PENNUC

Integrating NUCLEIDE and PENELOPE to Simulate Complete Decay Schemes

Overview

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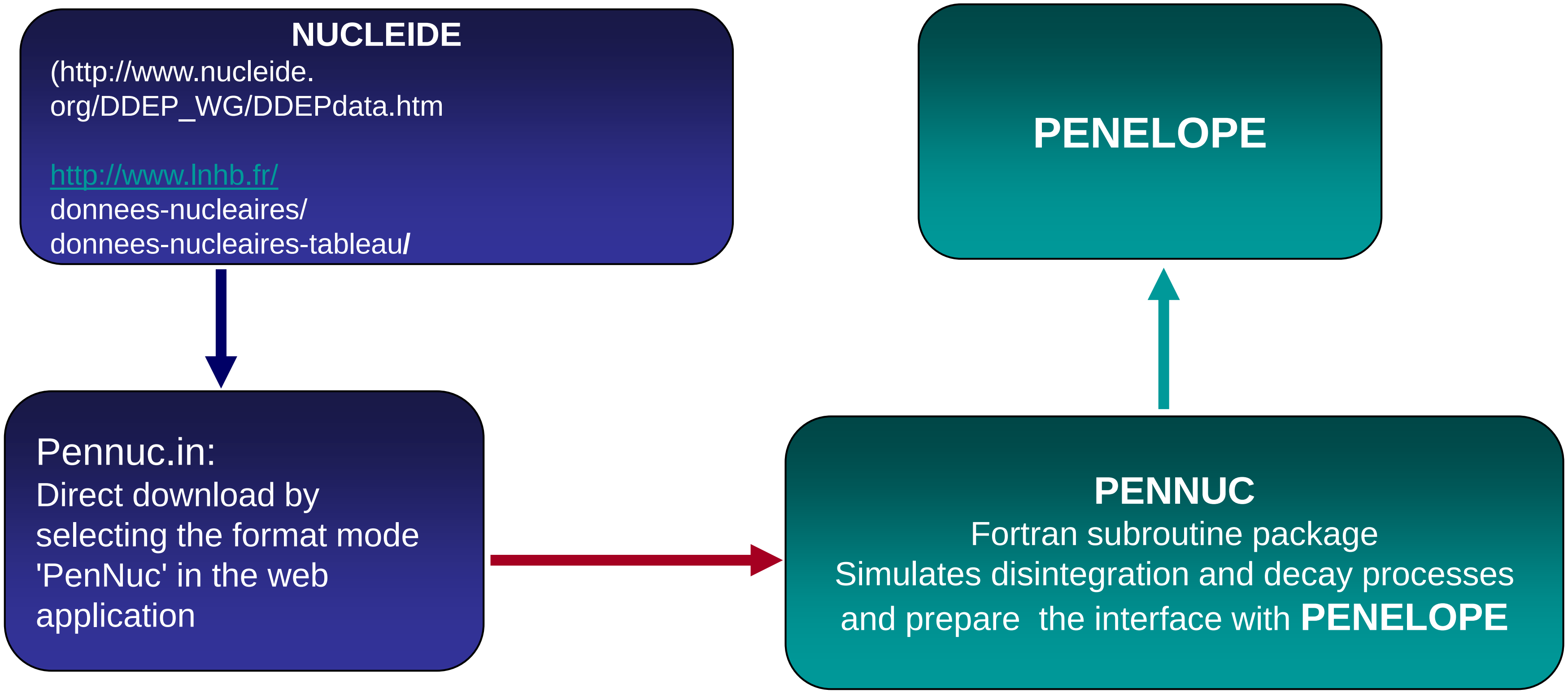

How to integrate PENELOPE and NUCLEIDE?

PENMAIN version 2014 includes a modification that allows a user-defined SOURCE model by means of a external routine:

SKPAR=0 activates a user-defined SOURCE model

To generate each cascade of particles in a shower, SOURCE calls PENNUC.

PENNUC (How does it work?)

PNSAMPLER: (Output an array of particles (energies) associated to this particular pathway)

PENELOPE/PENMAIN

Other…

SOURCE:
Position of the decaying nucleus
Call PENNUC

PENNUC
Reads relevant data (from NUCLEIDE)
Re-normalizes data for simulation
Generates random decay pathways

PENNUC has a subroutine structure: each call generates a cascade of charged particles and photons that describe a complete decay pathway.

- Energy
- Type of Particle (e^-, e^+, photon)
- Time
- Direction

PENNUC physics

Beta spectra are generated using EFFY routines

> Empirical prohibition factors have been derived from measured energy spectra for those nuclides for which enough experimental information is available [15]. Our subroutines include these factors for a set of nuclides of metrological interest (^{11}C, ^{13}N, ^{18}F, ^{22}Na, ^{24}Na, ^{36}Cl, ^{32}P, ^{40}K, ^{49}Sc, ^{63}Ni, ^{68}Ga, ^{89}Sr, ^{90}Sr, ^{90}Y, ^{89}Zr, ^{99}Tc, ^{129}I, ^{138}La, ^{141}Ce, ^{186}Re, ^{204}Tl, ^{210}Bi and ^{241}Pu).

Atomic rearrangement follows PENELOPE physics

Simulates the emission of characteristic radiation and Auger electrons that result from vacancies produced in K, L and M shells by photoelectric absorption, Compton scattering and electron/positron impact. PENELOPE uses a table of possible transitions, transition probabilities and energies of the emitted x rays or electrons.

PENNUC physics

Electron capture

The program simulates the relaxation of a singly ionised atom of the element IZ with a vacancy in the IS shell (the K shell or an L or M subshell) with the PENELOPE relaxation subroutines.

Since atomic rearrangement is included in the simulation, coincidence summing with X rays is fully implemented.

Depopulation of a level

The program randomly selects if ground level is reached by gamma ray emission or internal convertion. In the last case, the relaxation of the daughter nucleus is made with the PENELOPE relaxation subroutines.

Metastable level

If, during the cascade generation, a metastable level is *randomly* found (in funtion of level lifetime and detector resolution time), the cascade is finished and re-started at next call.

PENNUC data format (^{152}Eu)

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```
PAR EU152
AZP 152 ; 63
NDA 2
COM **************** Evaluation Date: 19/04/2004 ***************
COM ==================== Daughter Separator ====================
DAU SM152
DDE 0.721 ;  ; 19 ; 66
Q   1874.3 ; 0.7
COM --------------------- Branch Separator ---------------------
CK  0.000448 ; 0.000033 ; 19 ; 105.2 ; 0.7 ; 0
CL  0.000176 ; 0.000013 ; 19 ; 105.2 ; 0.7 ; 0
CM  0.0000447 ; 0.0000034 ; 19 ; 105.2 ; 0.7 ; 0
CN  0.0000113 ; 0.000001 ; 19 ; 105.2 ; 0.7 ; 0
COM --------------------- Branch Separator ---------------------
CK  0.000283 ; 0.000021 ; 18 ; 117.149 ; 0.7 ; 0
CL  0.000097 ; 0.000007 ; 18 ; 117.149 ; 0.7 ; 0
...
COM ------------- Level Separator - T1/2 in seconds ------------
LED 1769.1 ; 0.03 ; 23 ;  ;  ; 19
GA  0.00008 ; 0.00003 ; 239.42 ; 0.17 ; 13
EK  0.0000018 ; 0.0000007 ; 192.59 ; 0.17 ; 13
EL  0.00000025 ; 0.00000009 ; 232.17 ; 0.17 ; 13
EM  0.000000053 ; 0.00000002 ; 238.05 ; 0.17 ; 13
EN  0.000000016 ; 0.000000006 ; 239.26 ; 0.17 ; 13
GA  0.000106 ; 0.000013 ; 727.99 ; 0.14 ; 8
EK  0.000000176 ; 0.000000022 ; 681.16 ; 0.14 ; 8
...
COM ==================== Daughter Separator ====================
DAU GD152
DDE 0.279 ;  ; 15 ; 13
Q   1818.8 ; 1.1
COM --------------------- Branch Separator ---------------------
BEM 0.000203 ; 0.000011 ; 15 ; 126.4 ; 1.1 ; 0
COM --------------------- Branch Separator ---------------------
...
```

Two Daugthers

Coincidence summing correction:
Combination of simulations made with the PENELOPE and PENNUC codes

Two simulations

Complete decay scheme:

Number of counts as a function of the energy for radionuclide X and per one disintegration

$[N(E;X) / A(X)] = I\gamma(E;X) \cdot FC(E;X) \cdot \varepsilon(E) =$

$= I\gamma(E;X) \cdot \varepsilon^{app}(E;X)$

Independent emission events:

All levels are considered metastable

$[N\ (\text{Ind})\ (E;X) / A(X)] = I\gamma(E;X) \cdot \varepsilon(E)$

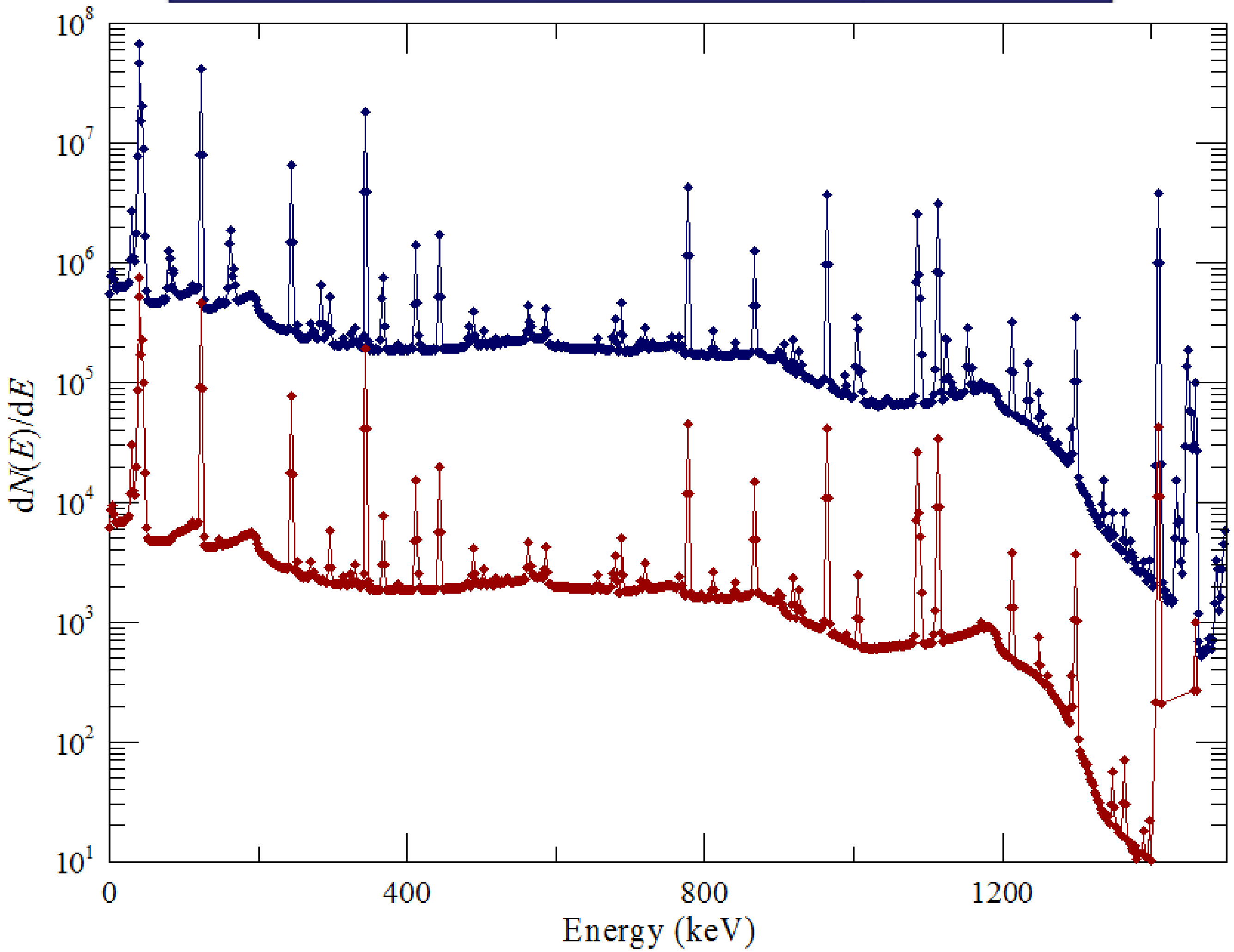
$FC(E;X) = \varepsilon^{app}(E;X) / \varepsilon(E)$

Coincidence summing correction:
Combination of simulations made with the PENELOPE and PENNUC codes

Two simulations: Eu-152 Source 2

Complete decay scheme

Independent emission events



PENNUC practical information

PENNUC is distributed as a zip file named pennuc.zip which contains (**pennuc/fsource**) and the Fortran source files **pennuc.f, source.f**, and the decay-generator program **pnsampler.f**.

References

- E. García-Toraño, V. Peyres, M.-M. Bé, C. Dulieu, M.-C. Lépy, and F. Salvat (2016) "Simulation of decay processes and radiation transport times in radioactivity measurements". Nuclear Instruments and Methods B 396 (2017) 43–49.

- F. Salvat, Penelope-2014: A Code System for Monte Carlo Simulation of Electron and Photon Transport (OECD/NEA Data Bank, NEA/NSC/DOC(2015)3, Issy-les- Moulineaux, France, 2015); http://www.nea.fr/lists/penelope.html.

- J. Almansa, F. Salvat-Pujol, G. Díaz-Londoño, A. Carnicer, A. M. Lallena, and F. Salvat (2016) "PENGEOM – A general-purpose geometry package for Monte Carlo simulation of radiation transport in material systems defined by quadric surfaces", Comp. Phys. Commun. 199, 102–113.