Isotope choice for Elements in hadronic reactions

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How nuclear isotopes appear in Geant4

- Stable (Z,A) isotopes can appear as target nuclei with natural abundance (~300)
- Any isotope (excluding such as ^{5}He or ^{5}Li, which are short lived) can appear as reaction products (4500+hypernuclei?)
- Radioactive isotopes and isomers stop and contribute to collected radioactivity
- In models isotope/isomer/hypernuclear masses can be used for splitting energy

Desired isotope/isomer/hypernuclei DB

- The DB must include the measured masses of isotopes, isomers, hypernuclei
- For those which are not measured, the extrapolation function must be provided
- The DB must include the PDG code which is already published this summer (2006)
- The DB must include known and predicted decay channels for radioactive nuclei
- The abundance can be in a separate DB

Nuclear PDG codes: 10SNNNZZZI

- Nuclear PDG codes must be included in G4GenericIon by Geant4 Particle team
- I = Isomer Number (I=0 for GS isotopes)
  ^{180}Ta is an isomer with natural abundance
- ZZZ = charge (not number of protons, Λ_C^+)
- NNN = number of neutrons in the isotope
- S = number of Λ's (for hypernuclei)
- 0 is reserved for high S nuclear states (strangelets) or for charmed nuclei (0=C)

Problems in Geant4 hadronic processes

- Geant4 can not transport isomers and hypernuclei, most of which are relatively long living – Models suppress them ?!
- G4Isotope vector defined for Elements with unnatural abundance is used only by CHIPS through G4QIsotope interface. User cannot set unnatural isotopes.
- Creation of the G4Isotope vector for Elements with natural isotope abundance destructively interferes with G4QIsotope

G4QIsotope interface of hadronic package

- Electromagnetic package is not sensitive for the isotope content of Elements
- G4QIsotope is a universal hadronic class
  - hardwired natural isotope abundance (Z,ind=0)
  - Can create unnatural Elements (Z,ind=ElemV)
  - Can calculate mean Cross-Section (XSVector)
  - Can randomize A of the isotope (using XSVect)
  - Can Get/Set the XS vector for any Element
  - Can cash the XS·abundance product vectors

Examples of usage of G4QIsotope class

- Usage is widely explained in G4QIsotope.hh
- The concrete examples can be found in G4QCaptureAtRest, G4QCollision, G4QElastic, and in Combined Elastic of V.I.
- Usage of G4QIsotope lets to take into account unnatural abundance in Elements
- G4QIsotope unifies the Geant4 abundance of Elements, while at present HP, HInelastic have different strategies and are not sensitive for the user defined Elements

Proper Isotope Choice in Hadronic Package (Dennis Wright)

- In G4HadronicProcess, choice of A is based on approximation: $\sigma_Z=(\sigma_0/\langle A\rangle^{2/3})\cdot\Sigma_A abund_A\cdot A^{2/3}$, while it must be: $\sigma_Z=\Sigma_A abund_A\cdot\sigma_{Z,A}$.
- Many cross-section sets do not have isotope-wise cross sections or temperature dependence
- Needs methods to access isotope-specific XS
- Needs a common system for all XS data sets

Preliminary Solution 1 (Dennis Write)

- Add methods to G4HadronicProcess
  - GetAWICS(G4DynamicParticle*, G4Element*, G4double temp)
    - get Abundance-Weighted Isotope Cross Section
    - method returns array of products of abundance*isotope cross section for each element (too big array! – M.K.)
    - if no user-defined element, use natural abundance
  - GetIsotopeCrossSection(G4DynamicParticle*, G4Isotope*, G4double temp)
    - virtual method to be defined by G4HadronInelasticProcess, G4HadronElasticProcess, G4HadronCaptureProcess, G4HadronFissionProcess
    - called by GetAWICS method for each isotope of Element

Preliminary Solution 2 (Dennis Write)

- Also add virtual method to G4VCrossSectionDataSet
  - GetIsoCrossSection(G4DynamicParticle*, G4Isotope*, G4double temp)
    - ~20 classes need to be modified in order to implement this method: G4HadronElasticDataSet, G4Tripathi, ...
- Add method to G4CrossSectionDataStore
  - GetIsoCrossSection
- Similarly, add isotope-dependent methods to G4HadronicCrossSections
  - CalculateScatteringCrossSection, etc. will now need to do proper calculation or look-up of isotope cross-section

Preliminary Solution 3 (Dennis Write)

- A uniform solution requires changes to:
  - HP neutron cross-sections
  - Glauber cross-sections
  - CHIPS cross sections (if not CHIPS solution)
  - default (GHEISHA) cross-sections
- Basically, any hadronic class deriving from the class G4VCrossSectionDataSet will need to be modified
- Some work on this conversion has already been done following algorithm used in CHIPS elastic cross section class (G4QElastic using G4QIsotope interface)
  - GHEISHA-style cross sections could be converted to isotope-wise in two days, using this G4QIsotope method

Nuclear/atomic masses in Geant4

- This question must be solved by Geant4 Particle team together with Hadronic group
- The general approach is already realized by Geant4 Particle team, but the DB
  - is not up-to-date (measured masses)
  - does not include isomers and hypernuclei
  - has old fashion extrapolation of masses
  - does not include decay channels, which are separately supported by the Decay Package
- Needs serious update.

Conclusion

- The Isotope Choice problem in Hadronic Package can be solved on the Hadronic-Element level with the abundance DB on the Hadronic level because nobody else needs abundances
- The Nuclear Mass and Nuclear PDG Code problems must be solved on the Particle level and Elements can use the Isotope masses (equivalent to atomic masses) from the Particle DB, which provides atomic masses for Isotopes
- Geant4 Tracking must be ready for transportation of isomers and hypernuclei (with possible decay)