UCRL-TM-229453

Cosmic-ray Shower Library (CRY)

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March 24, 2012

1 Introduction

The CRY software library generates correlated cosmic-ray particle shower distributions at one of three elevations (sea level, 2100 m, and 11300 m) for use as input to transport and detector simulation codes. Particles from cosmic ray showers [1] over a wide range of energies (1 GeV – 100 TeV primary particles and 1 MeV – 100 TeV secondary particles) are generated from data tables. These tables are derived from full MCNPX 2.5.0 [2] simulation for muons, neutrons, protons, electrons, photons, and pions for several altitudes. The CRY software package generates shower multiplicity within a specified area (up to 300 m by 300 m) as well as the time of arrival and zenith angle of the secondary particles. Currently we do not model the "East-West" effect, but we do provide a latitude dependent geomagnetic cutoff of the primary cosmic-ray spectrum and modulation of the spectrum over time based on the average solar cycle.

For a more detailed discussion of the cosmic-ray model used to generate the input tables see [3]. The description of options and the basic C++ interface are given below. The software library and examples can be downloaded from `http://nuclear.llnl.gov/simulation`.

CRY can run as a stand-alone program, or linked and run directly in Geant4, MCNP, and MCNPX.

2 Creating the library

Type `make` from the top-level directory of the software distribution. This creates the software library `lib/libCRY.a`. This will also compile and run a short test program `test/testMain.cc` and compare the output to a reference. On most systems the test results will be identical to the reference.

3 Examples

For an example of using CRY as a stand-alone program see `test/testMain.cc`. For an example that also uses the CERN root package see `test/testRoot.cc`. Examples using CRY as a built-in source for Geant4, MCNP, and MCNPX are in the `geant`, `mcnp`, and `mcnpx` directories. See the `README` file in these directories for specific information regarding each transport code.

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4 Available options

Options to change the default behavior of CRY are set using an ASCII input file `setup.file`. In Geant4 the options can also be specified via the native Geant4 input format. In MCNP/MCNPX there are additional options accessed via idum/rdum keywords in the standard input deck, see `mcnpx/README`.

The CRY option syntax is always `<token> <value>` pairs where extra white space is ignored.

Types of secondary particles

By default all particle types are returned. Each can be disabled independently using these flags (n=1 return the particle, 0 do not return the particle)

```
returnNeutrons n
returnProtons n
returnGammas n
returnElectrons n
returnMuons n
returnPions n
```

Altitude (meters)

```
altitude n
```

Allowed values are 0 (default), 2100, and 11300 m.

Latitude (degrees)

```
latitude L
```

The default is zero, i.e. the magnetic equator. The allowed range is (-90, 90), where 90 is the magnetic North pole. The Earth's magnetic field acts as a filter on the low-energy spectrum of the primary cosmic-ray particles. The effect is implemented as a cutoff ($E_{\rm min}$) on the energy of the primary cosmic-ray proton that hits the upper atmosphere ($\sim$ 15 GeV at the equator, 0 GeV at the poles). For the latitude dependence (dipole component) of this cutoff we use the approximation from [4] and Chapter 2 equation 2.35 from [5] where L is the latitude in degrees and the zenith angle is 90°:

$$E_{\rm min}(\text{GeV}) = 14.8 \cos^4(\pi L/180^\circ).$$

The parameters of this function can be changed by editing the values stored in the data files in the section labelled `bfieldCorr::cosLatitude`.

Date

```
date month-day-year
```

Adjusts the cosmic-ray distributions to account for the eleven year, sunspot cycle. The date is a string of integers separated by a dash ("-") representing the month, day, and year, e.g., December 1, 2009 is 12-1-2009. The default value 1-1-2007.

The effect of solar activity on the cosmic-ray flux at the Earth can be roughly approximated by a sinusoidal variation between a solar minimum and solar maximum energy spectrum of the primary cosmic rays [6]. Maximum solar activity corresponds to minimum cosmic-ray flux onto the Earth because the magnetic field carried in the solar wind plasma traps the low-energy portion of the primary cosmic-ray spectrum, which reduces the number of primary cosmic rays that reach the Earth.

The min and max primary energy spectra, the solar activity period and offset are recorded in the CRY data files. The default energy spectra parameters are from Papini *et al.* [1]. The default period is 11.0 years. The default solar minimum date is January 1, 2008.

Control of the number of particles

```
nParticlesMin n
nParticlesMax n
```

Showers with more than the specified value (n) are truncated.

The lateral size of interest (meters)

```
subboxLength n
```

Particles are returned inside a box (actually a square plane surface) of `n` by `n` meters. The maximum allowed value is 300 m. Data tables are provided for 1, 3, 10, 30, 100, and 300 m. For box sizes in between these discrete values, the next largest table is utilized and particles outside of the specified window are dropped.

5 Interface

To specify the location of the input data and the user selected setup:

```
CRYSetup* setup = new CRYSetup(setupString, "./data");
CRYGenerator gen(setup);
```

The first argument to CRYSetup is a string containing the contents of the setup file, and the second is the location of the data tables.

To generate all particles of interest for a single shower use:

```
std::vector<CRYParticle*>* ev = new std::vector<CRYParticle*>;
ev->clear();
gen.genEvent(ev);
```

The shower is returned as a list of particles, represented by CRYParticle. The particle type, energy, location, timing, and direction cosines are accessible (see CRYParticle.h for more information). The default units are:

```
Energy = MeV
Position = meter
Time = second
```

Elapsed time

The generator can also be queried for the elapsed time in the simulation for normalization purposes via `gen.timeSimulated()`.

Random number generator

The random number generator can be changed by passing a pointer to the location of the function that returns random numbers:

```
CRYSetup::setRandomFunction(double (*newFunc)(void))
```

References

[1] "An estimate of the secondary-proton spectrum at small atmospheric depths," P. Papini, C. Grimani and S.A. Stephens, Nuovo Cimento 19C, 367 (1996). 1, 3

[2] MCNPX User's Manual, Version 2.5.0, Laurie Waters, ed., LA-CP-05-0369 (2005). http://mcnpx.lanl.gov/documents.html 1

[3] "Monte Carlo Simulation of Proton-induced Cosmic-ray Cascades in the Atmosphere," Lawrence Livermore National Laboratory, UCRL-TR (2007). 1

[4] D. J. Cook, Physical Review Letters, Vol 51 No 4, (1983). 2

[5] "Cosmic Rays in Magnetospheres of the Earth and other Planets," L. Dorman, Astrophysics and Space Science Library 358 (2009) 2

[6] "Cosmic Ray Effects on Microelectronics, Part I," J.H. Adams, Jr., R. Silberberg, and C.H. Tsao, NRL Memorandum Report 4506 (1981). 3