Geant4 v9.3

Hadron Physics III

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Low energy (< 20MeV) neutrons physics

- High Precision Neutron Models (and Cross Section Data Sets)
  - G4NDL
    - ENDF
  - Elastic
  - Inelastic
  - Capture
  - Fission
- NeutronHPorLEModel(s)
- ThermalScatteringModels (and Cross Section data Sets)
- JENDL High Energy Files (cross sections < 3GeV)

G4NDL
(Geant4 Neutron Data Library)

- The neutron data files for High Precision Neutron models
- The data are including both cross sections and final states.
- The data are derived evaluations based on the following evaluated data libraries (in alphabetic order)
  - Brond-2.1
  - CENDL2.2
  - EFF-3
  - ENDF/B-VI.0, 1, 4
  - FENDL/E2.0
  - JEF2.2
  - JENDL-FF
  - JENDL-3.1,2
  - MENDL-2
- The data format is similar ENDF, however it is not equal to.

Evaluated Nuclear Data File-VI

- "ENDF" is used in two meanings
- One is Data Formats and Procedures
  - How to write Nuclear Data files
  - How to use the Nuclear Data files
- The other is name of recommended libraries of USA nuclear data projects.
  - ENDF/B-VI.8
    - 313 isotopes including 5 isomers
    - 15 elements
  - ENDF/B-VII.0
    - Released on 2006 Dec
    - almost 400 isotopes
    - not yet migrated

- After G4NDL3.8 (3.13 is latest) we concentrated on translation from ENDF library.
  - No more evaluation by ourselves.

G4NeutronHPElastic

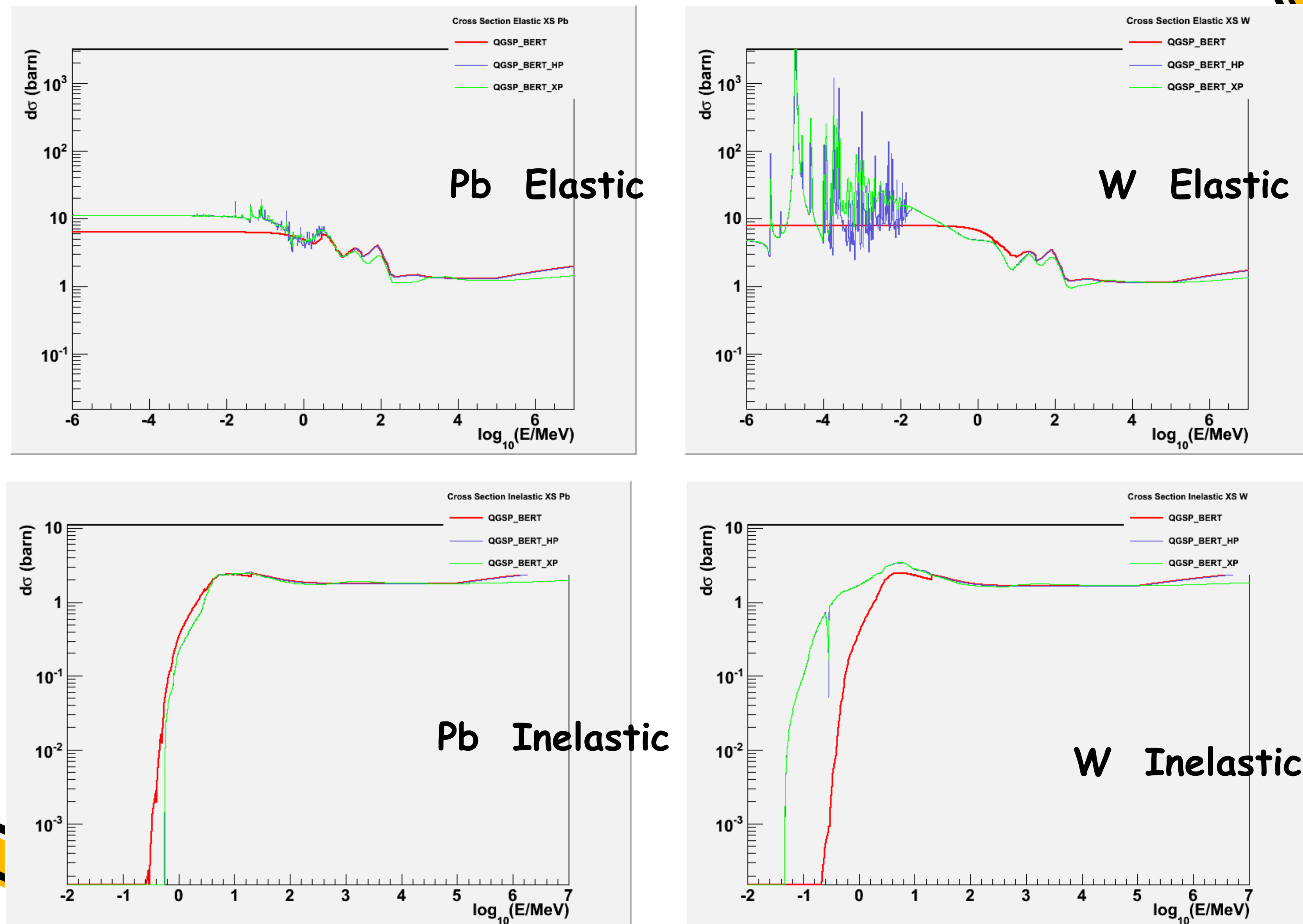
- The final state of elastic scattering is described by sampling the differential scattering cross-sections
  - tabulation of the differential cross-section $$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}(\cos\theta, E)$$
  - a series of legendre polynomials and the legendre coefficients

$$\frac{2\pi}{\sigma(E)}\frac{d\sigma}{d\Omega}(\cos\theta, E) = \sum_{l=0}^{n_l}\frac{2l+1}{2}a_l(E)P_l(\cos\theta)$$

G4NeutronHPInelastic

- Currently supported final states (discrete and continuum) are following:
  - np, nd, nt, n ^{3}He, nα, nd2α, nt2α , n2p, n2α, n3α, 2nα, 2np, 2nd, 2nα, 2n2α, nX, 3n, 3np, 3nα, 4n, p, pd, pα, 2p d, dα, d2α, dt, t, t2α, ^{3}He, α, 2α, and 3α.
- Secondary distribution probabilities are supported
  - isotropic emission
  - discrete two-body kinematics
  - N-body phase-space distribution
  - continuum energy-angle distributions
    - legendre polynomials and tabulation distribution
    - Kalbach-Mann systematic $A + a \rightarrow C \rightarrow B + b$, C:compound nucleus
  - continuum angle-energy distributions in the laboratory system

Neutron XS : Elastic and Inelastic



G4NeutronHPCapture

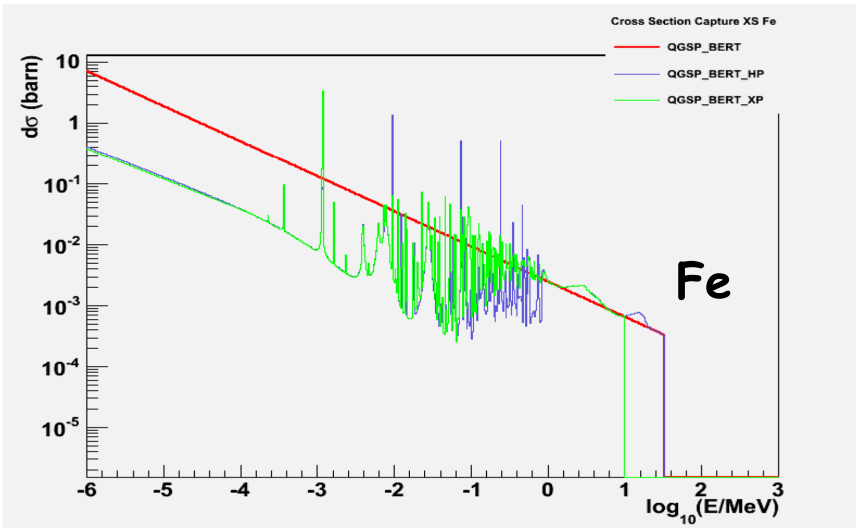
- The final state of radiative capture is described by either photon multiplicities, or photon production cross-sections, and the discrete and continuous contributions to the photon energy spectra, along with the angular distributions of the emitted photons.
- For discrete photon emissions
  - the multiplicities or the cross-sections are given from data libraries
- For continuum contribution
  - E neutron kinetic energy, E_γ photon energies

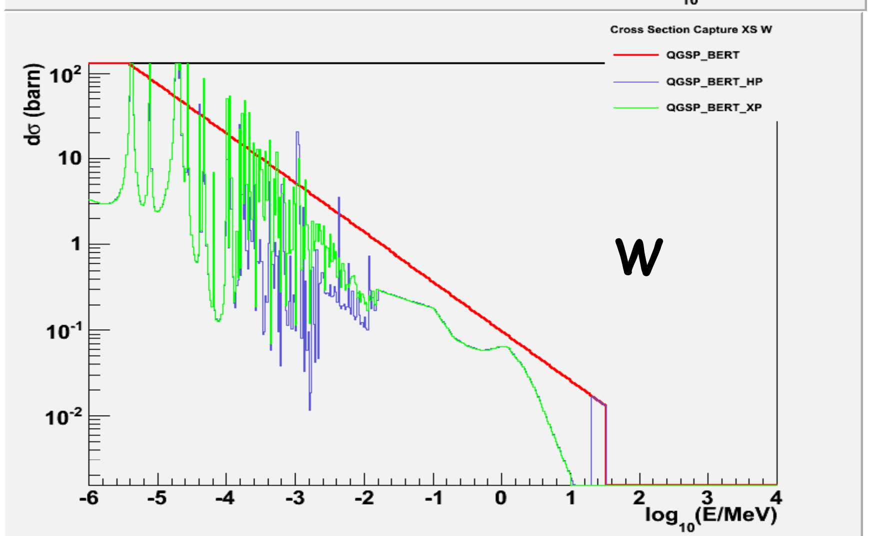
$$f(E \to E_\gamma) = \sum_i p_i(E) g_i(E \to E_\gamma)$$

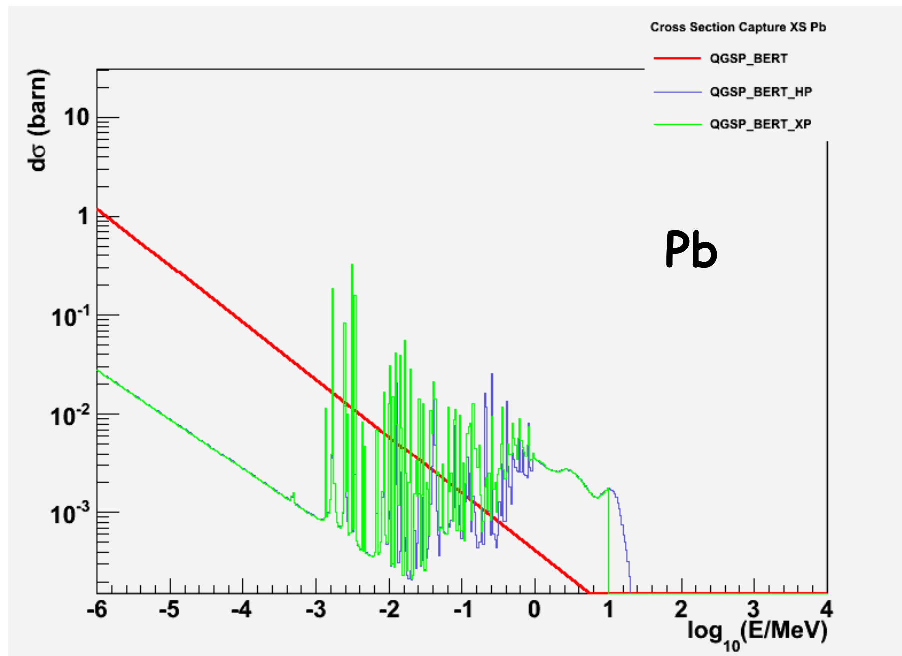
  - p_i and g_i are given from data libraries

Neutron capture cross section

Defines neutron diffusion
Precise in HP Physics Lists





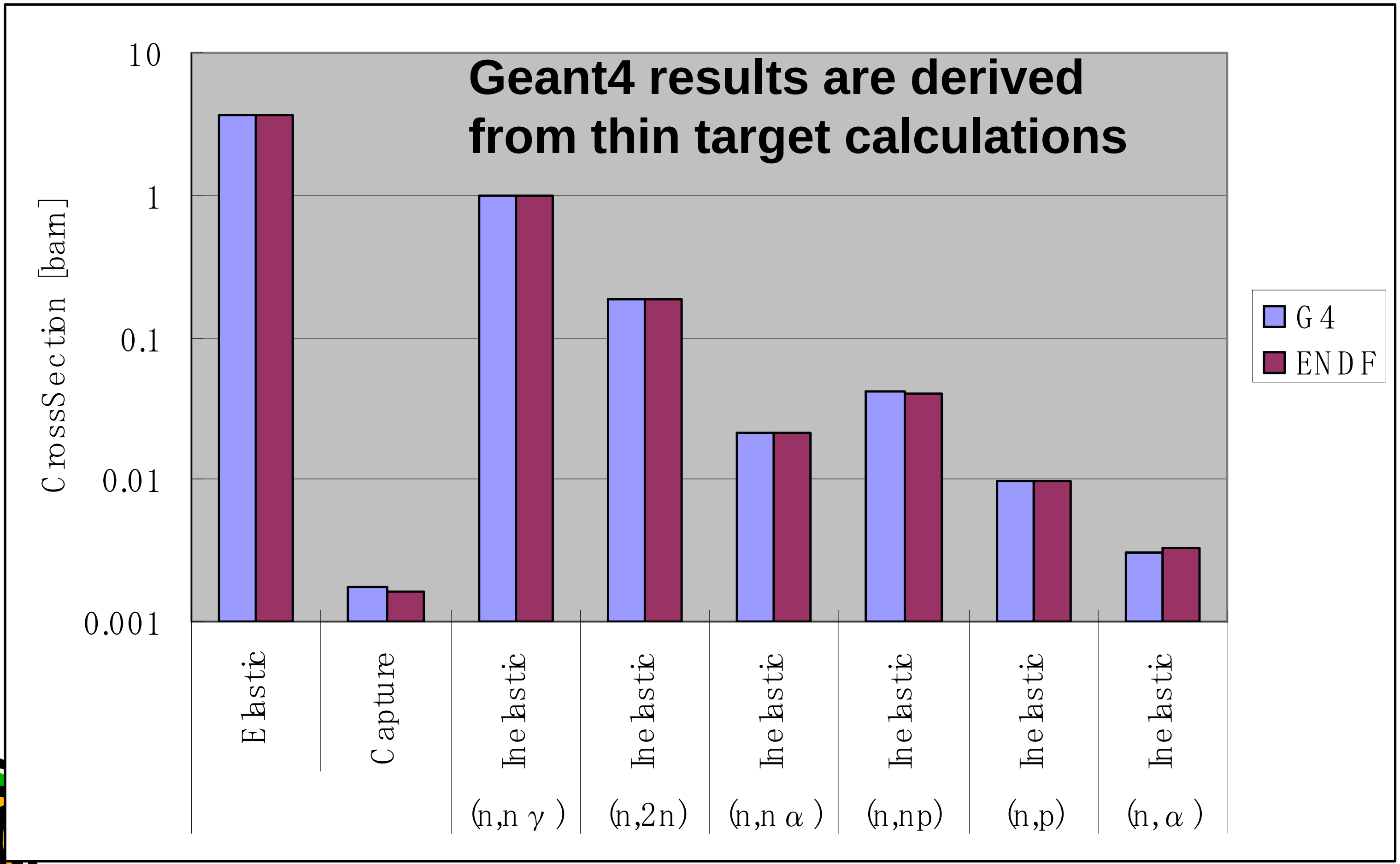


G4NeutronHPFission

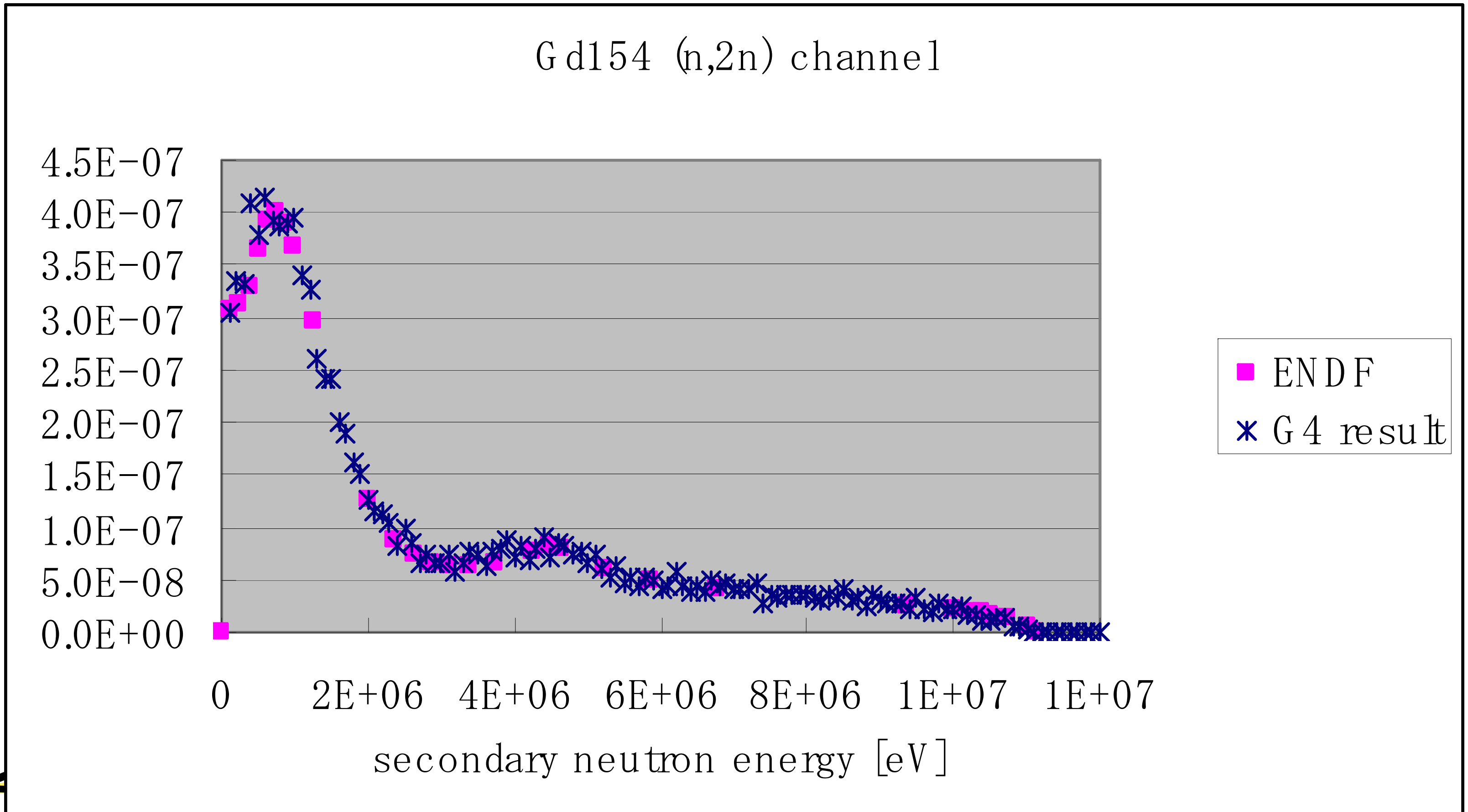
- Currently only Uranium data are available in G4NDL
- first chance, second chance, third chance and forth chance fission are into accounted.
- The neutron energy distributions are implemented in six different possibilities.
  - tabulated as a normalized function of the incoming and outgoing neutron energy – $f(E \rightarrow E')$
  - Maxwell spectrum – $f(E \rightarrow E') \propto \sqrt{E'} e^{E'/\Theta(E)}$
  - a general evaporation spectrum – $f(E \rightarrow E') \propto E' e^{E'/\Theta(E)}$
  - evaporation spectrum – $f(E \rightarrow E') = f\left(E' / \Theta(E) \right)$
  - the energy dependent Watt spectrum – $f(E \rightarrow E') \propto e^{E'/a(E)} \sinh \sqrt{b(E)E'}$
  - the Madland Nix spectrum – $f(E \rightarrow E') = \frac{1}{2}\left[g\left(E', \langle K_l \rangle\right) + g\left(E', \langle K_h \rangle\right) \right]$

Verification of High Precision Neutron models
Channel Cross Sections

20MeV neutron on ^{157}Gd



Verification of High Precision Neutron models
Energy Spectrum of Secondary Particles



G4NeutornHP or LEModels

- Many elements remained without data for High Precision models.
- Those models make up for such data deficit.
- If the High Precision data are not available for a reaction, then Low Energy Parameterization Models will handle the reaction.
- Those can be used for not only for models (final state generator) but also for cross sections.
- Elastic, Inelastic, Capture and Fission models are prepared.

Thermal neutron scattering from chemically bound atoms

- At thermal neutron energies, atomic translational motion as well as vibration and rotation of the chemically bound atoms affect the neutron scattering cross section and the energy and angular distribution of secondary neutrons.
- The energy loss or gain of incident neutrons can be different from interactions with nuclei in unbound atoms.
- Only individual Maxwellian motion of the target nucleus (Free Gas Model) was taken into account the default NeutronHP models.

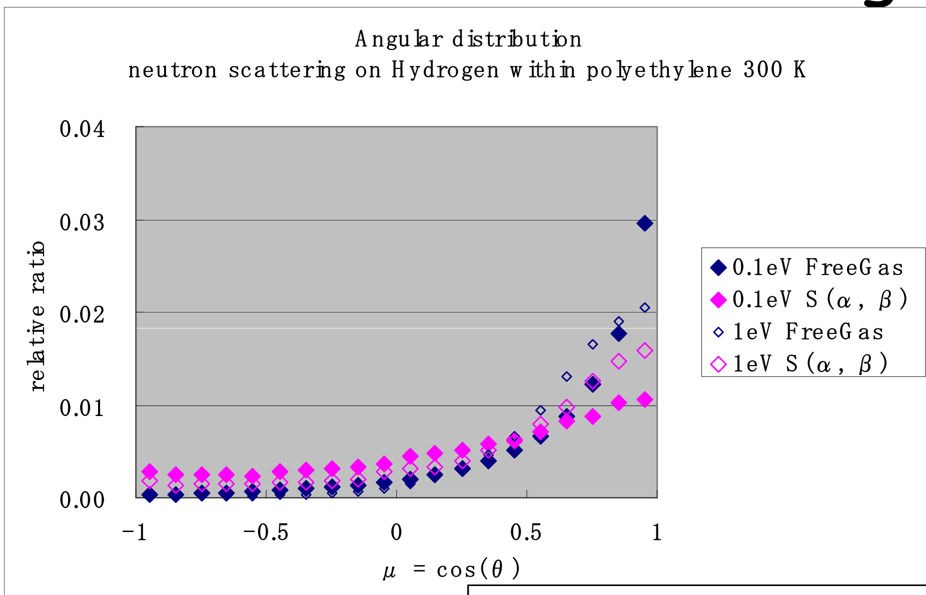
Thermal neutron scattering files from the evaluated nuclear data files ENDF/B-VI, Release2

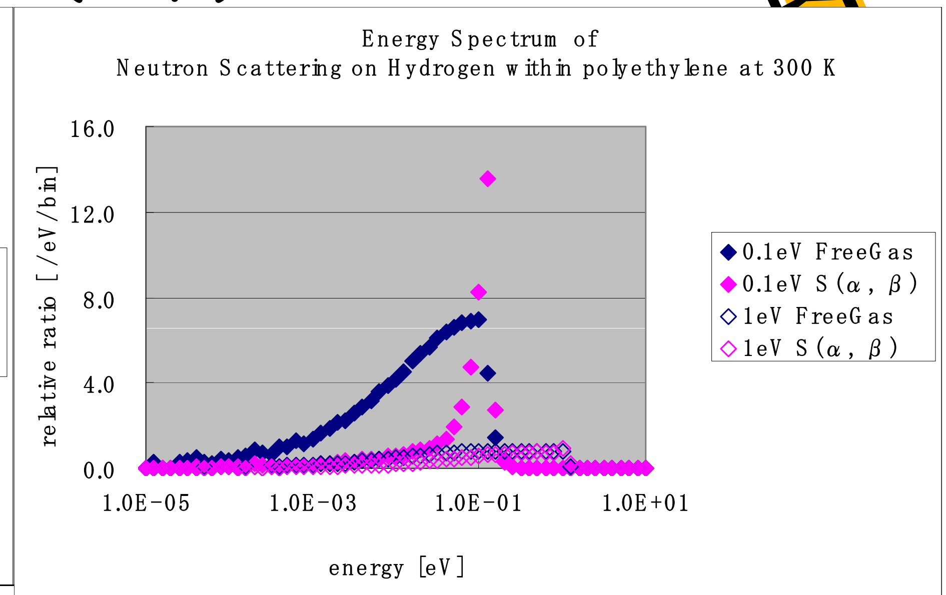
- These files constitute a thermal sub-library
- Use the File 7 format of ENDF/B-VI
- Divides the thermal scattering into different parts:
  - Coherent and incoherent elastic; no energy change
  - Inelastic; loss or gain in the outgoing neutron energy
- The files and NJOY are required to prepare the scattering law S(α,β) and related quantities.

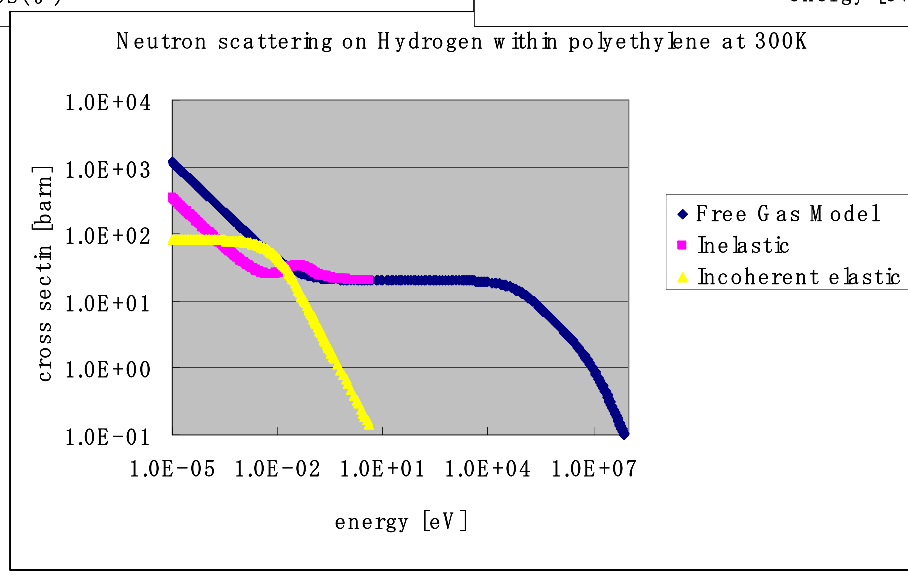
$$\text{Scattering cross section}: \sigma(E \to E', \mu) = \frac{\sigma_b}{2kT}\sqrt{\frac{E'}{E}}S(\alpha,\beta);$$

$$\text{momentum transfer}: \alpha = \frac{E' + E - 2\sqrt{E'E}\,\mu}{AkT}, \text{ energy transfer}: \beta = \frac{E' - E}{kT}$$

Cross section and Secondary Neutron Distributions using S(α, β) model







Summary

- High Precision Neutron models are data driven models and its used evaluated data libraries.
- However the library is not complete because there are no data for several key elements.
- Thermal neutron scattering model is not available in reference Physics List and should be included by user.