Probing Planetary Bodies for the Structure of Subsurface Volatiles:

Geant4 Models of Fast, Epithermal, and Thermal Neutron Emission
of Varying Stratigraphy of Water Bearing Regoliths.

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Annual Meeting of the

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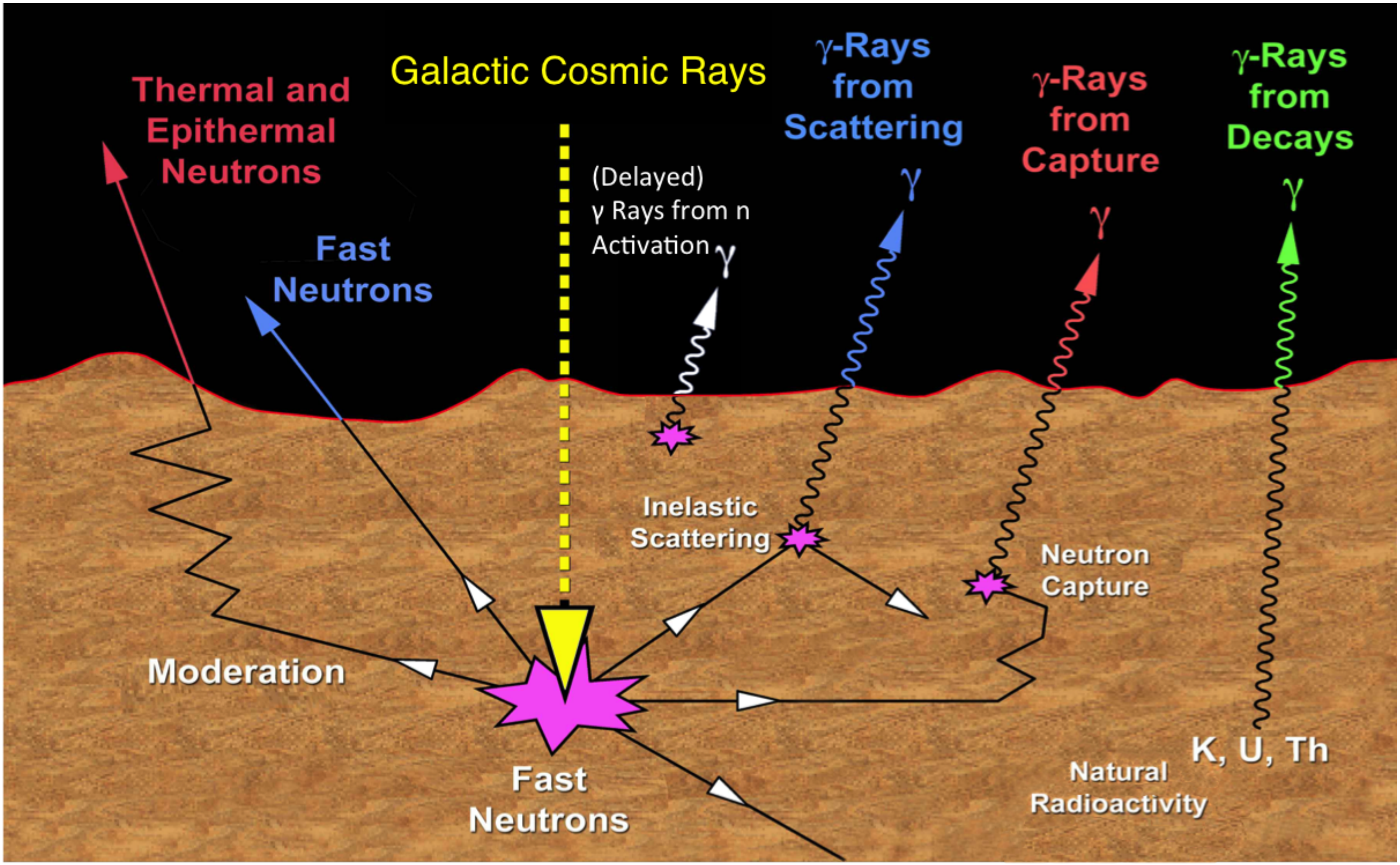
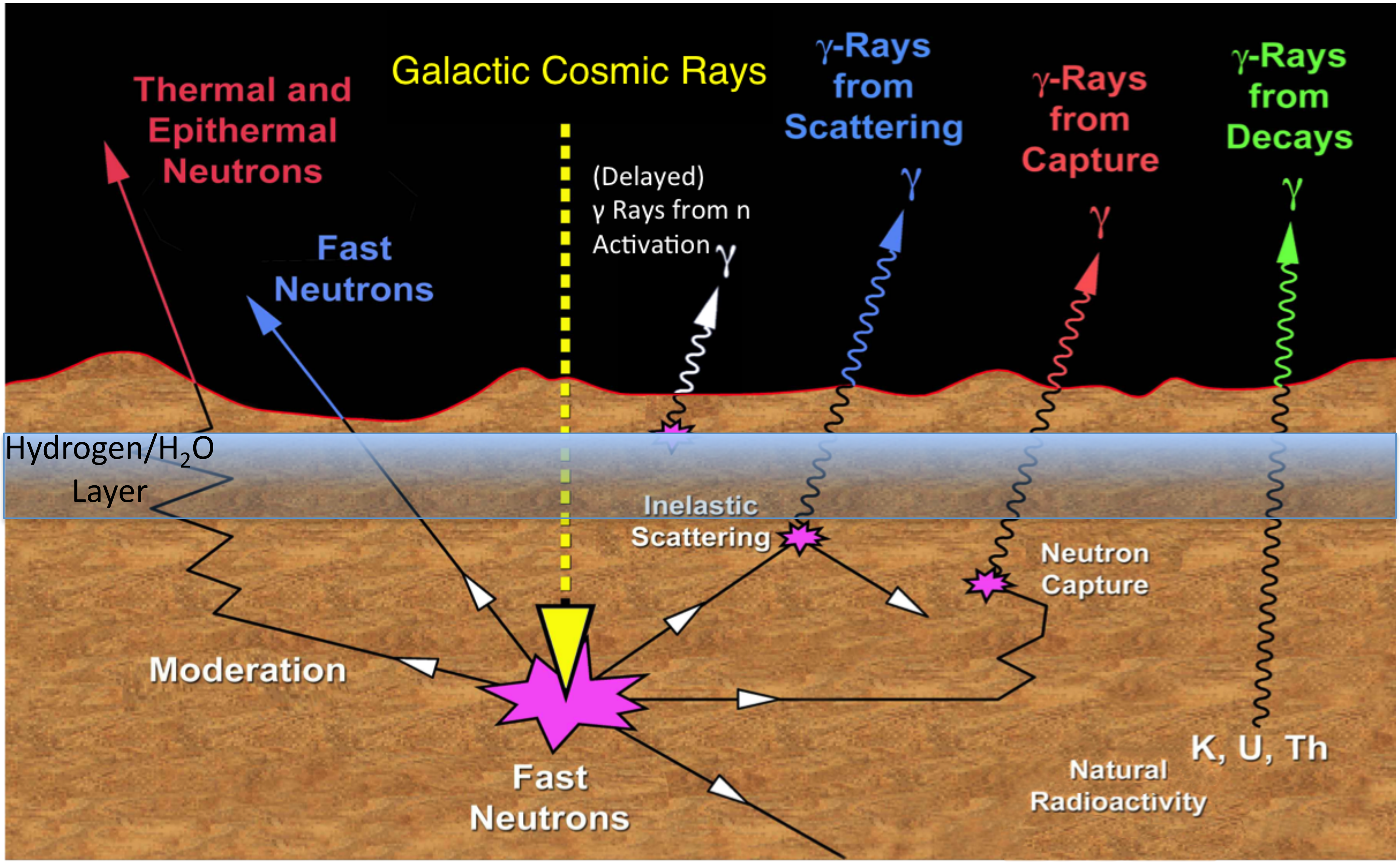
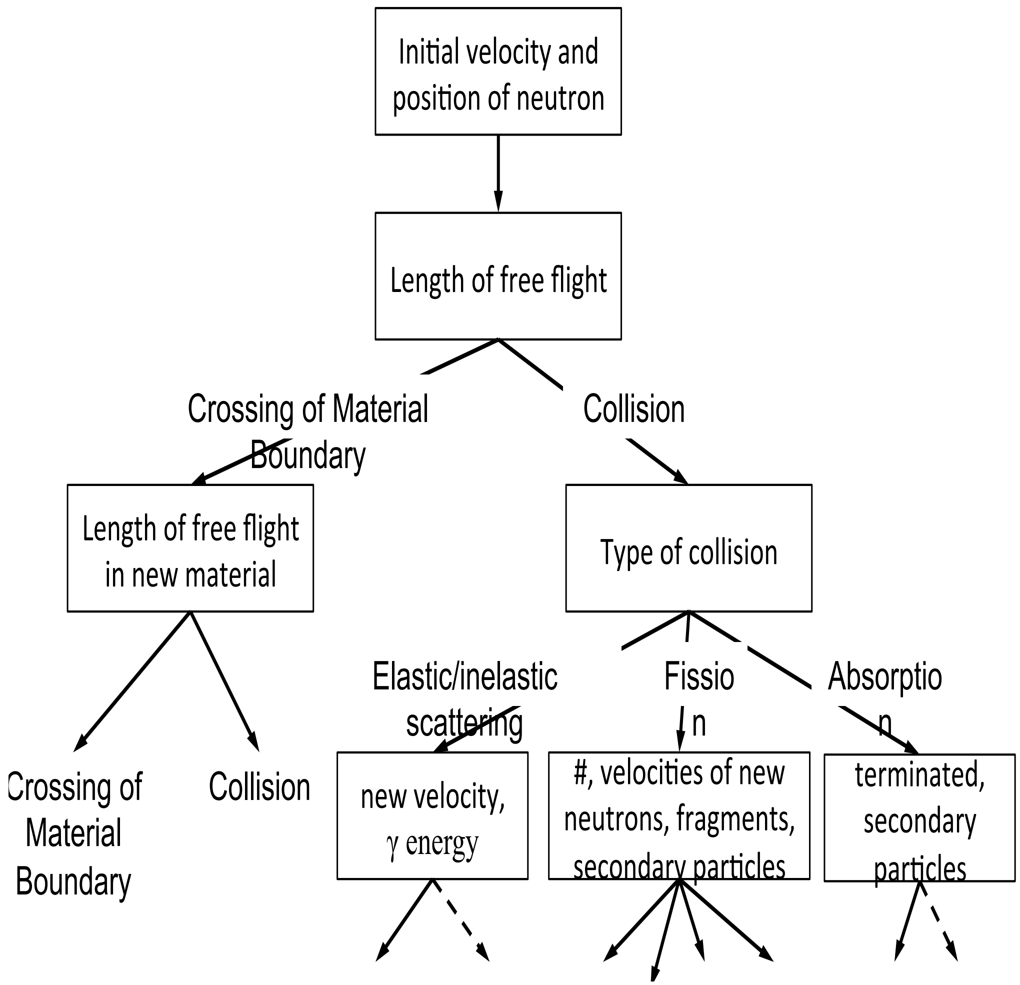


Thermal and Epithermal Neutrons
Galactic Cosmic Rays
γ-Rays from Scattering
γ-Rays from Capture
γ-Rays from Decays
(Delayed) γ Rays from n Activation
γ
γ
γ
γ
Fast Neutrons
Inelastic Scattering
Neutron Capture
Moderation
Fast Neutrons
K, U, Th
Natural Radioactivity



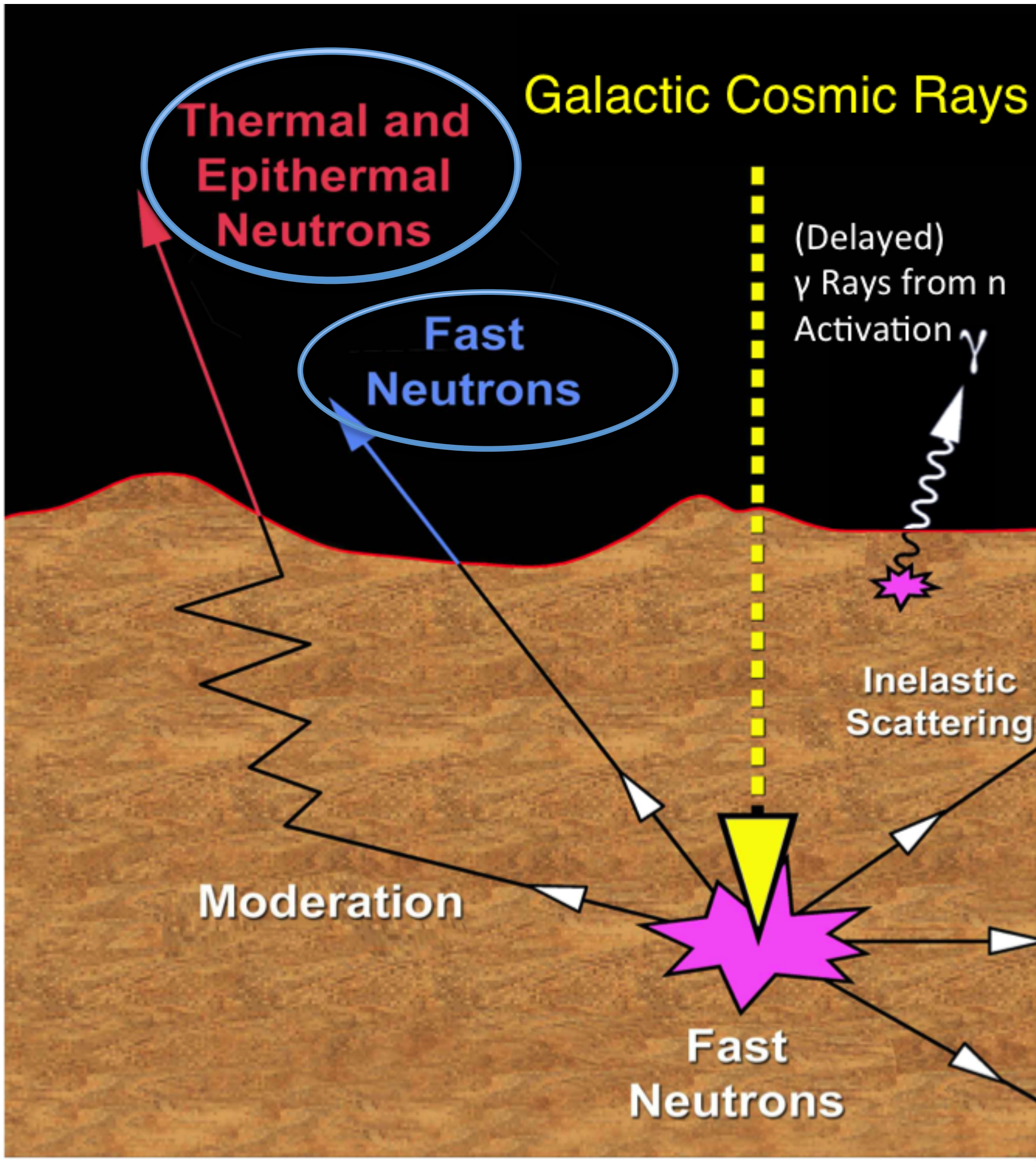
Thermal and Epithermal Neutrons
Galactic Cosmic Rays
γ-Rays from Scattering
γ-Rays from Capture
γ-Rays from Decays
(Delayed) γ Rays from n Activation
γ
γ
γ
γ
Fast Neutrons
Hydrogen/H_2O Layer
Inelastic Scattering
Neutron Capture
Moderation
Fast Neutrons
K, U, Th
Natural Radioactivity

Monte Carlo Simulations can model the generation and transport of neutrons in planetary regolith



- Monte Carlo (MC) technique was initially developed by von Neumann, Metropolis, Rosenbluth and others for the Manhattan Project at the Los Alamos National Lab (Metropolis *et al.* 1953).
- MC Codes such as MCNPX (Pelowitz, 2005) and FLUKA (Fasso *et al.* 2000) are available to simulate gamma ray and neutron production through the spallation process and the leakage spectrum from planetary surfaces.
- **Geant4** is an open source toolkit developed by CERN, Fermilab, SLAC, KEK, ESA and others for the simulation of the passage of particles through matter. It is widely used for high energy, nuclear and accelerator physics, as well as medical and space science. http://geant4.cern.ch
- **Geant4** output is a **Root** object therefore has powerful built-in graphics, statistical, and data analysis methods

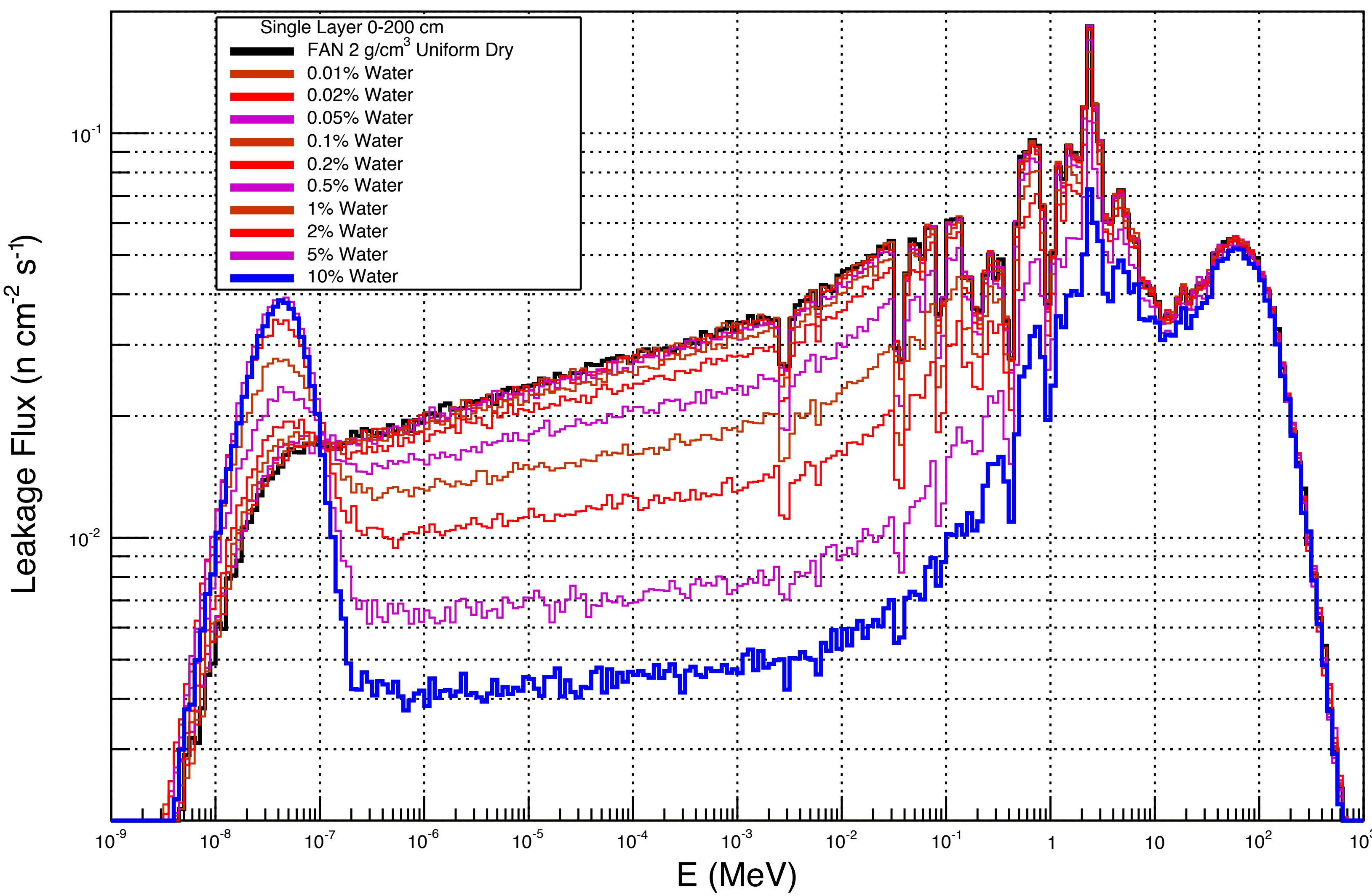
Geant4 Models of 3 Types of Subsurface Water Structure



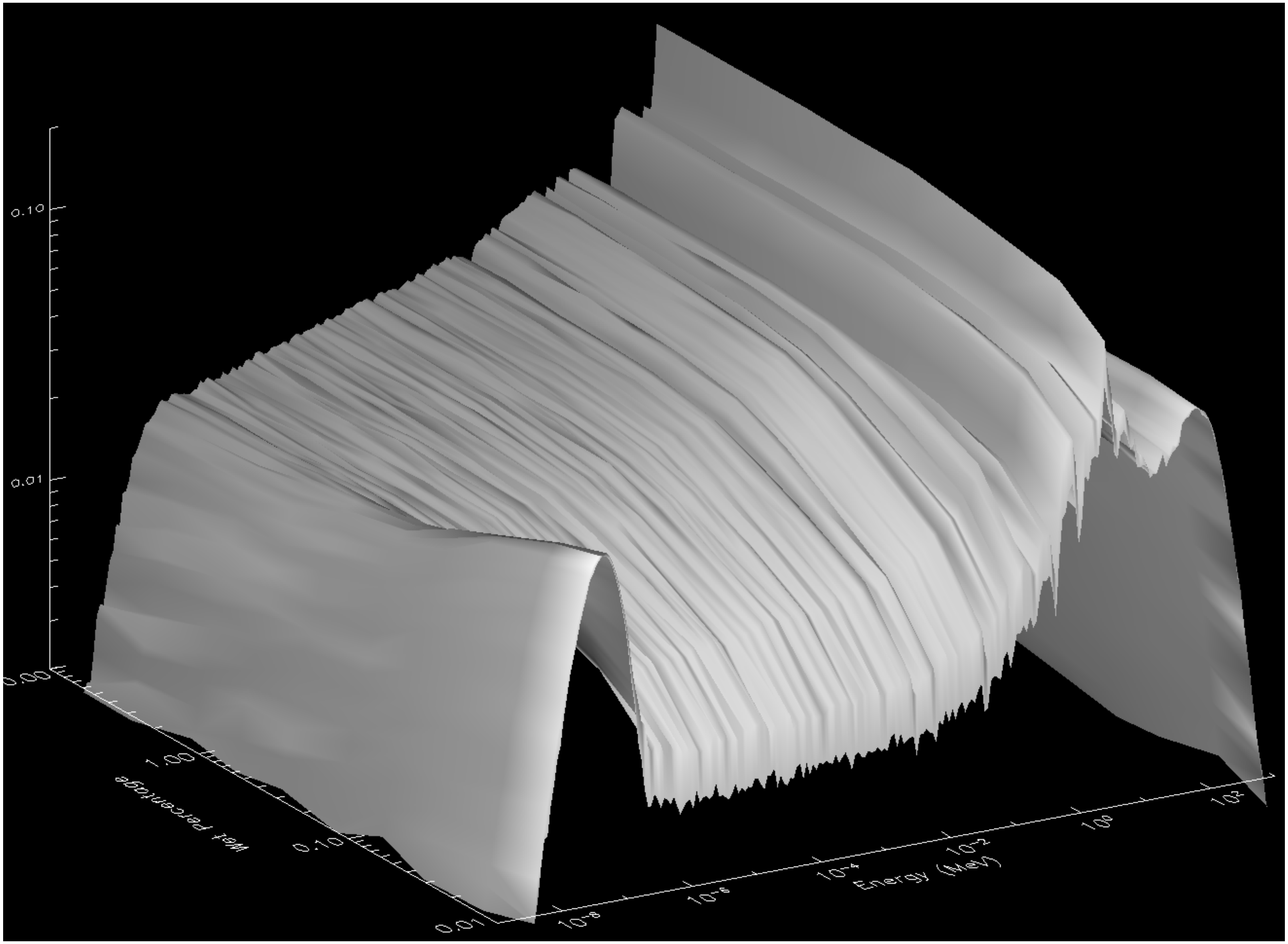
Dry FAN 2 gm/cm^3

Water Structure
Single Uniform Layer
200 cm thick
Water Abundance
0.1 to 10 % Wt

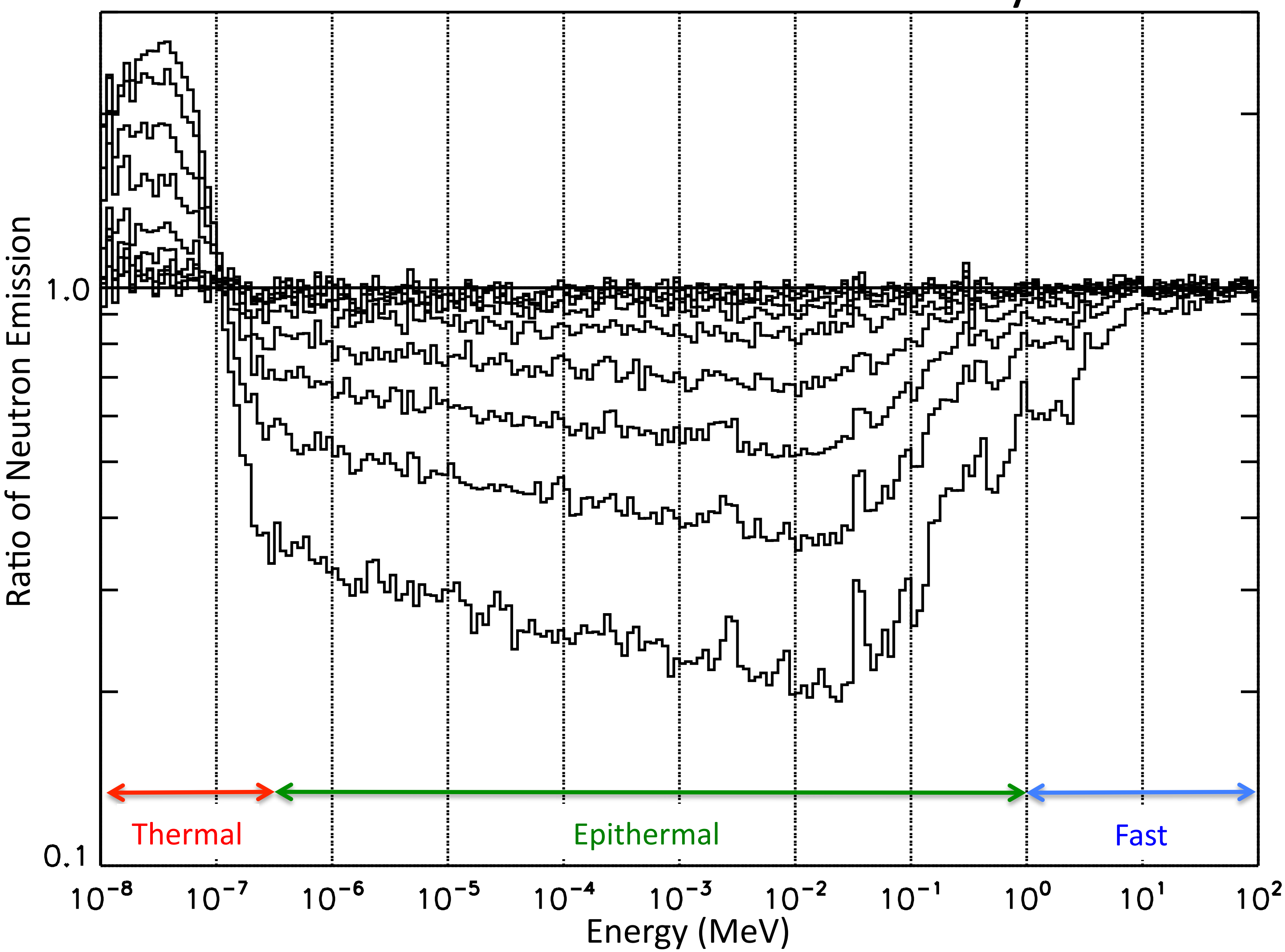
FAN Single Layer 200 cm thick 0.01 - 10% Wet

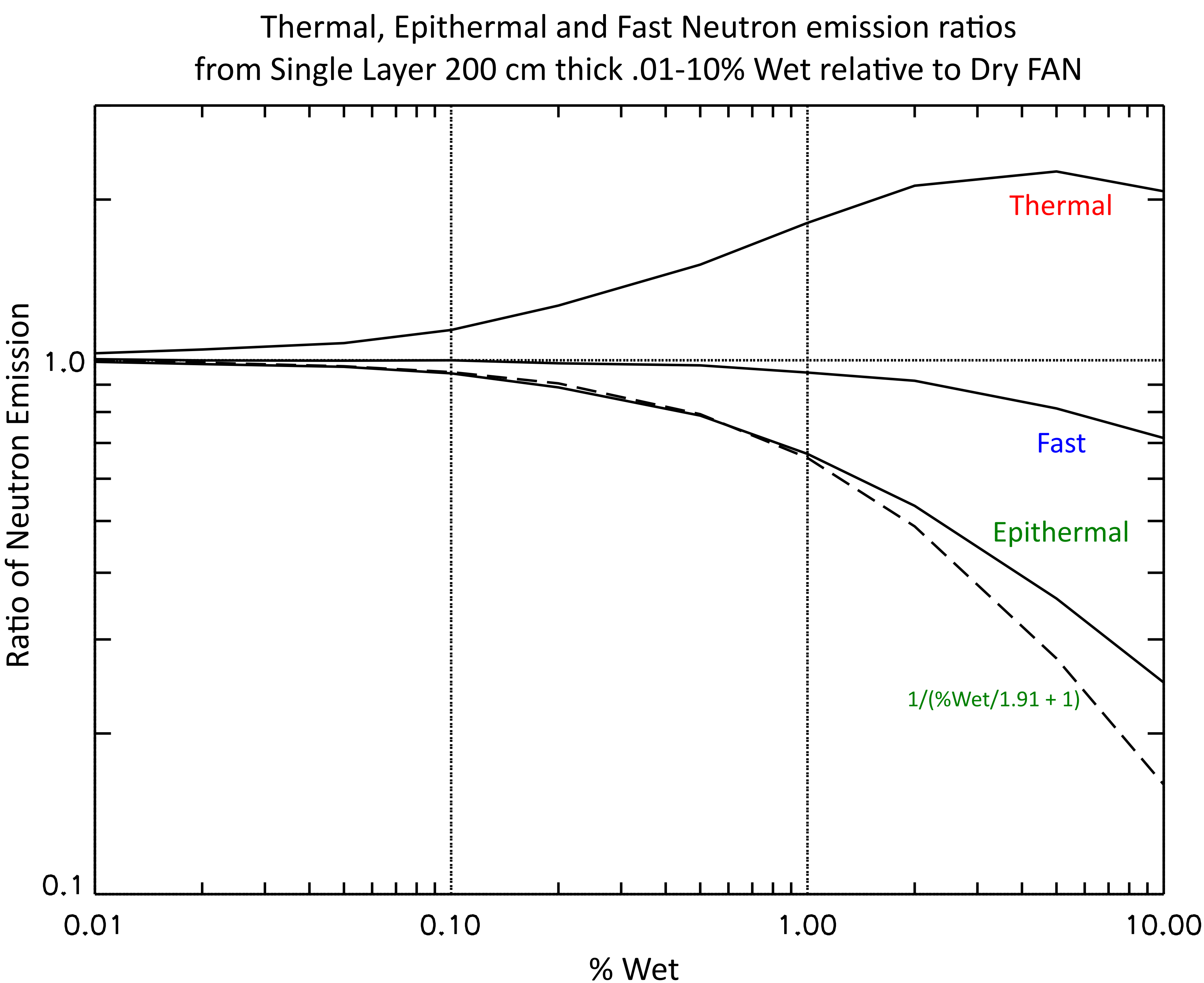


FAN Single Layer 200 cm thick .01-10% Wet

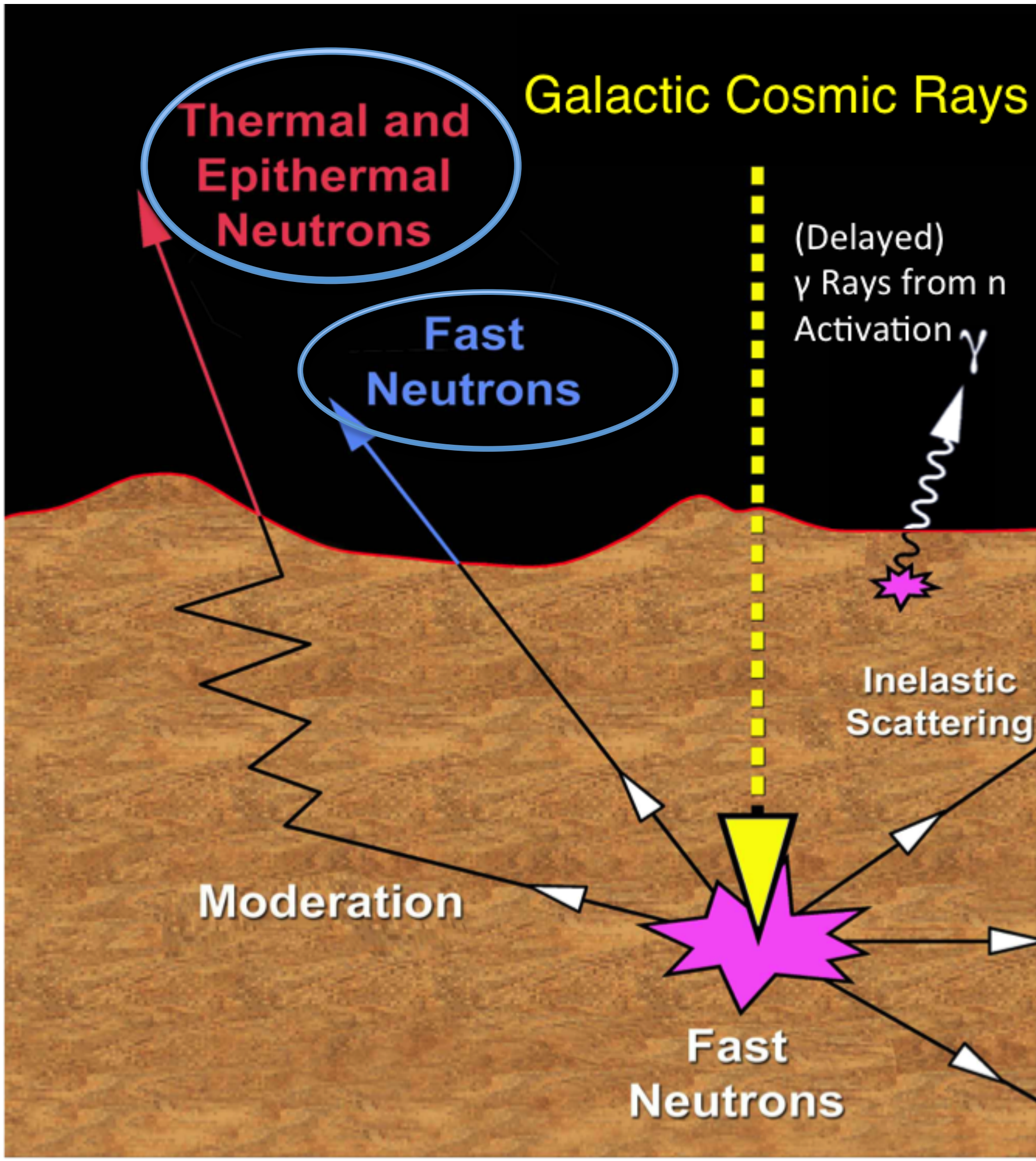


Neutron Emission Ratio from Single Layer 200 cm thick .01-10% Wet relative to Dry FAN



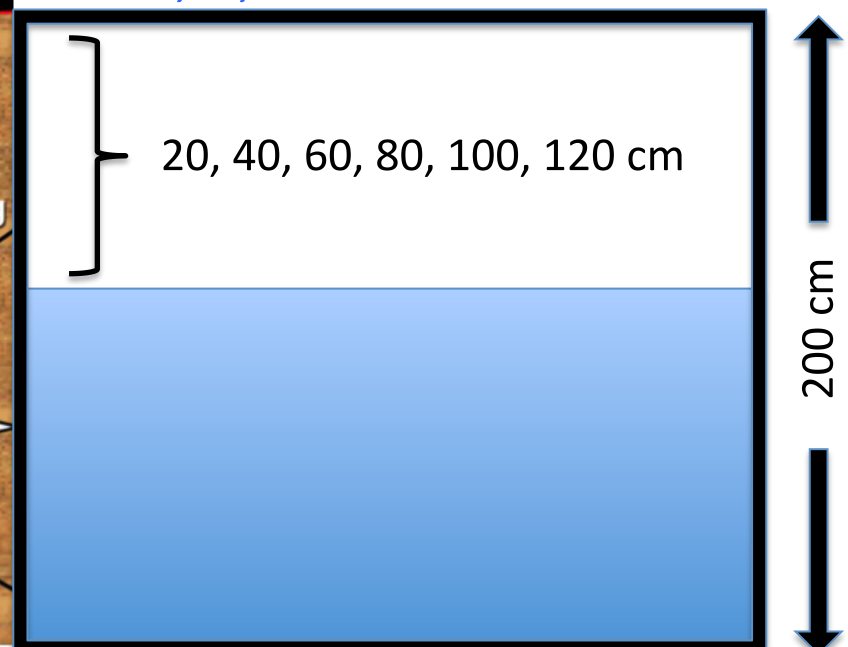

Thermal, Epithermal and Fast Neutron emission ratios
from Single Layer 200 cm thick .01-10% Wet relative to Dry FAN
Ratio of Neutron Emission
1.0
0.1
0.01
0.10
1.00
10.00
% Wet
Thermal
Fast
Epithermal
1/(%Wet/1.91 + 1)

Geant4 Models of 3 Types of Subsurface Water Structure

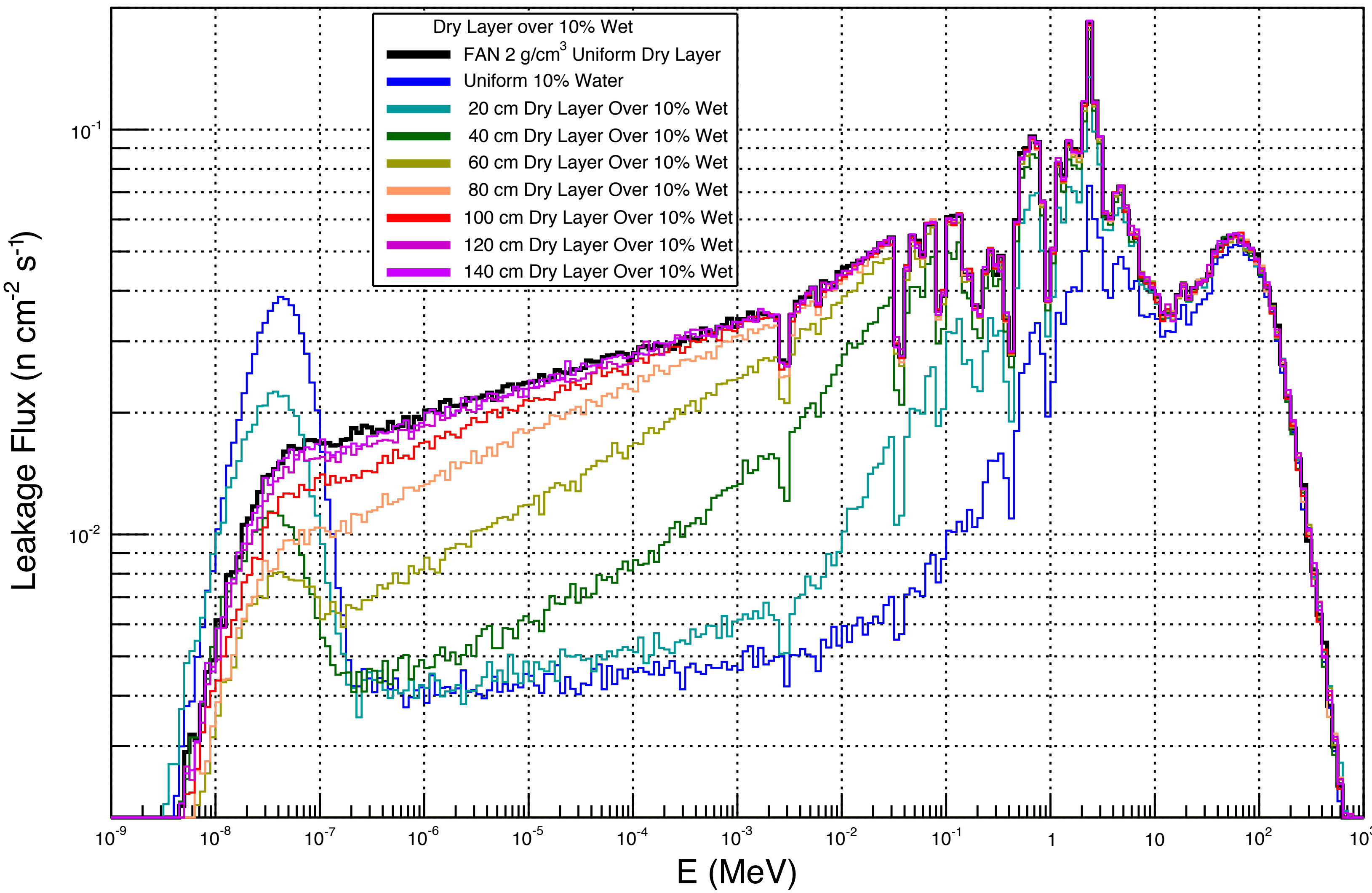


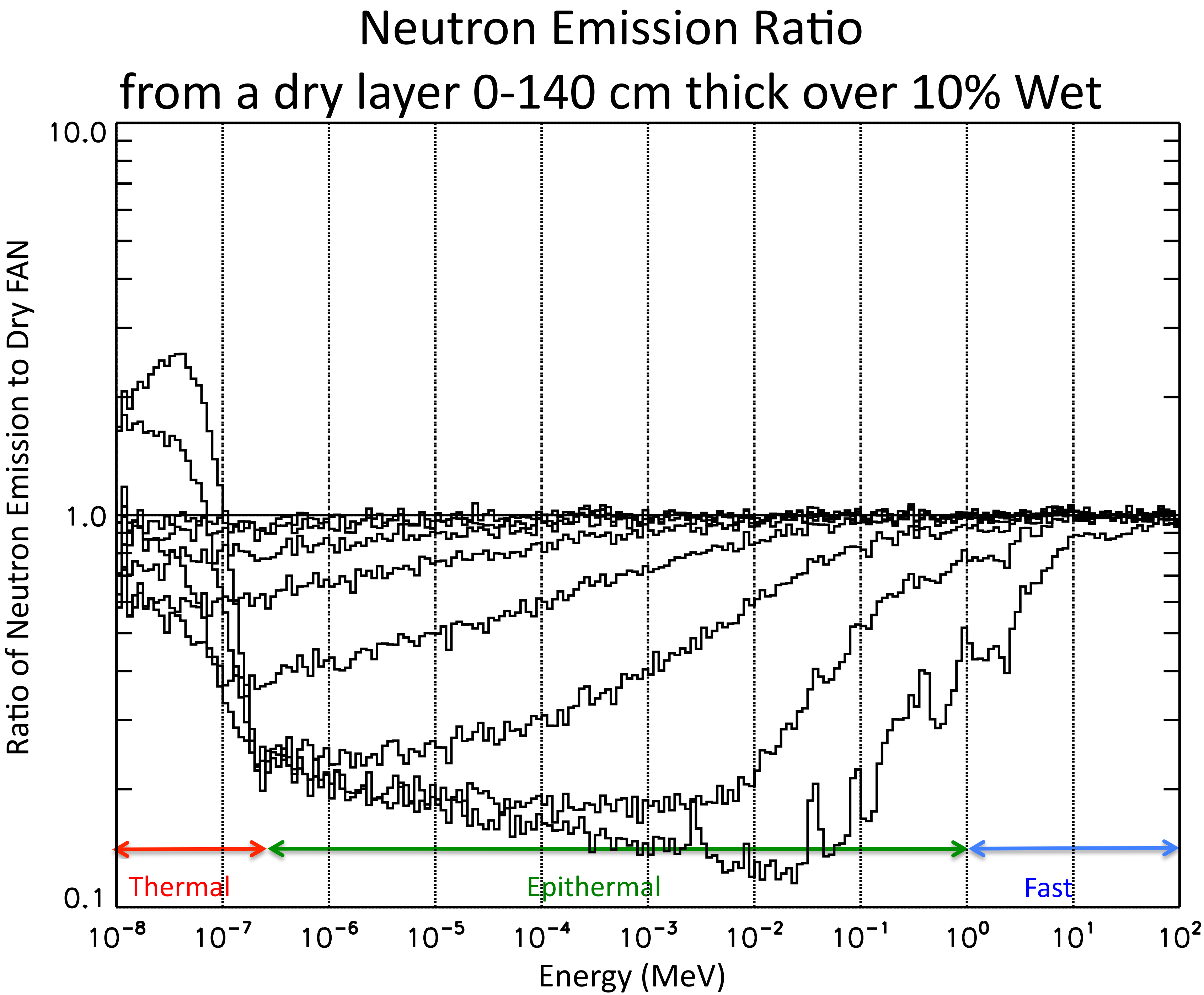
Dry FAN 2 gm/cm^3

Water Structure
Single Uniform Layer
Varying Depth
Water Abundance
1, 2, 5 and 10 % Wt



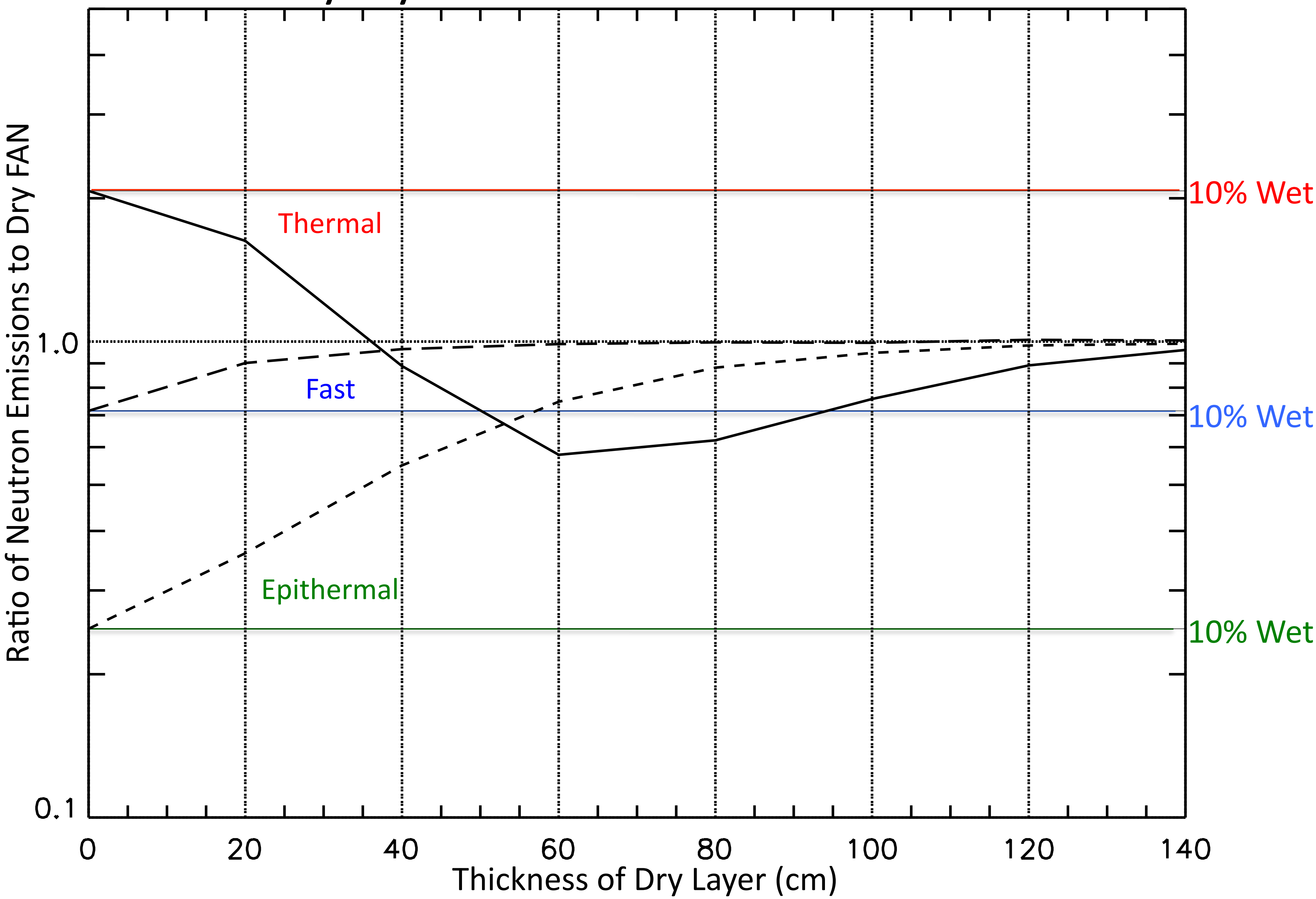
Dry FAN over 10% Wet



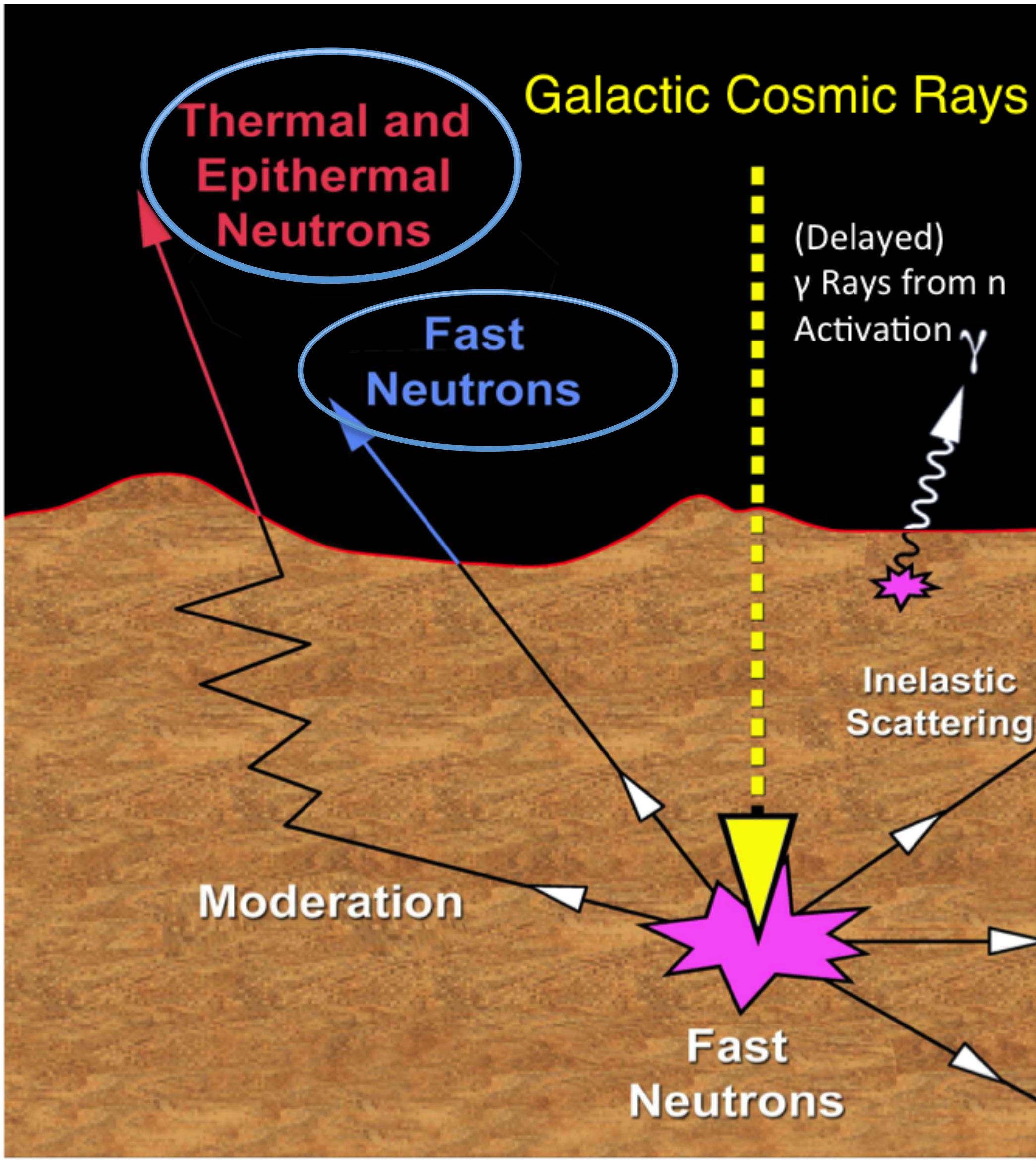


Neutron Emission Ratio
from a dry layer 0-140 cm thick over 10% Wet
Ratio of Neutron Emission to Dry FAN
10.0
1.0
0.1
Thermal
Epithermal
Fast
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}
Energy (MeV)

Neutron Emission Ratio
from a dry layer 0-140 cm thick over 10% Wet

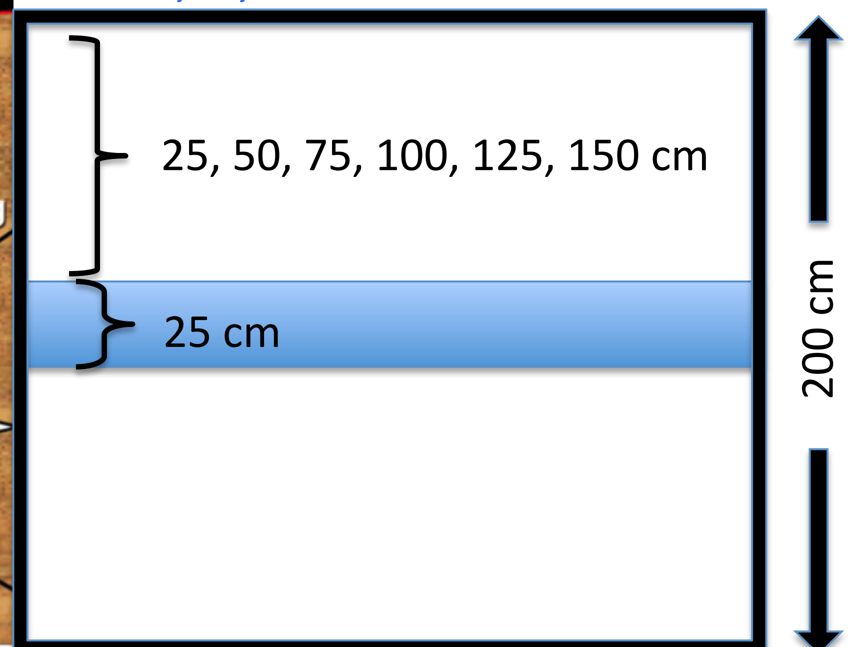


Geant4 Models of 3 Types of Subsurface Water Structure

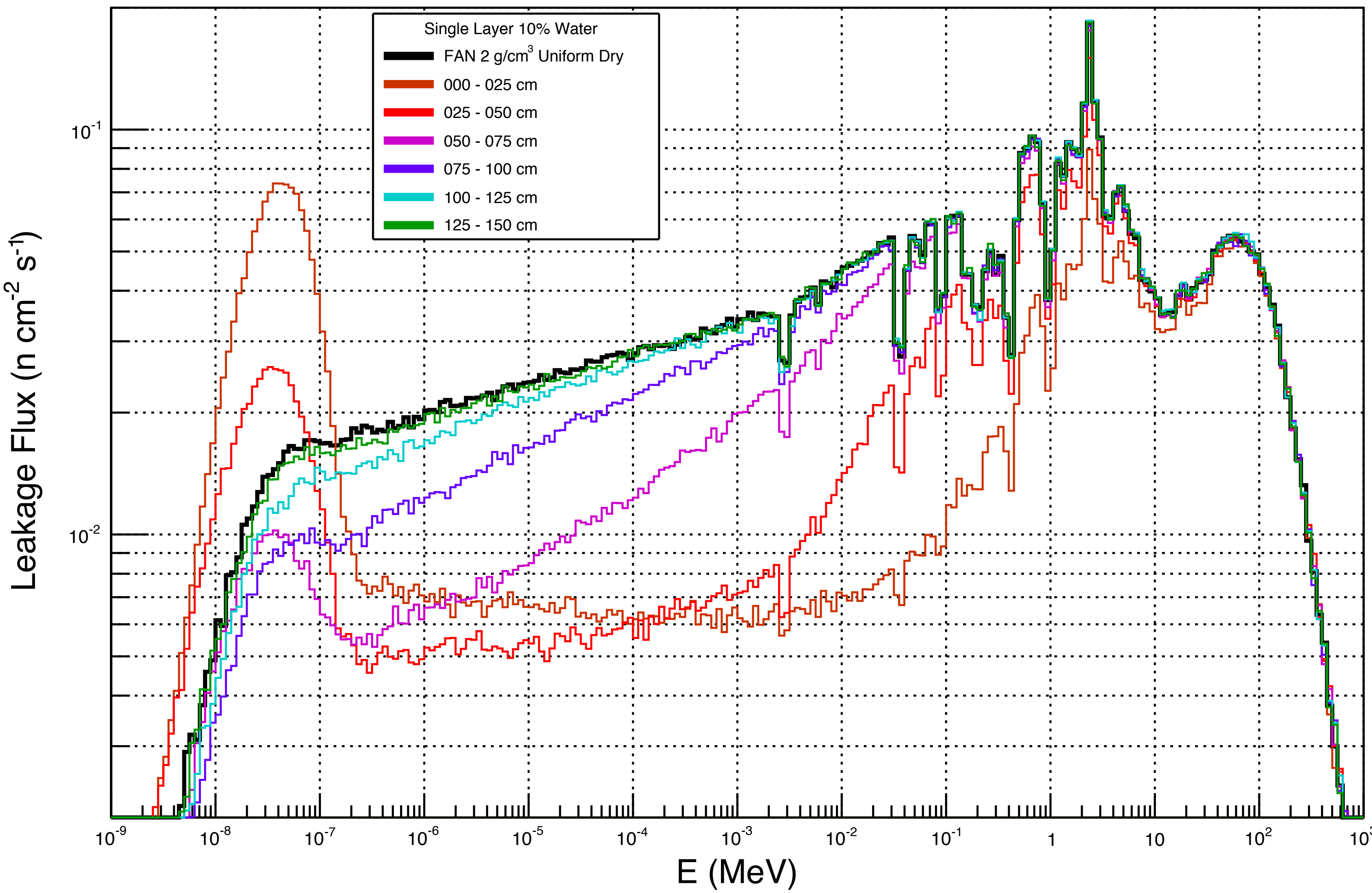


Dry FAN 2 gm/cm^3

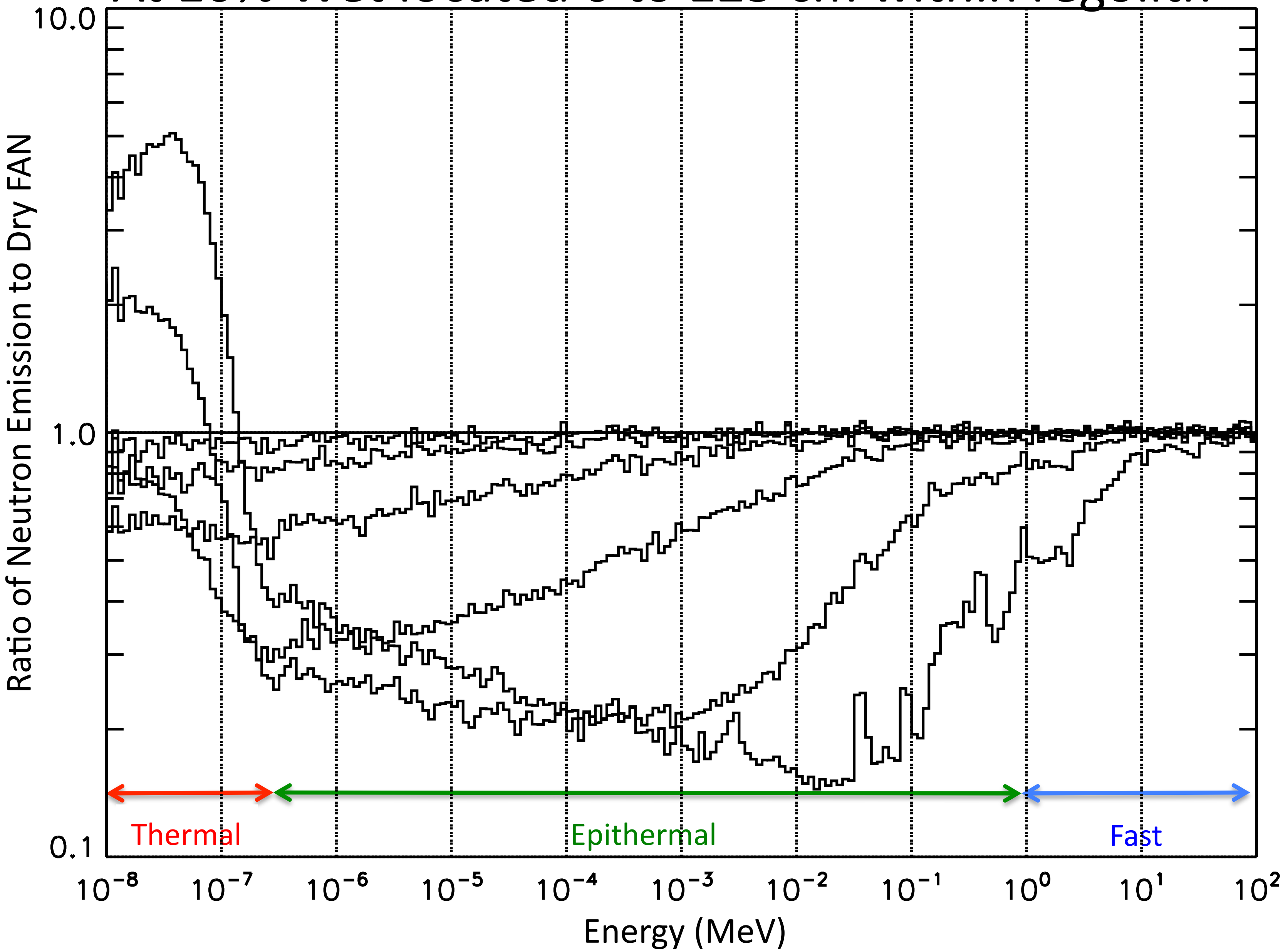
Water Structure
Single Uniform Layer 25 cm
Varying Depth
Water Abundance
1, 2, 5 and 10 % Wt

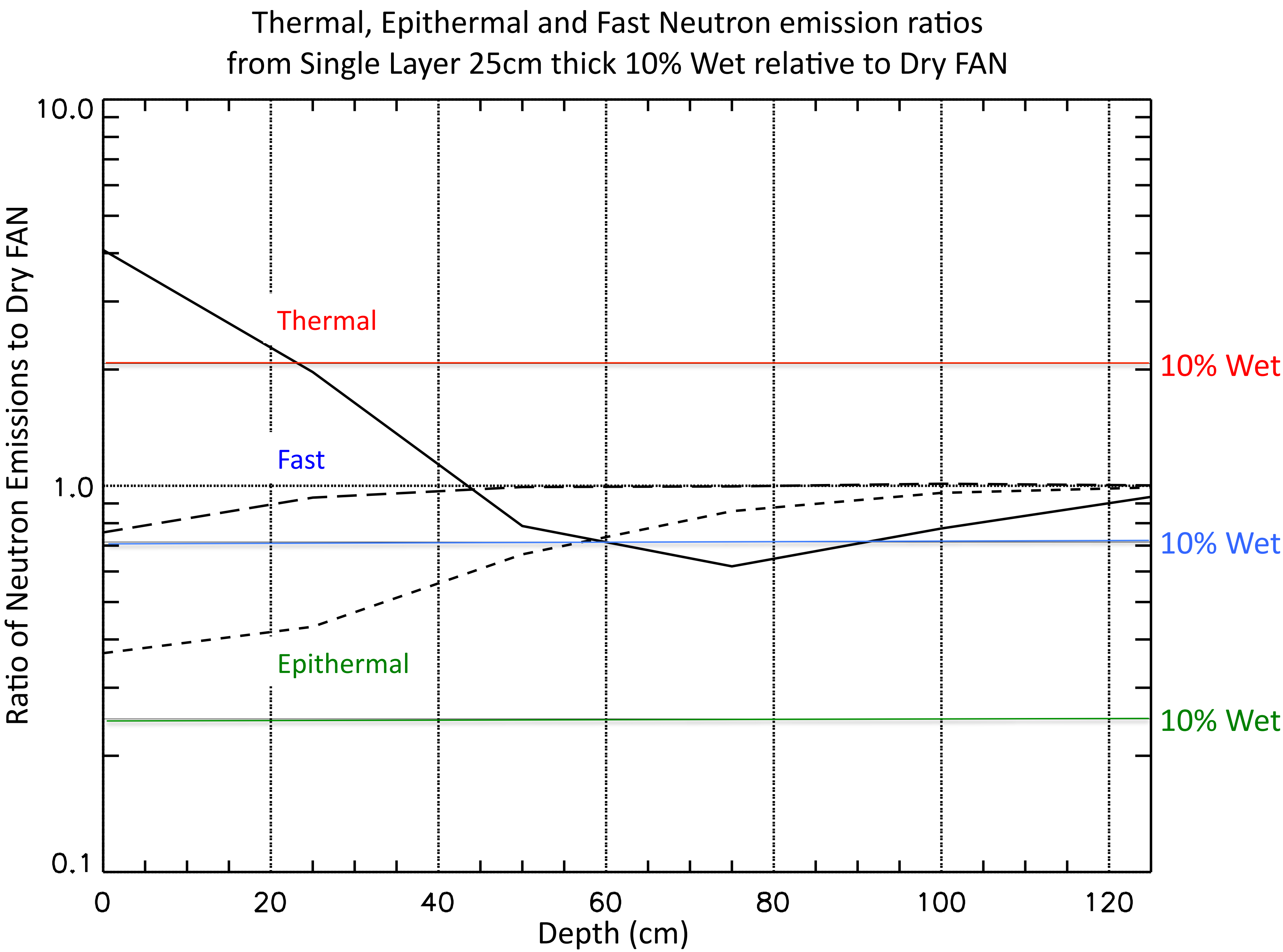


FAN Single Layer 25 cm thick 10% Wet



Neutron Emission Ratio from a layer 25 cm thick At 10% Wet located 0 to 125 cm within regolith




Thermal, Epithermal and Fast Neutron emission ratios
from Single Layer 25cm thick 10% Wet relative to Dry FAN
Ratio of Neutron Emissions to Dry FAN
10.0
1.0
0.1
Thermal
Fast
Epithermal
10% Wet
10% Wet
10% Wet
0
20
40
60
80
100
120
Depth (cm)

Conclusions

- Neutron energy can be binned into Thermal, Epithermal and Fast neutron ranges.
- Abundance of hydrogen/water can be inferred by the suppression of Epithermal neutrons.
- Thermal neutron emission is enhanced by the presence of hydrogen/water, and is highly sensitive its abundances but at abundances >2% the curve flattens out.
- **Burial depth of wet soil layer modifies the emergent neutron spectrum.**
  - Emergent flux compared to flux from dry soil in Thermal, Epithermal, and Fast energy bins show different behavior as a function of depth
  - Thermal neutron flux decreases monotonically with burial depth to about 60 cm, whereas epithermal neutron flux increases monotonically as burial depth increases.
  - Is there diurnal variation of the vertical structure layering (thermal vertical pumping) of lunar volatiles?