u>Before Interaction</u>
Position ? (X,Y,Z)
Moving Direction ? (U,V,W)
Energy ? (E)

<u>After Interaction / Next Step</u>
Position ? (X,Y,Z)
Moving Direction ? (U,V,W)
Energy ? (E)
Energy Deposition (EDEP)

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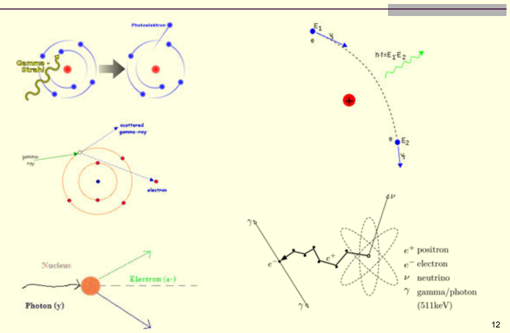
Radiation Interactions



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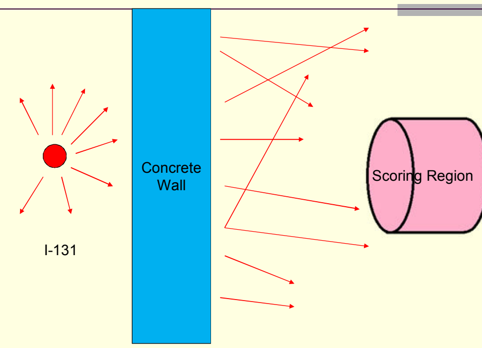
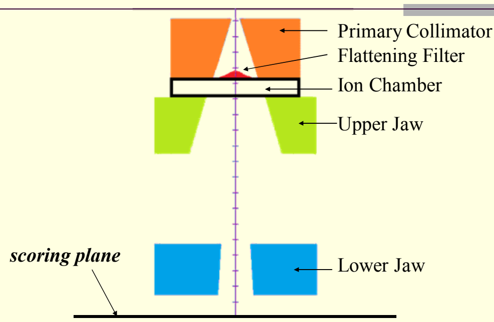
Disadvantage of Monte Carlo Technique

History Runs ~ 1000000

Application: Radiation Protection



Application: Linear Accelerator Simulation



Application: Linear Accelerator Simulation (PDD)

Dose calculations by AAA for stereotactic radiotherapy in NPC 401

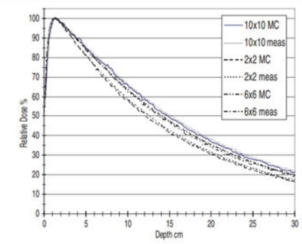
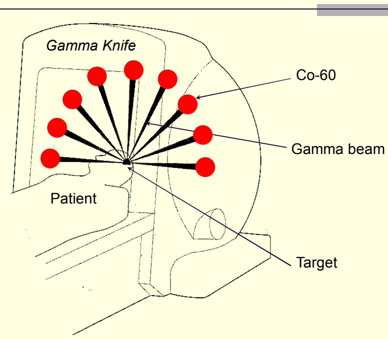


Figure 2. The Monte Carlo simulated and measured percentage depth dose curve in a homogeneous water phantom matches for various field sizes.

Application: Radiosurgery



Application: Radiosurgery (Gamma Knife)

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11. Cheung JY, Yu KN, Yu CP, Ho TK Robert, Choice of phantom materials for dosimetry of Leksell Gamma Knife unit: a Monte Carlo study, Medical Physics, Oct 2002, 29(10) p2260-1
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15. Joel Y.C. Cheung, K.N. Yu, Josie F.K. Chan, Robert T.K. Ho, and C.P. Yu, Dose Distribution Close to Metal Implants in Gamma Knife Radiosurgery: A Monte Carlo study, Medical Physics, July 2003, Volume 30, Issue 7, pp. 1812-1815.
16. C.P. Yu, Joel Y.C. Cheung, Joise F. K. Chan, Samuel C. L. Leung, Robert T.K. Ho, Prolonged Survival in a Subgroup of Patients with Brain Metastases Treated by Gamma Knife Surgery, Journal of Neurosurgery, Vol. 102 Special Supplement, pp 262, January 2005.
17. Joel YC Cheung, KN Yu, LETTER TO THE EDITOR: "Dose Distribution Close to Metal Implants in Gamma Knife Radiosurgery: A Monte Carlo Study, Med. Phys., July 2003, Volume 30, Issue 7, pp. 1812-1815", Medical Physics, Volume 32, Issue 5, 1448-1449, 2005.
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Application: Radiosurgery (X-Knife)

Dose enhancement close to platinum implants for the 4, 6, and 10 MV stereotactic radiosurgery

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(Received 28 April 2004; revised 12 July 2004; accepted for publication 3 August 2004; published 15 September 2004)

Three photon interaction processes, namely, the photoelectric effect, Compton effect, and pair production, can occur when materials with high atomic numbers are irradiated by the high- and low-energy bremsstrahlung photons from a linear accelerator. A dose enhancement, due to the photoelectric effect and pair production, near targets with platinum implants (with a high atomic number) in radiosurgery cannot be predicted by the XKnife® radiosurgery treatment planning system. In the present work, Monte Carlo simulations using PRESTA EGS4 were employed to investigate the resulting dose enhancements from 4, 6, and 10 MV energies commonly used in the stereotactic radiosurgery system. Dose enhancements from 32% to 68% were observed close to the platinum implant for the above energies when using a 12.5 mm collimator. Comparatively higher dose enhancements were observed when using smaller collimators. It was found that this dose enhancement increased with beam energy but decreased as beam size increased. © *2004 American Association of Physicists in Medicine.* [DOI: 10.1118/1.1797531]

Key words: XKnife®, Leksell Gamma Knife®, stereotactic radiosurgery, EGS4 Monte Carlo, platinum implant

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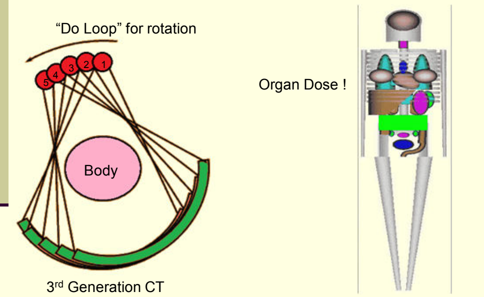
Application: CT Simulation



http://www.doseinfo-radar.com/RADARphan.html

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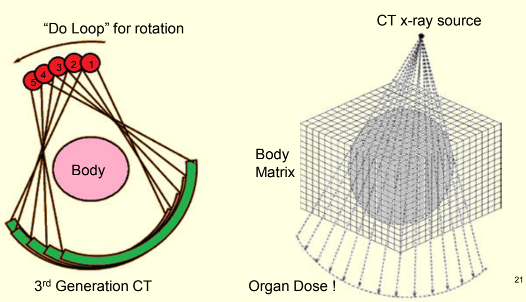
Application: CT Simulation



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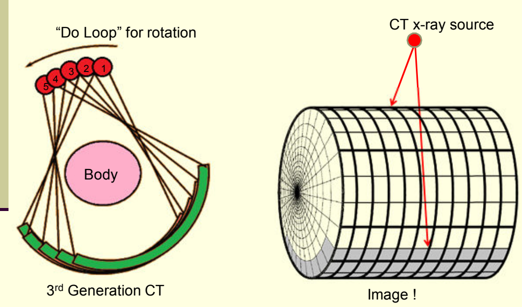
Application: CT Simulation



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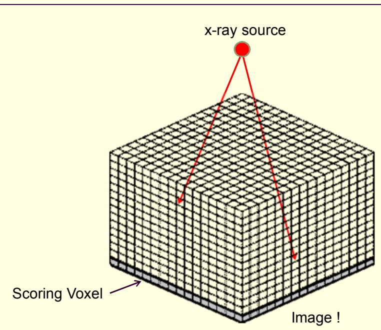
Application: DRR Simulation



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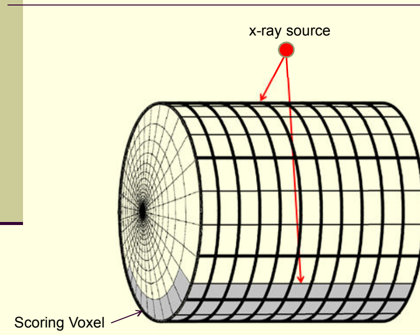
Application: DRR Simulation



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Application: Radiography

Health Physics:
October 2007 - Volume 93 - Issue 4 - pp 267-272
doi: 10.1097/01.HP.0000264450.81683.51
Paper

THE CALCULATION OF DOSE ENHANCEMENT CLOSE TO PLATINUM IMPLANTS FOR SKULL RADIOGRAPHY

Cheung, Joel Y.C.*; Tang, Fuk-hay†

Abstract

Materials with high atomic numbers experience the occurrence of the photoelectric effect when they are irradiated by low energy photons. A short range dose enhancement, due to the dominant photoelectric effect, close to platinum implants ($Z = 78$) in diagnostic radiography cannot be easily measured experimentally. The enhanced dose may increase the risk for adverse health effects from cancer or may damage vital brain structures close to the high atomic number implants. In the present work, Monte Carlo simulation using the LSCAT version of PRESTA EGS4 was employed to investigate the resulting dose enhancements. The results show that the highest estimated dose enhancement of 79% for brain tissues close to platinum implants was calculated for 65 kV x-ray energy and 180% for 120 kV x-ray energy.

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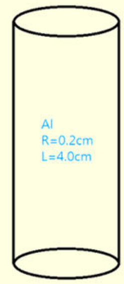
Application: Brachytherapy Source



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Application: Brachytherapy Source

Phys. Med. Biol. 42 (1997) 401–406. Printed in the UK PII: S0031-9155(97)73288-3

The dose distribution close to an ^{192}Ir wire source: EGS4 Monte Carlo calculations

Y C Cheung†, Peter K N Yu†, E C M Young†, C
Francis Tang‡
† Department of Physics and Materials Science, City Universit
‡ Department of Radiotherapy and Oncology, Queen Elizabetl
Kong

Received 29 March 1996, in final form 18 October 1996

Abstract. A Monte Carlo simulation using the PRESTA ver
employed as an investigative tool to calculate the absorbed d
implants. It has been shown that a treatment planning system,
Sievert integral and the Meisberger polynomial is only able to r
at radial distances of 1 mm and farther away. The Sievert in
polynomial is proven to be in good agreement with the Monte
between 1 mm and 1 cm.

Pergamon
Appl. Radiat. Isot. Vol. 48, No. 7, pp. 965–990, 1997
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0969-8043/97 $17.00 + 0.00
PII: S0969-8043(96)00280-1

The Electron-dose Distribution Surrounding An ^{192}Ir Wire Brachytherapy Source Investigated using EGS4 Simulations and GafChromic™ Film

Y. C. CHEUNG[1], PETER K. N. YU[1], E. C. M. YOUNG[1], C. L. CHAN[2], M. F. NG[2], FRANCIS N. F. TANG[2] and TONY P. Y. WONG[3]

[1]Department of Physics and Materials Science, City University of Hong Kong, Kowloon, Hong Kong, [2]Department of Radiotherapy and Oncology, Queen Elizabeth Hospital of Hong Kong, Hong Kong and [3]Austin & Repatriation Medical Centre, Victoria 3081, Australia

(Received 7 June 1996; in revised form 15 August 1996)

The steep dose gradient around ^{192}Ir brachytherapy wire implants is predicted by the EGS4 (PRESTA version) Monte Carlo simulation. When considering radiation absorbing regions close to the wire source, the accurate dose distribution cannot be calculated by the GE Target II Sun Sparc treatment-planning system. Experiments using GafChromic™ film have been performed to prove the validity of the EGS4 user code when calculating the dose close to the wire source in a low energy range. © 1997 Elsevier Science Ltd

Monte Carlo Packages

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Monte Carlo packages

The availability of standardized Monte Carlo packages such as:

- EGS4 : EGSNRC / EGS5
- BEAM
- ETRAN/ITS
- PENELOPE
- MCNP
- GEANT

along with the development of more powerful and inexpensive computers has allowed more widespread use of the technique.

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EGS4 – Electron Gamma Shower

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EGS4 (Electron Gamma Shower) code

Standford Linear Accelerator Center
- by Nelson, Harayama and Rogers.

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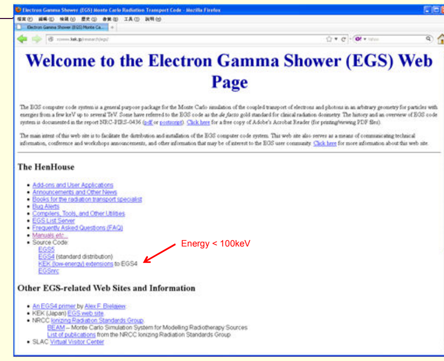
http://rcwww.kek.jp/research/egs/



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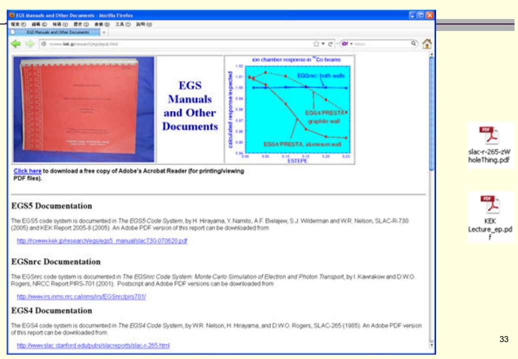
http://rcwww.kek.jp/research/egs/epub.html



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http://rcwww.kek.jp/research/egs/egs5.html

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EGSnrc Code

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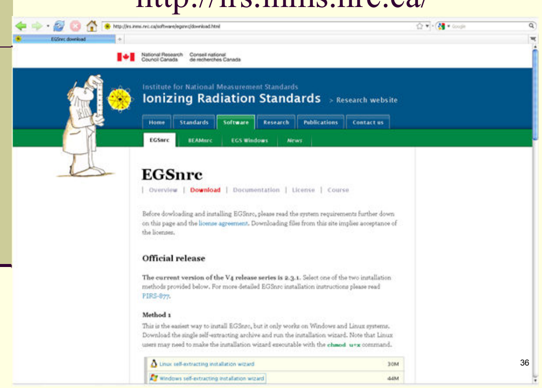
http://irs.inms.nrc.ca/



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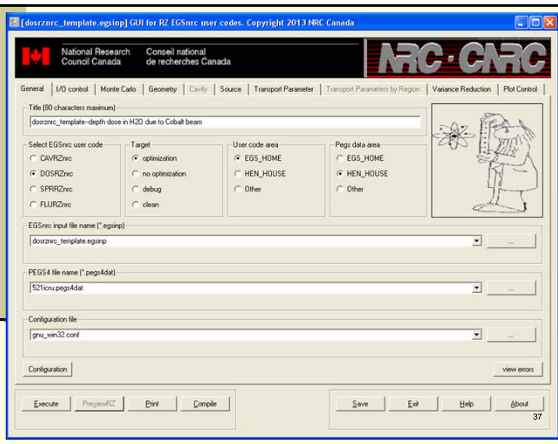

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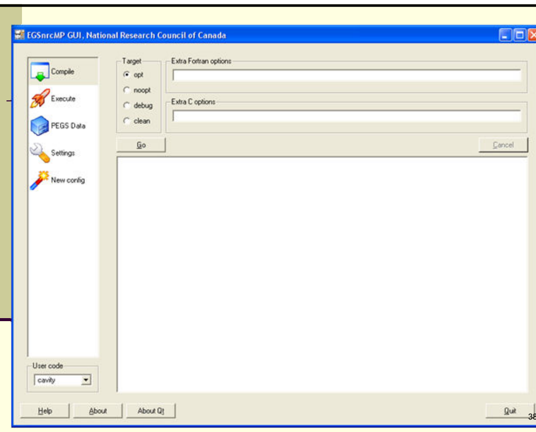

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Fortran Compilers

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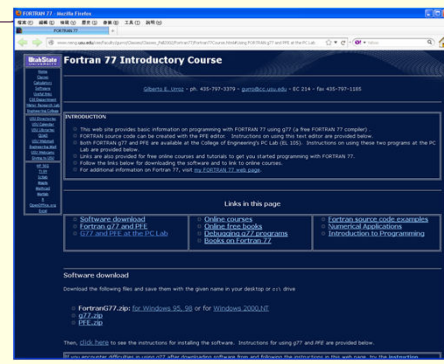
Fortran Compilers



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Pseudorandom Number Generators

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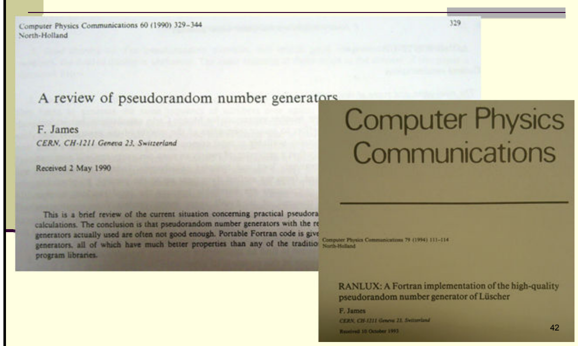
Pseudorandom Number Generators


Computer Physics Communications 60 (1990) 329–344
North-Holland

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A review of pseudorandom number generators

F. James
CERN, CH-1211 Geneva 23, Switzerland

Received 2 May 1990

This is a brief review of the current situation concerning practical pseudora[…] calculations. The conclusion is that pseudorandom number generators with the re[…] generators actually used are often not good enough. Portable Fortran code is give[…] generators, all of which have much better properties than any of the traditio[…] program libraries.

Computer Physics Communications

RANLUX: A Fortran implementation of the high-quality pseudorandom number generator of Lüscher

F. James

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Pseudorandom Number Generators

F. James / A review of pseudorandom number generators 343

Table 2
Properties of some Pseudorandom Number Generators

Generator	Randomness	Portability	Approx. period	Needed to initialize [wd]	Needed to restart [wd]	Disjoint sequences, no. × length
traditional	unreliable	poor	10^{9}	1	1	sequential
super-duper	acceptable	none	10^{18}	2	2	sequential
RANECU	good	good	10^{18}	2	2	$(10^{9} \times 10^{9})$ [a]
RANMAR	good	good	10^{43}	1	100	$10^{9} \times 10^{34}$
RCARRY	good	good	10^{170}	1	25	$10^{9} \times 10^{161}$

[a] RANECU can make independent subsequences, but not conveniently.

times are given for 1000 calls. The times given are not accurate (or even repeatable) to more than about 10%. Super-duper is in IBM assembler only. The implementation of RNDM (CERN Program Library) is very computer-dependent, but times are given to allow users to compare with a generator which they may already be using. RN32 [8] is a nearly portable Fortran function generating the same numbers on different machines.

The Fortran code for RANECU, RANMAR, and RCARRY was absolutely identical on all machines,

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EGS4 Code

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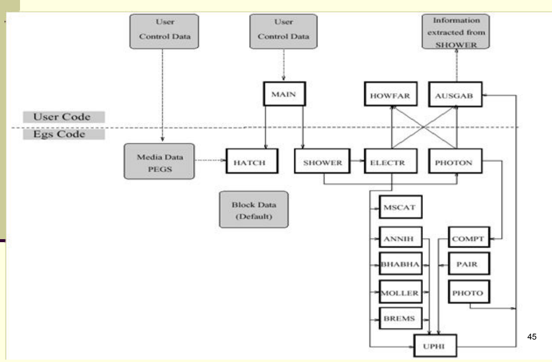
EGS4 Structure



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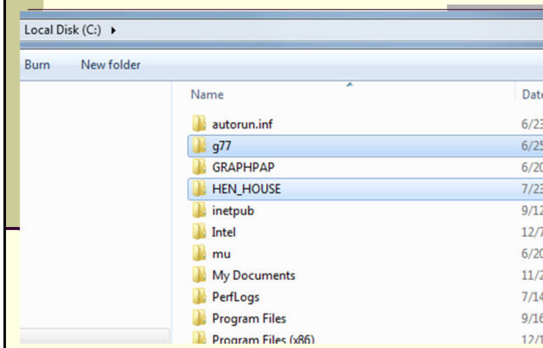
EGS4 Distribution / Fortran Compiler



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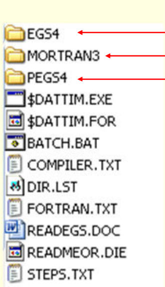
EGS4 folders on PC



Main folder

Converting code into Fortran

Creating material file(s) for radiation interaction

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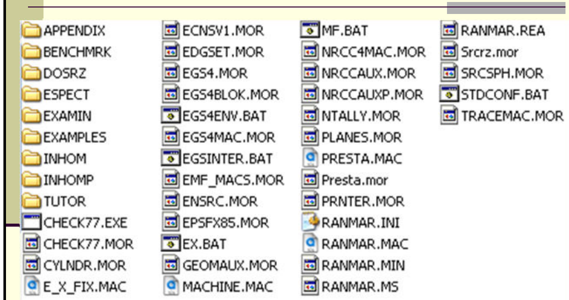
EGS4 - Main Folder



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Mortran or Fortran

KEK Lecture_ep.pdf

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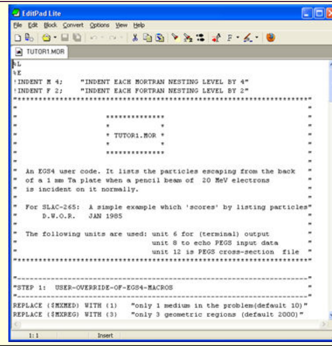
User Code: Tutor1.mor



```
%L
%E
!INDENT M 4;    "INDENT EACH MORTRAN NESTING LEVEL BY 4"
!INDENT F 2;    "INDENT EACH FORTRAN NESTING LEVEL BY 2"
"***********************************************************************"
"                                                                       "
"                       **************                                  "
"                       *            *                                  "
"                       * TUTOR1.MOR *                                  "
"                       *            *                                  "
"                       **************                                  "
"                                                                       "
"  An EGS4 user code. It lists the particles escaping from the back    "
"  of a 1 mm Ta plate when a pencil beam of  20 MeV electrons          "
"  is incident on it normally.                                         "
"                                                                       "
"  For SLAC-265:  A simple example which 'scores' by listing particles"
"      D.W.O.R.   JAN 1985                                             "
"                                                                       "
"  The following units are used: unit 6 for (terminal) output          "
"                                unit 8 to echo PEGS input data        "
"                                unit 12 is PEGS cross-section  file   "
"***********************************************************************"

"-----------------------------------------------------------------------"
"STEP 1:  USER-OVERRIDE-OF-EGS4-MACROS                                  "
"-----------------------------------------------------------------------"
REPLACE {$MXMED} WITH {1}   "only 1 medium in the problem(default 10)"
REPLACE {$MXREG} WITH {3}   "only 3 geometric regions (default 2000)"
```

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User Code: CALL SHOWER

DO J=1,1000000 [

CALL SHOWER (IQIN,EIN,XIN,YIN,ZIN,UIN,VIN,WIN,IRIN,WTIN) ;

]

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User Code: HOWFAR

```
SUBROUTINE HOWFAR;
COMIN/EPCONT,PLADTA,STACK/;

IRL=IR(NP);  "SET LOCAL VARIABLE"

IF(IRL.NE.2) [IDISC=1; "TERMINATE THIS HISTORY"]
ELSE [
$PLAN2P(IRL,IRL+1,1,IRL-1,IRL-1,-1);
]

RETURN;
END;" END OF SUBROUTINE HOWFAR
```

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User Code: AUSGAB

```
SUBROUTINE AUSGAB(IARG);
COMIN/EPCONT,SCORE,STACK,GEOM/;

IF (IARG.LE.3) [
ESCORE(ITEMP1)=ESCORE(ITEMP1)+EDEP;]
]

RETURN;END;"END OF AUSGAB"
```

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Compiling a Tutor Code

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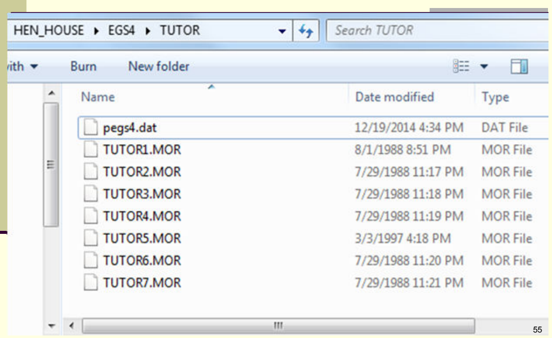
Folder Content



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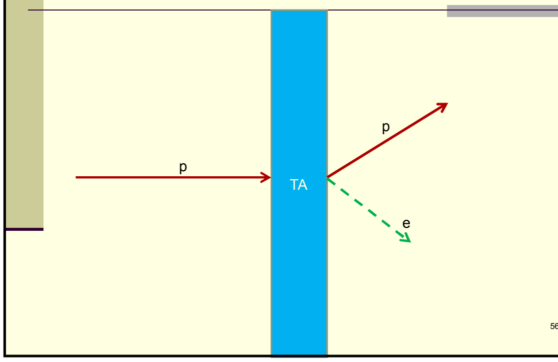
HOWFAR (Tutor1)



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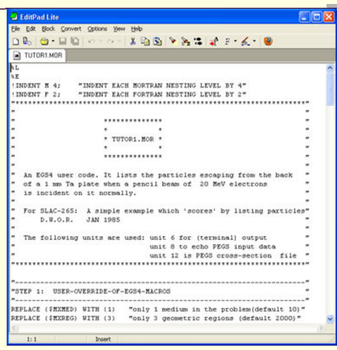
User Code: Tutor1.mor



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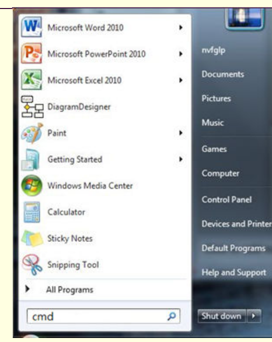
Open a DOS prompt



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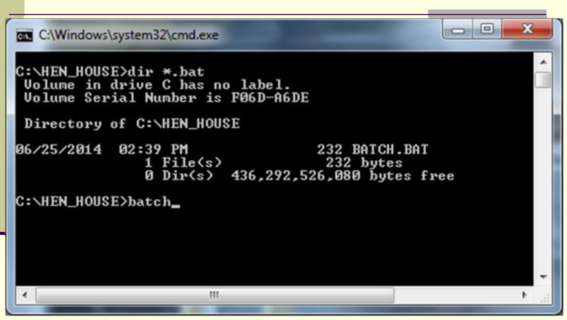
Setup Enviroment



C:\cd hen_house

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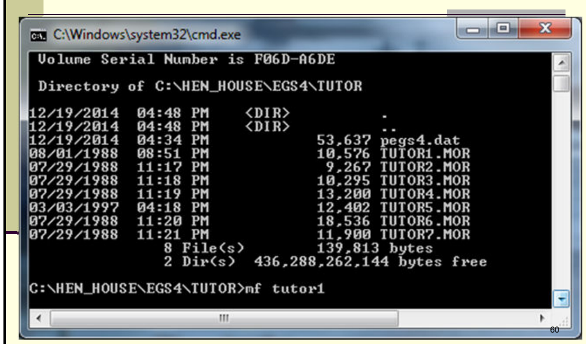
Mortran to Fortran and Compile



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Execute Tutor1

```
C:\Windows\system32\cmd.exe
Compiling ....

Could Not Find C:\HEN_HOUSE\EGS4\TUTOR\$mortjob.*
Could Not Find C:\HEN_HOUSE\EGS4\TUTOR\tutor1.exe
Could Not Find C:\HEN_HOUSE\EGS4\TUTOR\echo.dat
c:\hen_house\EGS4\EGS4MAC.MOR
c:\hen_house\EGS4\NRCC4MAC.MOR
c:\hen_house\EGS4\MACHINE.MAC
TUTOR1.MOR
c:\hen_house\EGS4\PRNTER.MOR
c:\hen_house\EGS4\EGS4BLOK.MOR
c:\hen_house\EGS4\EGS4.MOR
        1 file(s) copied.
        1 file(s) copied.

Stop - Program terminated.

 DATE: 19-DEC-2014  TIME: 17:01:50.43
C:\HEN_HOUSE\EGS4\TUTOR>ex tutor1 ta
```

Results of Tutor1

```
C:\Windows\system32\cmd.exe
                          0.491           0          30.9
                         17.669          -1          42.6
 START HISTORY   6
                          0.923           0          25.6
                         16.432          -1          17.6
 START HISTORY   7
                          0.275           0          58.3
                         17.421          -1          55.8
 START HISTORY   8
                          0.363           0          17.1
                         17.757          -1          29.0
 START HISTORY   9
                         18.450          -1          15.9
 START HISTORY  10
                          4.350           0          24.1
                          0.640           0          26.9
                          1.322           0          23.6
                         10.526          -1          32.9

C:\HEN_HOUSE\EGS4\TUTOR>_
```

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Assignment #1: Al attenuation coefficient

$$\ln\left(\frac{I_o}{I}\right) = \mu t$$

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Assignment #1: al.inp

```
al.inp
ELEM
 &INP  &END
AL                                  AL
AL
ENER
 &INP AE=0.512,UE=20.511,AP=.001,UP=20 &END
TEST
 &INP  &END
PWLF
 &INP  &END
DECK
 &INP  &END
```

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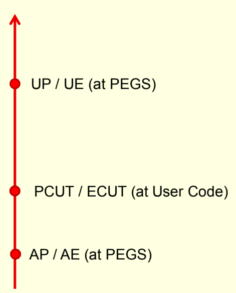
Assignment #1: Energy Cut Off



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Assignment #1: aluminum data file

```
C:\Windows\system32\cmd.exe

C:\HEN_HOUSE\PEGS4>dir *.bat
 Volume in drive C has no label.
 Volume Serial Number is F06D-A6DE

 Directory of C:\HEN_HOUSE\PEGS4

07/05/2004  11:05 PM             6,616 MAKEPEGS.BAT
07/09/2013  05:29 PM             5,049 PEGS4B.BAT
               2 File(s)         11,665 bytes
               0 Dir(s)  436,295,667,712 bytes free

C:\HEN_HOUSE\PEGS4>pegs4b al_
```

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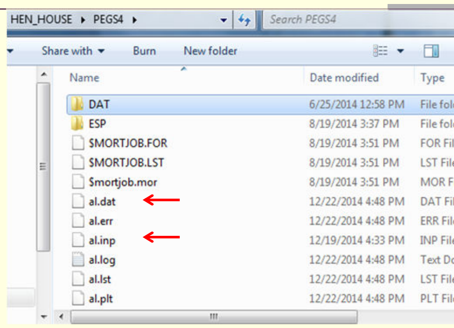
Assignment #1: al.dat



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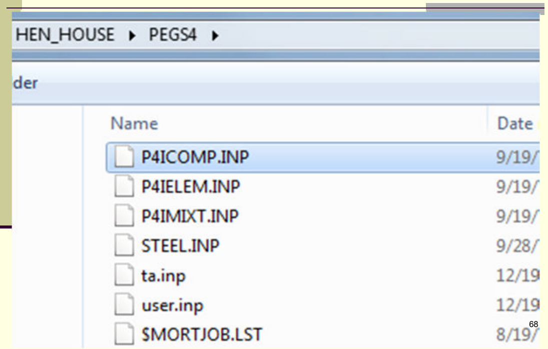
PEGS4 - Template



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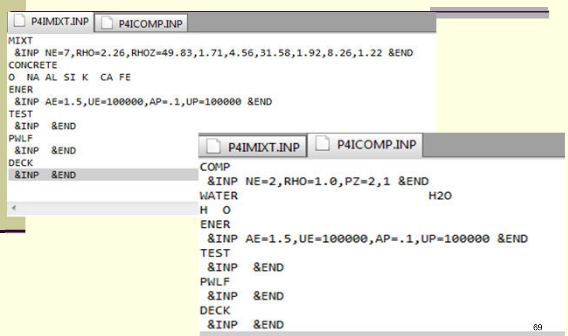
Mixture / Compound



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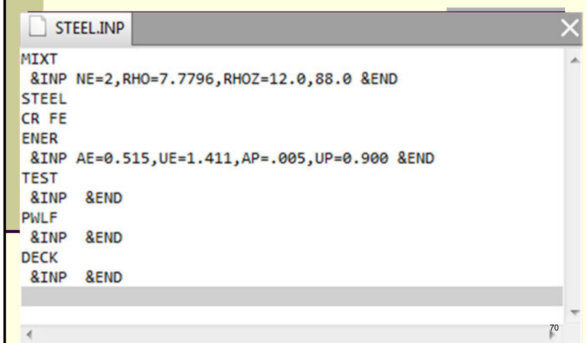
Steel



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Assignment #1: Result

$$\ln\left(\frac{I_o}{I}\right) = \mu t$$

I_0=1000000
I=438007
t=5cm
μ=0.165104 cm^{-1} (ref 0.165942 cm^{-1})

Broad Beam μ= ?

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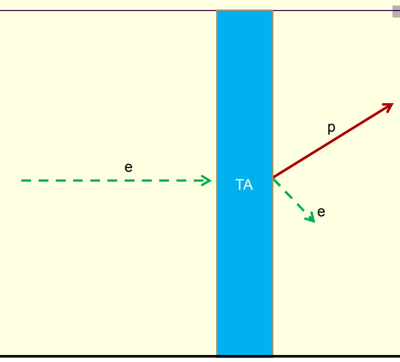
Assignment #2: Al Bremsstrahlung Spectrum



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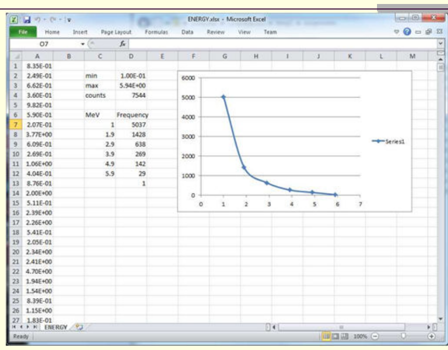
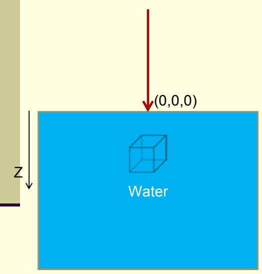
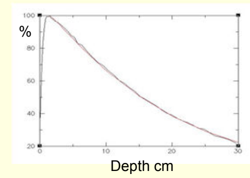
Assignment #2: Results



Assignment #3: Linac PDD Calculation





Assignment # 3: EDEP

3 The Meaning of the Main Variables used in EGS4

The variables used in EGS4 and their meanings are given in APPENDIX 2 of SLAC-265.
The main variables which are necessary to write the User Code are as follows:

```
COMMON/STACK
X(NP), Y(NP), Z(NP)   Position of a particle.
U(NP), V(NP), W(NP)   Directional cosines of a particle.
WT(NP)                Statistical weight of the current particle (default=1.0).
E(NP)                 Total energy in MeV.
IQ(NP)                Integer charge of a particle (+1, 0, -1).
IR(NP)                Index of a particle's current region.
NP                    The stack pointer (i.e., the particle
                      currently being pointed to).
COMMON/BOUNDS
ECUT          Array of regions' charged particle cutoff energies
              in MeV.
PCUT          Array of regions' photon cutoff energies in MeV.
COMMON/EPCONT
EDEP          Energy deposited in MeV.
TSTEP         Distance to the next interaction(cm).
TVSTEP        Actual total (curved)step length to be tranported.
IROLD         Index of previous region.
IRNEW         Index of new region.
COMMON/MEDIA
NMED          number of media being used (default=1).
RLC           Array containing radiation length of the media in cm.
RHO           Array containing the density of media in b/cm^3.
```

Initial parameters of source particles are defined as the following variables and transferred to SUBROUTINE SHOWER as the argument of SUBROUTINE CALL:

```
XI, YI, ZI  : Position of a source particle
UI, VI, WI  : Direction cosines of a source particle
EI          : Total energy of a source particle
IQI         : Integer charge of a source particle
IRI         : Index of a source particle's incident region
WTI         : Statistical weight of a source particle
```

KEK Lecture_ep.pdf

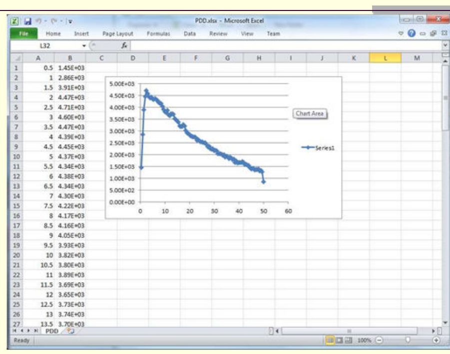
Assignment # 3: IARG

Table 1(a) Value for IARG and corresponding situation.

IARG	IAUSFL	Situation
0	1	A particle is going to be transported by distance TVSTEP.
1	2	A particle is going to discarded because its energy is below the cutoff ECUT (for charged particles) or PCUT (for photons)—but its energy is larger than the corresponding PEGS cutoff AE or AP, respectively.
2	3	A particle is going to be discarded because its energy is below both ECUT and AE (or PCUT and AP).
3	4	A particle is going to be discarded because a user requested it (in HOWFAR usually).
4	5	A photoelectric interaction has occurred and either: a) the energy of the incident photon was below the K-edge binding energy and it is going to be discarded, or b) a (fluorescent) photon is going to be discarded with the K-edge binding energy.

KEK Lecture_ep.pdf

Assignment # 3: Results



Thank You!