Monte Carlo Methods

JASS06 – course 2

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Introduction

The purpose of this work was to define the basic characteristics and features of Monte Carlo codes, to define bases of carrying out of computational experiments with them, to perform experiments on Fluka and to compare with Geant4. Therefore the given work has survey character.

Actuality

Programs on the basis of Monte Carlo simulation allow to perform computer experiments in various areas of modern physics, such as: nuclear physics, high-energy physics, cosmic rays, neutrino physics. Such experiments are necessary to better understand the nature of processes, to make forecasts concerning real experiments. But also application of these packages of interest increases in medicine, for example: by means of similar programs it is possible to investigate influence of radioactive radiation on tissues of the person. It is used at treatment of cancer. Thus Monte Carlo codes have a great importance.

Gamma-rays

We shall consider physics of processes. For concreteness we shall consider gamma-rays.

Gamma-radiation, i.e. high-frequency electromagnetic oscillations $\omega \approx 10^{20}\, s^{-1}$, arises either in a nuclear transformation (radioactive decay, nuclear reactions, nuclear fission) or with charged particles slowdown in environment (bremsstrahlung) or with an annihilation of particles and antiparticles (for example: electron with positron).

Gamma-radiation may be considered as a particle totality (for example: quantum or photon), moving with light speed $c = 3 \cdot 10^{10}\, cm/s$, energy $E = \eta\omega$ and momentum/impulse $p = \frac{\eta\omega}{c}$, $\eta = 1.054 \cdot 10^{-27}\, erg \cdot s$. This approximation exists because corpuscular properties of electromagnetic oscillations become apparent at high-frequency electromagnetic oscillations.

Gamma-quanta which are emitted by majority of natural and artificial radiation isotopes, have their energy belongs to the interval from 0.01 to 10 MeV. $E_q \in (0.01;10) MeV$

One more important value characterizing gamma-quantum is a quantum wave length equal to $\lambda = \frac{m_0 c}{E}$.

At passage through a substance the gamma-quanta energy transfers mainly to electrons. There are more than ten types of elementary processes of gamma-rays interactions with matter. But as for concerned energies only three processes have a place with visible probability, this is photoelectrical absorption, Compton scattering and pair production process.

As a result of each of this process either whole gamma-quantum energy or its portion transfers to electrons: photoelectron, Compton electron or electron-positron couple, respectively. Received energy is transmitted to the matter by electrons and positrons as a result of complicated processes.

Portion of energy transferred by quanta as a result of interaction with matter may be emitted as radiation (fluorescence, annihilation radiation, slowing-down radiation of electrons and positrons). But its intensity is much less than primary emanation, therefore it can be neglected.

Scattering cross-section

For the quantitative characteristic of dissipation and absorption probabilities the quantity of dissipation and absorption cross-section are introduced. Cross-section may be defined as

following. Let's suppose that electron is located in point O and homogeneous and parallel to z axis beam of gamma-quanta infinite in x and y directions falls on it. Let gamma-quanta flux density, i.e. number of quanta, passing through unit of surface in a unit of time, be equal to N_0 and number of scattered quanta in unit of time be equal to N, i.e. scattered flux. Then cross-section is defined as following ratio: $\sigma_s = \frac{N}{N_0}$, which has dimension of a squared length. It's clear that if n_0 dispersive electrons are located in unit of volume, then number of scattered gamma-quanta passing volume $d\upsilon$ is equal to $dN = N_0 \sigma_s n_0 d\upsilon$. Then probability of quantum to scatter at unit of length dl is $dw = \sigma_s n_0 dl$.

Thus cross-section is numerically equal to the probability of quantum dispersion per unit of length in substance containing one electron in unit of volume.

Certainly arguments described above can be realized for processes of absorption and pair production in the same manner.

Photoelectrical effect

Photoelectrical effect is a process of gamma-quantum absorption by atom of substance. Quantum energy is transmitted to one electron of atom. After that this electron is ejected from the atom with energy E_e equals to the difference $E_e = E_q - E_b$ of quantum energy E_q and binding energy of electron and atom E_b.

Photoelectric cross-section has strong dependence on charge of atomic nucleus Z and quantum energy. With increasing nucleus charge photoelectric cross-section arises as Z in n-th degree where n depends on quantum energy and belongs to the interval from 4 to 5. Moreover with energy increase photo-effect cross-section falls down as $1/E^3$ with low energy, and with high energy – as $1/E$. Thus it is important to take into consideration photoelectric effect for heavy matters and low quantum energy. Note that cross-section has jumps when quantum energy becomes equal to the atom binding energy.

Compton effect

At interaction with electron gamma-quantum has probability of scattering at some angle ϑ and this process passes with transmission gamma-quantum energy to the electron. Such process is called Compton scattering. As electron binding energy in atom is little in comparison with gamma-quantum energy and atom electron velocity is less then light speed so electron before interaction may be considered as free and rest. Such assumption and energy and momentum conservation laws lead to following association of scattering angle and quantum energies before and after interaction: $E' = \frac{E}{1 + E/m_0 c \cdot (1 - \cos\vartheta)}$, where E – falling quantum energy and E' - scattered one, $m_0 c$ - electron rest-energy. This equality may be rewritten in terms of wave length: $\lambda' = \lambda + 1 - \cos\vartheta$ where λ and λ' are a wave length before and after interaction, respectively. On the basis of energy conservation law Compton electron has energy: $E_e = E - E'$. It appears from this expressions that scattered radiation energy decreases with scattering angel growing under fixed falling quantum energy. It reaches minimal value equals to $E' = \frac{E}{1 + 2E/m_0 c}$ with scattering angel equals to $\vartheta = \pi$. With high energy of initial quanta backward scattered quantum energy tends to minimal value equal to $0.25 MeV$ and with low energy – to energy of initial quanta $E' \to E$. Thus at backward scattering low-energy quanta don't almost modify their energy. When $E > m_0 c$ backward scattered quantum energy depends little on initial quantum energy: when initial energy

E changes from one to infinity back scattered quantum energy $E'(\vartheta = \pi)$ changes from 0.17 to 0.25 MeV. $0.17MeV$ $0.25MeV$

At forward quantum scattering $\vartheta = 0$ its energy doesn't change $E' = E$. Moreover on a basis of expression $E' = \dfrac{E}{1 + E/m_0 c \cdot (1 - \cos\vartheta)}$ scattered energy can't be null. Hence at Compton scattering gamma-quantum can't disappear.

At Compton interaction process quanta can be scattered at any angel $0 \le \vartheta \le \pi$ $\vartheta \in (0;\pi)$. But Compton electrons can have only such velocities that direction amounts to acute angel with direction of initial quantum ψ $\psi \in (0;\pi/2)$. Electron receives maximum energy when quantum scatters back: $E_e(\vartheta = \pi) = \dfrac{E}{1 + m_0 c/2E}$ In that case electron is ejected "forward" $\psi = 0$. At little scattering angel quanta transmit to electrons only insignificant portions of energy and the latest depart in direction close to perpendicular to movement direction of initial quantum.

Pair production

Gamma-quantum can generate electron-positron couple either in nucleus field or atom electron field. At the same time gamma-quantum disappears. For pair production gamma-quantum has to have energy equal or more than sum of electron and positron binding energy $E = 2m_0 c = 1.022MeV$. Therefore pair production cross-section is equal to zero when this condition is not fulfilled $E < 2m_0 c$ and it is growing droningly otherwise. Pair production cross-section arises as Z^2 with nucleus charge growing. Thus pair production effect has considerable influence under high-energy quanta in heavy elements.

Total linear coefficient of radiation interaction with matter

If parallel gamma-quant beam passes through a substance than anyone of above described processes leads to quanta leaving from the beam. At photo-effect and pair production these quant leaving results from their disappearing and at Compton process – because of them scattering. On a basis of expression $dw = \sigma_s n_0 dl$ it can be concluded that number of leaved from the beam quanta at path dl is $dN = N_0 S(\sigma_{Cs} + \sigma_f + \sigma_{pp})ndl$, where σ_{Cs} σ_f σ_{pp} – are cross-sections calculated per one atom of matter, n – is atom number per unit of volume, N_0 - flux density and S – beam cross-section. Thus quantitative characteristic of gamma-radiation interaction with matter is given by total interaction cross-section per one atom of matter: $\sigma = \sigma_{Cs} + \sigma_f + \sigma_{pp}$ equals to the sum of cross-sections of elementary processes. Quantity, equal to the composition of whole/total cross-section by atom concentration, is called linear absorption factor $\mu = \sigma \cdot n$. It represents probability that quantum interacts with matter per unit of path. Linear absorption factor has dimension of CGS – cm^{-1}. Note that quantity, contrary to the linear absorption factor, represents mean free path/length. Sometimes it is effective to use mass absorption factor that equals to μ/ρ, where ρ - density of concerned matter. It has dimension of cm^2/g and equals to the probability of quantum interaction with column of matter with cross-section equal one squared cm^2 cm and mass equals to one gram $1g$.

For every element whole range of gamma-quantum energy variation can be divided into three parts so that one of considered processes has major probability in concrete energy region. At low energy quanta interact with matter in general by photo-effect; at medium energy Compton scattering prevails; and at last at high energy major interaction process is pair production.

On a basis of these processes cross-sections quantity of energy lost by quantum per unit of path can be introduced. It equals to $dE = N_0 SE\sigma_{Cs} f_{Cs} ndl + N_0 SE\sigma_f f_f ndl + N_0 SE\sigma_{pp} f_{pp} ndl$. First component is responsible for photo-effect, second and third – for Compton scattering and pair production respectively. Biological effect of gamma-rays is characterized by amount of energy absorbed by body. This magnitude is called by absorbed doze.

Model

Now on the basis of the review made above it is possible to describe the physical model considered in examples on Fluka and Geant4. We consider cubic volume with an edge equal to one meter, filled by air. We irradiate this volume by a gamma-quanta beam, radiated by a point like mono energetic source. Gamma-quanta eject in a same direction. When they get to the investigated volume, the processes described above start to occur with them, these are a photo effect, Compton scattering and pair production. Secondary particles are formed as a result: electrons and positrons which according to above told will have a speed component distinct from zero, and having the same direction with a initial gamma-quanta beam. Hence, speak, that there is a stream of particles which have various energy. We wish to count quantity of a gamma-quanta with the energy laying in a certain interval, i.e. energy distribution of particles, and also angular distribution of particles, which given particles form at crossing a plane with a normal to a plane. For this purpose in the middle of a cube with air we shall put detecting plane which registers the secondary particle crossing detecting plane, its energy and a angle. On it the description of model is finished.

Two ways

In general there are two ways of modelling: deterministic methods and the Monte Carlo method. Deterministic methods involve solution of an integral or a differential equation that describes the dependence on spatial coordinates or time of some behavioural characteristic of the system in question. The equation is cast in an approximate form that permits calculation of the incremental change in the characteristic caused by an incremental change in the variable(s). The value of the characteristic itself is then calculated at each of successive points on a spatial or temporal grid. The accuracy of deterministic methods is limited by how well the equation approximates physical reality and by the practical necessity of making the spatial or temporal difference between grid points finite rather than infinitesimal. Well-known deterministic methods include the finite-difference and finite-element methods.

The Monte Carlo method involves calculating the average or probable behaviour of a system by observing the outcomes of a large number of trials at a game of chance that simulates the physical events responsible for the behaviour. Each trial of the game of chance is played out on a computer according to the values of a sequence of random numbers. For that reason a Monte Carlo calculation has been defined in general as one that makes explicit use of random numbers.

Model

Let we consider the problem of estimating of the probability that a gamma-quantum emanating from some source passes through some radiation shield. For simplicity suppose that the source is anisotropic point source located at the center of the shield, which is a relatively thick spherical shell and consists of only one sort of particles or atom. Moreover assume that source emits monoenergetic gamma-quanta and three processes of the interaction of gamma-quantum with matter are replaced by only two processes: inelastic scattering which changes the direction but not the speed (and hence energy) of a gamma-quantum and absorption, such reaction that swallows up, or “kills,” a gamma-quantum. In this case a trajectory within the shield consists of a succession of straight-line paths whose lengths and directions appear to be random relative to each other. That “random walk” is the result of interactions of the gamma-quantum with atoms within the shield. Whether an interaction results in a gamma-quantum’s being absorbed or scattered can be predicted only probabilistically, as can the scattering angle if the gamma-quantum is scattered.

The probabilities of a gamma-quantum's being absorbed by various atoms have been measured, and so have the probabilities of its being scattered through various angles, all as functions of gamma-quantum energy.

Those probabilities, or cross sections, for the shield nuclei are necessary input to solving the problem at hand.

Also needed is the probability density function for the distance a neutron travels in the shield without undergoing an interaction with a atom (in other words, the probability density function for the lengths of the straight-line paths composing the neutron's trajectory). It is known that the probability density function for the "free-path" length in any material decreases exponentially.

In particular, the probability density that a gamma-quantum will travel a distance x before undergoing an interaction is given by $\rho\sigma e^{-\rho\sigma x}dx$, where ρ is the density of atoms and σ is the total cross section(here the sum of the scattering cross section integrated over scattering angle and the absorption cross section).

Application of the Monte Carlo method to the problem above involves using a sequence of numbers uniformly distributed on the interval (0, 1) to construct a hypothetical (but realistic) history for each of many gamma-quanta as it travels through the shield. (To say that a sequence of numbers is uniformly distributed on (0, 1) means that any number between 0 and 1 has an equal probability of occurring in the sequence. Such numbers, when generated by a computer, are called pseudorandom numbers.) The ratio of the number of neutrons that escape from the shield to the number of neutrons whose histories have been constructed is an estimate of the answer to the problem, an estimate whose statistical accuracy increases as the number of gamma-quanta histories increases. Details of the process can be illustrated by following the construction of a single neutron history.

Simulation steps

Constructing the first step of a neutron history involves deciding on a value for its first free-path length x_1.As pointed out above, the sequence of pseudorandom numbers generated by the computer is uniformly distributed on (0, 1), whereas the free-path lengths are distributed according to $e^{-\rho\sigma x}$ on (0,infinity). $(0;1)\Leftrightarrow(0;\infty)$ How can the sequence of uniformly distributed numbers ξ_i be used to produce a sequence of numbers x_i whose distribution mirrors the experimentally observed distribution of free-path lengths? It can be shown that the transformation $x_i=-(1/\rho\sigma)\ln(1-\xi_i)$ yields a sequence of numbers that have the desired inverse exponential distribution. So the first free-path length is obtained by setting $x_1=-(1/\rho\sigma)\ln(1-\xi_1)$.

The second step in the quantum history involves deciding whether the quantum's first interaction with an electron scatters or kills the gamma-quantum. Suppose it is known from the cross sections for the shield electrons that scattering is nine times more likely than absorption. The interval (0, 1) is then divided into two intervals, (0, 0.1) and [0.1, 1). Assume that x_2, the second pseudorandom number generated by the computer, is 0.2. Because 0.2 lies within the larger subinterval, the quantum is scattered rather than absorbed. $(0;1)\Rightarrow(0;0.1)\otimes[0.1;1)$

The third step in the gamma-quantum history involves deciding through what angle it is scattered. Again some transformation must be performed on the third pseudorandom number, a transformation that changes the uniform distribution of the ξ_i into a distribution that mirrors the observed distribution of scattering angles (the scattering cross section as a function of scattering angle). $\xi_i\Rightarrow\vartheta$

Further steps in the history are generated until the gamma-quantum is absorbed or until the radial distance it has travelled within the shield exceeds the thickness of the shield. The histories of many more gamma-quanta are generated in the same manner.

Assume that N gamma-quanta histories are generated and that n of the histories terminate in escape of the neutron from the shield. To calculate an estimate for the probability that any single

gamma-quantum escapes, assign a "score" s_i to each quantum as follows: $s_i = 0$ if the quantum is absorbed within the shield, and $s_i = 1$ if the gamma-quantum escapes. Then the estimated probability of escape is given by the mean score $\bar{s}$, that is, by $\bar{s} = (1/N)\sum s_i = n/N$. The relative error (relative statistical uncertainty) in that probability estimate is related to the so-called variance of the s_i, $Var(s_i)$, which can be approximated, when N is large, by the difference between the mean of the squares of the scores and the square of the mean score: $Var(s_i) \approx \frac{1}{N}\sum_i s_i^2 - \left(\frac{1}{N}\sum_i s_i\right)^2 = \frac{n(N-n)}{N^2}$. The relative error in the probability estimate is then given by $\frac{\sqrt{Var(s_i)/N}}{\bar{s}} = \sqrt{\frac{(N-n)}{Nn}}$. For example, if $N = 100$ and $n = 47$, the probability of escape is estimated as 0.47 and the relative error is a little less than 11 percent.

The simplifying assumptions invoked in the above example of a Monte Carlo radiation-transport calculation do not of course hold in general. The radiation may consist of particles other than gamma-quanta (or of more than one type of particle), and other types of interactions may be involved (Compton scattering, pair production photo-effect). The radiation may not be mono energetic, and it may emanate from a source that is neither point-like nor isotropic. The material through which the radiation travels may be non uniform in composition and intricate in geometry. All those additional complexities can be handled provided the necessary input data are available.

Variance Reduction

The result of a Monte Carlo calculation has associated with it a statistical uncertainty. How can that uncertainty be reduced and the result thereby be made more accurate? One obvious way to do so is to increase the number of neutron histories generated. But that "brute-force" approach is costly in terms of computer time. More sophisticated techniques are available to achieve a lower uncertainty without increasing the number of histories or to achieve the same uncertainty from a smaller number of histories. Four types of such "variance-reduction" techniques are available: truncation, population control, probability modification, and pseudodeterministic methods.

Truncation involves ignoring aspects of the problem that are irrelevant or inconsequential. For example, the source-and-shield assembly described above may include structural elements that position the source at the center of the shield. Because the electrons in the structural elements, like the electrons in the shield, interact with the gamma-quanta, the structural elements should be included in the simulation. Suppose, however, that the structural elements are very fine rods and hence are considerably less massive than the shield itself. Then truncating the problem by ignoring the existence of the structural elements would have little effect on the results.

Population control involves sampling more important portions of the sampled population more often or less important portions less often. For example, suppose the gamma-quanta that escape from the left half of the spherical-shell shield are of greater interest (for eample, because someone's office is located there, whereas a little-used stairwell is located to the right) and that the left half of the spherical shell is composed of a material more effective at absorbing gamma-quanta. Each quantum that has a possibility of reaching the region of greater interest (any neutron that is emitted toward the left) is "split" into m neutrons (m > 1) and assigned a "weight" of 1/m. The scores of the histories of the split neutrons are multiplied by their weight so that the splitting stratagem does not alter the physical situation but does allow the sampling of more of the more important gamma-quanta. The corresponding technique for sampling fewer of the less important neutrons is referred to as Russian roulette. Applied to the same example, Russian roulette involves specifying that the gamma-quantum emitted to the right have a probability of (1-1/m) of being terminated immediately upon entering the shield. A quantum whose history begins with immediate death is of course tracked no further. Those gamma-quanta that do not suffer immediate death,

(1/m) of the neutrons emitted to the right (in the limit of large N), are assigned a weight of m. Thus the simulation of the real physical situation is unaltered.

Probability modification involves sampling from a fictitious but convenient distribution rather than the true distribution and weighting the results accordingly. For example, instead of applying splitting and Russian roulette to the gamma-quanta emitted to the left and right, respectively, by the isotropic neutron source, the spatially uniform neutron distribution is replaced, for the purpose of constructing histories, by a distribution such that more neutrons are emitted to the left. The "bias" that such a strategy would introduce into the result is removed by appropriately weighting the scores of the gamma-quantum histories.

Pseudodeterministic methods are among the most complicated variance-reduction techniques. They involve replacing a portion (or portions) of the random walk by deterministic or expected value results. Suppose, for example, that the spherical shell is surrounded by further shielding material with complex geometry. Instead of transporting each gamma-quantum via a random walk through the spherical shell to the more complex region of the shield, the quantum may simply be put at the interface between the two shield components and assigned a weight equal to the (presumably known) probability of its arriving there. The difficulties encountered when using pseudodeterministic methods arise in assigning the probabilities.

The use of modern variance-reduction methods has allowed Monte Carlo calculations to be carried out many orders of magnitude faster and yet maintain the same statistical accuracy. In fact, many calculations that once would have required prohibitive amounts of computer time are now routine.

Geometry description

Perhaps the greatest advantage of using the Monte Carlo method to simulate radiation transport is its ability to handle complicated geometries. That ability rests on the fact that, even though the geometry in question maybe complicated in its entirety, only the geometry in the vicinity of the particle for which a random walk is being constructed need be considered at any point in the construction. A given geometry can be modelled in its entirety in two ways: as a "combinatorial" object or as a "surface-sense" object. As its name implies, a combinatorial object is constructed by combining relatively simple geometric entities, such as rectangular parallelepipeds, ellipsoids, cylinders, cones, and so on. Combinatorial objects are easy to construct. A surface-sense object is constructed by combining bounding surfaces, each of which is assigned one of two sense values to indicate on which side of the bounding surface the object lies. Any combination of linear, quadratic, or toroidal surfaces in any orientation or even skew can be accessed by users.

Monte Carlo codes

Now it is possible to bring some result, concerning codes of modelling on the basis of a Monte-Carlo method. In any code it is possible to allocate following basic elements, features: a database (library), theoretical base, the generator of random numbers, the mechanism of the description of geometry. The database represents sets of the experimental data received as a result of real experiments, in the example considered above, this is a scattering cross-section necessary for an estimation of probability of one or another kind of interaction. The theoretical base is a set of theoretical data which is used for definition of conformity between parameter of system and a random number, in an example above it is the probability density function for free path length. The generator of random numbers - the mechanism which allows to receive sequences of the pseudo-random numbers with regular distribution in an interval from zero up to one, thus the period of the generator should be big enough to allow to model huge number of histories of particles transport And mechanisms of the description of geometry is either the combinatory mechanism, or the description by means of planes and curves of the second order.

Thus it is obvious that to have and hold in a head for each problem the code, for example: for modelling transport of electromagnetic radiation one code, and for designing mechanisms of protection - another, it at least is not convenient, including because there is an overlapping various

areas of physics and consequently requirements to a package increase. Therefore all can be characterized modern codes a wide spectrum of appendices which is caused by the expanded opportunities of the task of data for experiment. Thus the software should simple enough in use as possible. According to the above there is a set of packages with various characteristics and opportunities which realizing Monte Carlo method . Further I would like to give the brief characteristic of software packages with which there is a work at the department.

Geant4: status

So, Geant4. As its developers define Geant4 is a toolkit for the description of detectors and modelling. Thus, it is initially defined as a code intended for modelling of particles carrying out through a substance. First version of Geant has appeared in 1974. In 1982 has appeared Geant3 written on Fortran. The idea to create a new code with use modern technologies has appeared in 1993 and already in 1998 there was the first Gant4 release. The modern version of this software product has a wide scope: high-energy physics, nuclear experiments, studying in areas of medicine, accelerators and space physics.

Now, Geant4 is a free software package made of tools which can be downloaded from its web-site. And toolkit Geant4 is accessible to following platforms: flavours of Unix, Linux and Windows systems.

Main features

The toolkit includes: user interfaces, the built-in steering routines and command interpreters. In basis of Geant4 the big set of physical models for processing interaction of particles with substance in very wide power range lays. Geant4 it is written in C++. Thus modern technologies which were mentioned above, consists in that Geant4 is the object-oriented environment based on C++.

The user can create own independent applications. Thus during a writing of the program the user consistently passes all stages of carrying out of real experiment. At first the user "collects" detecting device. At this stage the geometry of the detector in a basis of combinatory technique is defined, and after that these objects are a filled up by substance. Then the user designs a radiation source. Here parameters of radiated particles are set: their kind, energy, direction of distribution, position of a source in space and other. After that particles and physical processes which occur to these particles inside the detector are set. At the same stage some restrictions on parameters of particles are established.

Each stage of statement of experiment in terms of the programming language represents some class. From the view point of program model all classes are united in a single whole and form a uniform program code.

The user can define a format of an output for the subsequent processing results which is carried out either with the built-in tools, allowing to make statistical processing and visualization, or external, for example program complex Root. Thus there is a modelling experiment on the basis of language Geant4.

Fluka: status

Now we shall consider carrying out of experiment by means of Monte-Carlo of code Fluka. Fluka is a general purpose tool for calculations of particle transport and interactions with matter, covering an extended range of applications spanning from proton and electron accelerator shielding to target design, calorimetry, activation, dosimetry, detectordesign, AcceleratorDrivenSystems, cosmicrays, neutrino physics, radiotherapy etc.

The history of Fluka goes back to1962-1967. During that period, Johannes Ranft was at CERN doing work on hadron cascades *under the guide of Hans Geibeland Lothar Homann*, and wrote the first highenergy Monte Carlo transport codes.

Starting from those early attempts it is possible to distinguish three different generation of "Fluka" codes along the years, which can be roughly identified as the Fluka of the ' 70s (main

authors J.Ranftand J.Routti), theFluka of the ' 80s (P.Aarnio, A.Fass ` o, H.-J.Mohring, J.Ranft, G.R.Stevenson), and the Fluka of today (A.Fass ` o, A.Ferrari, J.Ranftand P.R.Sala).

These codes stem from the same root and of course every new “generation” originated from the previous one. However, each new “generation” represented not only an improvement of the existing program, but rather a quantum jump in the code physics, design and goals. The same name “Fluka” has been preserved as a reminder of this historical development — mainly as a homage to J.Ranft who has been involved in it as an author and mentor from the beginning until the present days — but the present code is completely dierent from the versions which were released before 1990, and far more powerful than them.

Fluka of the first generation was used as the tool for shielding designing of high energy proton accelerators. Purpose Fluka of the second generation was to make Fluka a more user friendly hadron cascade code with flexible geometry and with a modern formulation of the hadron interaction model. And at last the third generation: at about the time when the last version was frozen (1987), a new generation of proton colliders, with large luminosities and energies of the order of several TeV, started to be planned. Because of its superior high-energy hadron generator, Fluka became the object of a great interest and began to be employed for shielding calculations and especially to predict radiation damage to the components of the machines and of the experiments. But soon many limitations of the code became evident: the design of the new accelerators (SSCandLHC) and associated experiments needed a capability to handle large multiplicities, strongm agnetic fields, energy deposition in very small volumes, high-energy effects, low-energy neutron interactions, which the code was lacking. A.Ferrari (INFN) and A.Fass ` o set up a plan to transform Fluka from a high-energy code mostly devoted to radiation shielding and beam heating into a code which could handle most particles of practical interest and their interactions over the widest possible energy range.

Modern Fluka is distributed as a tar file under the license. It can be downloaded from an official site.

Thus Fluka supports following platforms:

- Hewlett-Packard 9000 Series 700/800 running HP-UX
- Sun running SunOS
- DEC computers running Digital UNIX> 4.0
- Intel PCs running LINUX:
- RedHat 7.3
- RedHat 9.0
- Scientific Linux 4.1
- Fedora

Main features

In contrast to Geant4 Fluka it is written in Fortran. At that package consists of compiled libraries, user routing in source form, INCLUDE files, various unformatted and formatted data and a number of scripts for compiling, linking and running the program.

Carrying out of experiment by means of Fluka consists in the following. The user according to the certain rules in the fixed form fills a input file. According to Fluka terminology a line of an input file refer to cards or options. Each card consists of the name, one line parameter and from one up to six numerical parameters. By means of cards the user defines a particle source with corresponding parameters (a particles kind, their energy, its position), geometry, materials, thresholds and detectors. Also in an input file the number of particles which are necessary for simulating is set. On it the description of experiment comes to an end. The ready input file is transferred a starting script as parameter. As a result of work the formatted and not formatted files with the purpose of their subsequent processing by internal scripts or external applications are created.

Comparison main features

Though software packages Fluka and Geant4 differ by the principles incorporated in a basis (one of them object-oriented, and another is not), but apparently from following comparison they possess similar parameters of transport of electromagnetic radiation:

	Geant4	Fluka
- photoelectric effect:	10keV	1keV
- Compton effect:	10keV	1keV
- Bremsstrahlung:	1keV	1keV
- multiple scattering:	1keV	1keV.

And at the same time for Fluka it is not recommended to set up the lower value for energy but to set up its order 5-10 keV.

Whether but there is still a question they will yield identical results at the fixed parameters for modelling experiment. Unfortunately, at present I managed to make only preliminary processing of the result, therefore I cannot present any results of comparison.

Conclusion

Therefore at present it is possible to give only preliminary conclusions:

Both of a package give to the user ample opportunities on carrying out of computer experiment, formation of target data, their processing, both of a package have opportunities of graphic representation of results. At present I cannot allocate any of these packages