

# Progress and Plans in Radioactive Decay

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Geant4 Collaboration Meeting  
15 September 2016

# Outline

- Progress last year
  - decay by neutron emission, better energy conservation, improved photon evaporation and gamma level handling
- Projects underway
  - gamma correlation, beta-delayed n and p, floating levels, biasing work
- What's next
  - biasing, database, resolution of floating levels

# Progress Since Last Year

- Decay by neutron emission added
  - proton decay already added Oct. 2015
- Energy conservation much improved
  - $\alpha$  decay < 1 eV
  - $\beta$  decay  $\sim$  eV
  - IT, EC  $\sim$  30 eV
    - G4VAtomicDeexcitation now used (including Auger and fluorescence)
    - temporary fix of EC and IT proposed by Andreas Zoglauer
    - fix uses approximate shell energy method for handling outer electrons

# Progress Since Last Year

- Work begun to improve biasing code
  - rename method names to be more meaningful: GetTaoTime() → ConvolveSourceTimeProfile()
  - begun code refactoring: smaller methods, etc.
  - add production of gamma and electron spectra from deexcitation of excited levels in biased mode
- Removed obsolete classes
  - G4RIsoTable
  - G4NuclearDecayChannel and classes based on it
    - G4AlphaDecayChannel, G4BetaMinusDecayChannel, G4BetaPlusDecayChannel, G4ITDecayChannel, G4KShellECDecayChannel, G4LShellECDecayChannel, G4MShellECDecayChannel, G4ProtonDecayChannel

# Progress Since Last Year

- G4RadioactiveDecay::DecayIt() moved from **protected** to **public**
  - now consistent with PostStepDoIt() in other hadronic processes
  - enables process-level testing
- Photon evaporation model improved
  - cleaner design
  - several bugs removed
  - new gamma level management
- New databases now available with floating levels
  - RadioactiveDecay5.0
  - PhotonEvaporation4.0

# Projects Underway

- Correlation of gamma emission
  - angular distribution of emitted gamma will depend on previous emissions
  - requires addition of multi-polarity information in DB and modification of reader
  - most of the required code is implemented (G4PolarizationTransition, etc.)
- Beta-delayed neutron and proton emission
  - emission of n or p after beta decay to highly excited nuclear state
  - current plan:
    - add neutron emission branch to appropriate levels in DB → two-step decay will then happen
    - add new decay class for beta decay to continuum

# Projects Underway

- Floating (or X) levels
  - discrete levels in nucleus whose energy is either unknown or poorly determined
  - a chain of well-defined decays may be built on an X-level, leaving absolute scale undetermined
  - indicated in ENSDF by X,Y,Z,U,V,W,A,B,C,D,E
  - currently dealing with these as unique states
    - $^{234}\text{Pa}[73.92+X]$ , for example
    - replaces  $^{234}\text{Pa}[73.920004]$
- Required significant extension of G4Ions in /particles
  - to enable ion creation and use of particle gun
  - X, Y, Z, etc. dealt with as char

# Projects Underway

- Floating levels (continued)
  - **G4RadioactiveDecay modified (5.0 onward):**
    - parent levels: P 73.92 +X 69.54
    - daughter levels: BetaMinus 0 +X 69.93 398.6
  - **G4PhotonEvaporation modified (4.0 onward)**
    - all levels have floating level column: “-” for non-floating and “+X”, “+Y”, ... for floating
    - all levels like 73.920004 removed
- Is irreproducibility really gone?
  - **some tests still to do**



# What's Next?

- Continue work on biasing
  - remove analysis code from RDM process
  - use scoring instead
  - fix negative values bug in accumulated decay time spectra
  - use generic biasing methods
- Resolve some floating levels
  - 92 exist
  - enough data to resolve several of them
- Implement reduced number of DB files
  - version already available for photon evaporation
  - do the same for RDM

# What's Next?

- Revisit multi-threading
  - RDM code still far from optimal
- More detailed atomic de-excitation code
  - Kibedi code a good possibility
  - any conflict with low energy EM?
- Development of binary databases to save time and memory
- General code improvement
  - tests show Geant4 as a whole is CPU-bound
  - true for RDM?

# Tasks (green: completed, red: in progress)

- Martin Venhart
  - examine 92 known floating levels to see if existing data can be used to fix them
  - contact T. Kibede to see if Geant4 may use his atomic relaxation code
- Laurent Desorgher
  - add column in photon evaporation database for multi-polarity and delta
  - add beta-delayed neutron, proton data to database
- Alberto Ribon
  - test for thread saturation in random number generation
- Alex Howard
  - continue testing of random number generators

# Tasks

- Makoto Asai
  - add character argument to ions, as well as Get, Find, Create methods
  - attach scorer to process (for biasing)
  - work on binary database implementation
- Andrea Dotti
  - test for thread saturation in random number generation
  - work on binary database implementation
- Dennis Wright
  - make RDM model for testing which has all biasing code removed
  - replace G4UAtomicRelaxation with G4VAtomicRelaxation
  - implement double beta decay using spectrum from Luciano Pandola
- Marc Verderi
  - check correctness of generic biasing in both at-rest and in-flight modes

# Tasks

- Luis Sarmiento
  - write code for beta-delayed neutron, proton channel
- Unassigned
  - check lower limit on life time ( $10e-14$  ?)  ${}^9\text{B}$  decays
  - develop new RDM example (rdecay03) to demonstrate new decay channels
  - according to XEON-Phi tests Geant4 is now CPU-bound -> general improvement in coding is required
  - allow assignment of RDM to G4Region as well as G4LogicalVolume