Probing Planetary Bodies for Subsurface Volatiles: Geant4 Models of Thermal, Epithermal, and Fast Neutron Flux

Gordon Chin

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA,
(gordon.chin@nasa.gov)

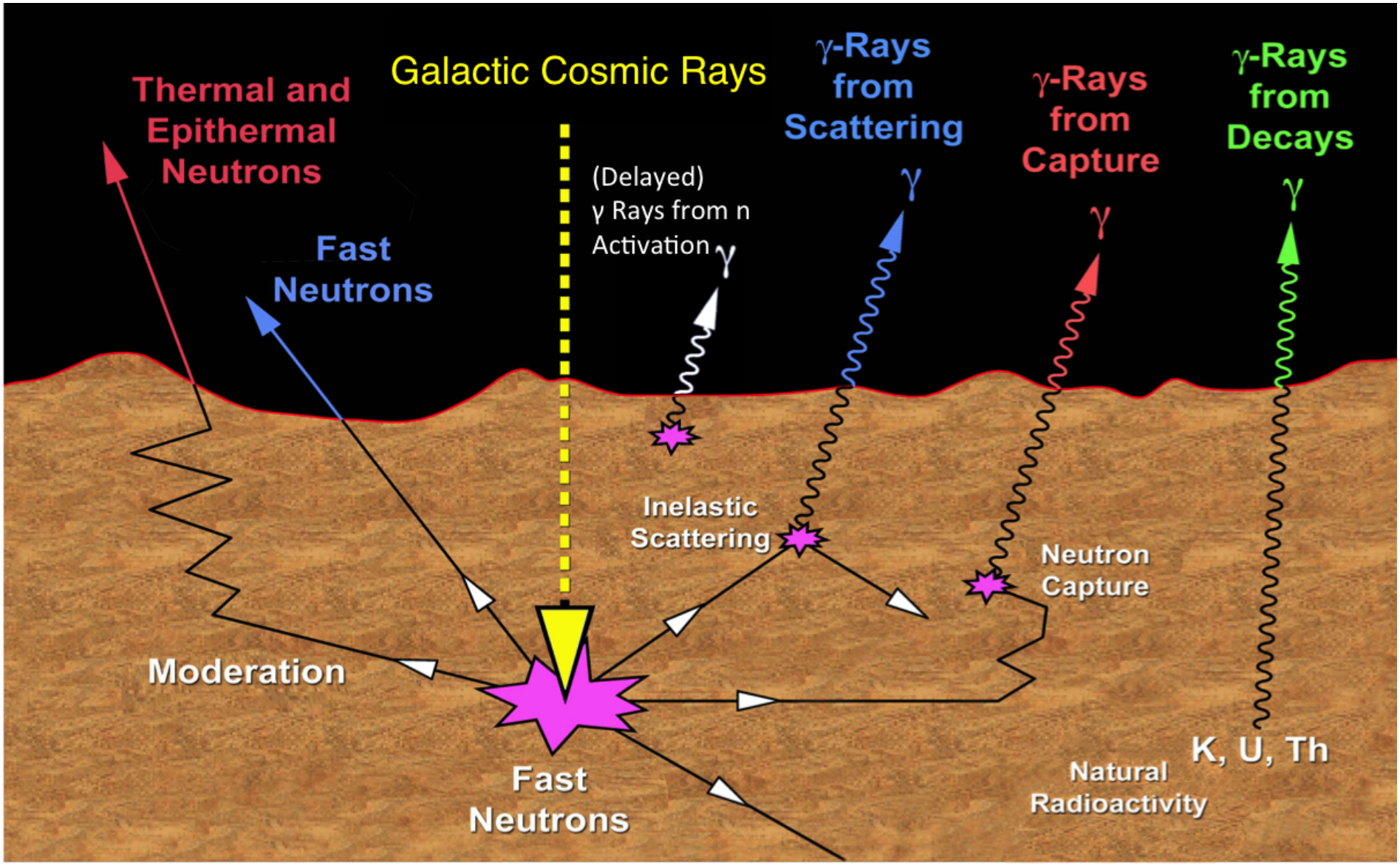
R. Sagdeev, J.J. Su, Joseph Murray

Department of Physics, University of Maryland, College Park, Maryland, USA

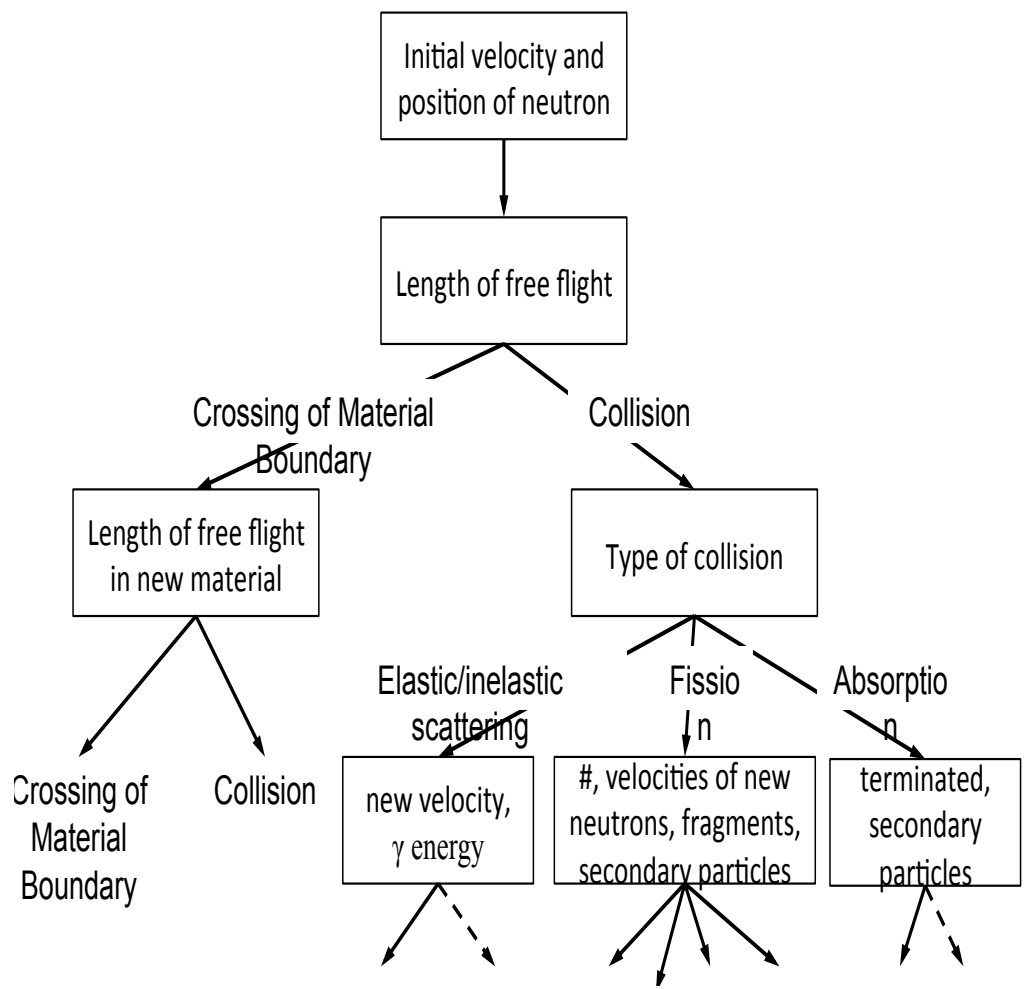
Exploration Science Forum II

NASA Ames, Mountain View CA, USA

July 21-23, 2015

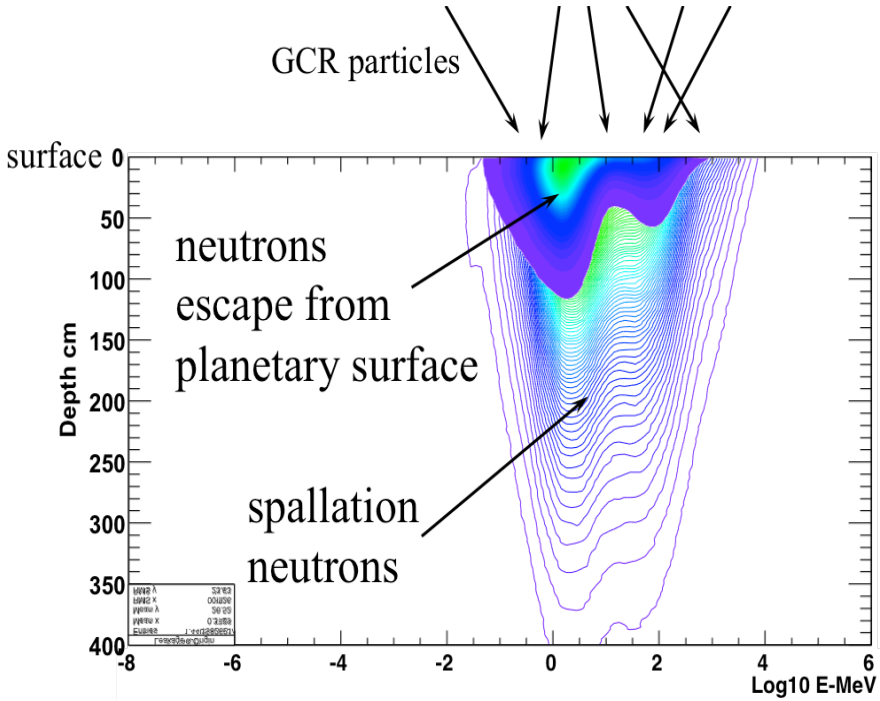

Thermal and Epithermal Neutrons
Galactic Cosmic Rays
γ-Rays from Scattering
γ-Rays from Capture
γ-Rays from Decays
(Delayed) γ Rays from n Activation
γ
Fast Neutrons
Inelastic Scattering
Neutron Capture
Moderation
Fast Neutrons
Natural Radioactivity
K, U, Th

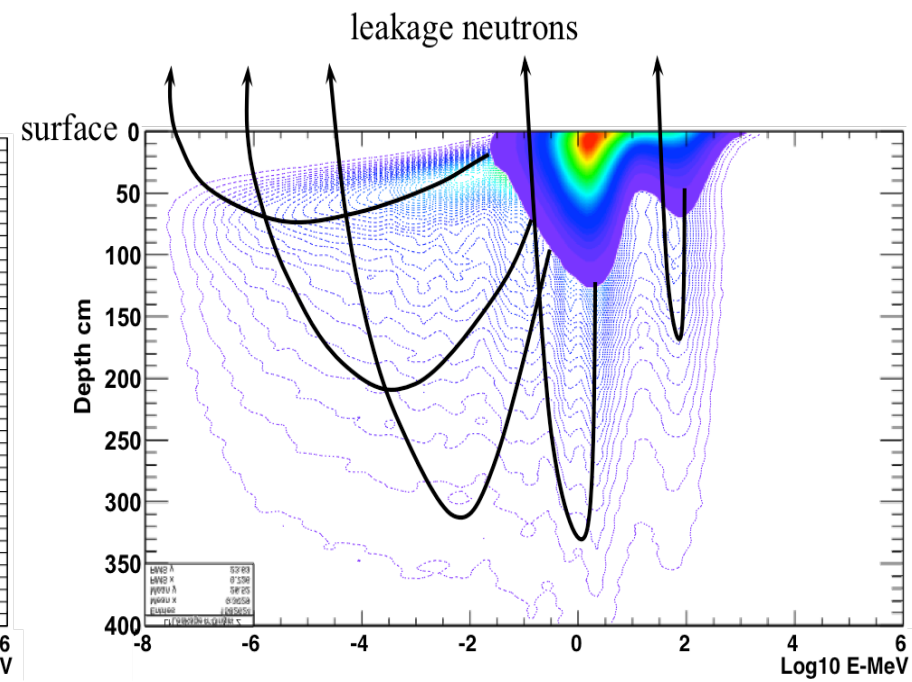
Monte Carlo Simulations can model the generation and transport of neutrons in planetary regolith



- 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 simulates the production and transport of neutrons and gamma rays generated by GCR impact



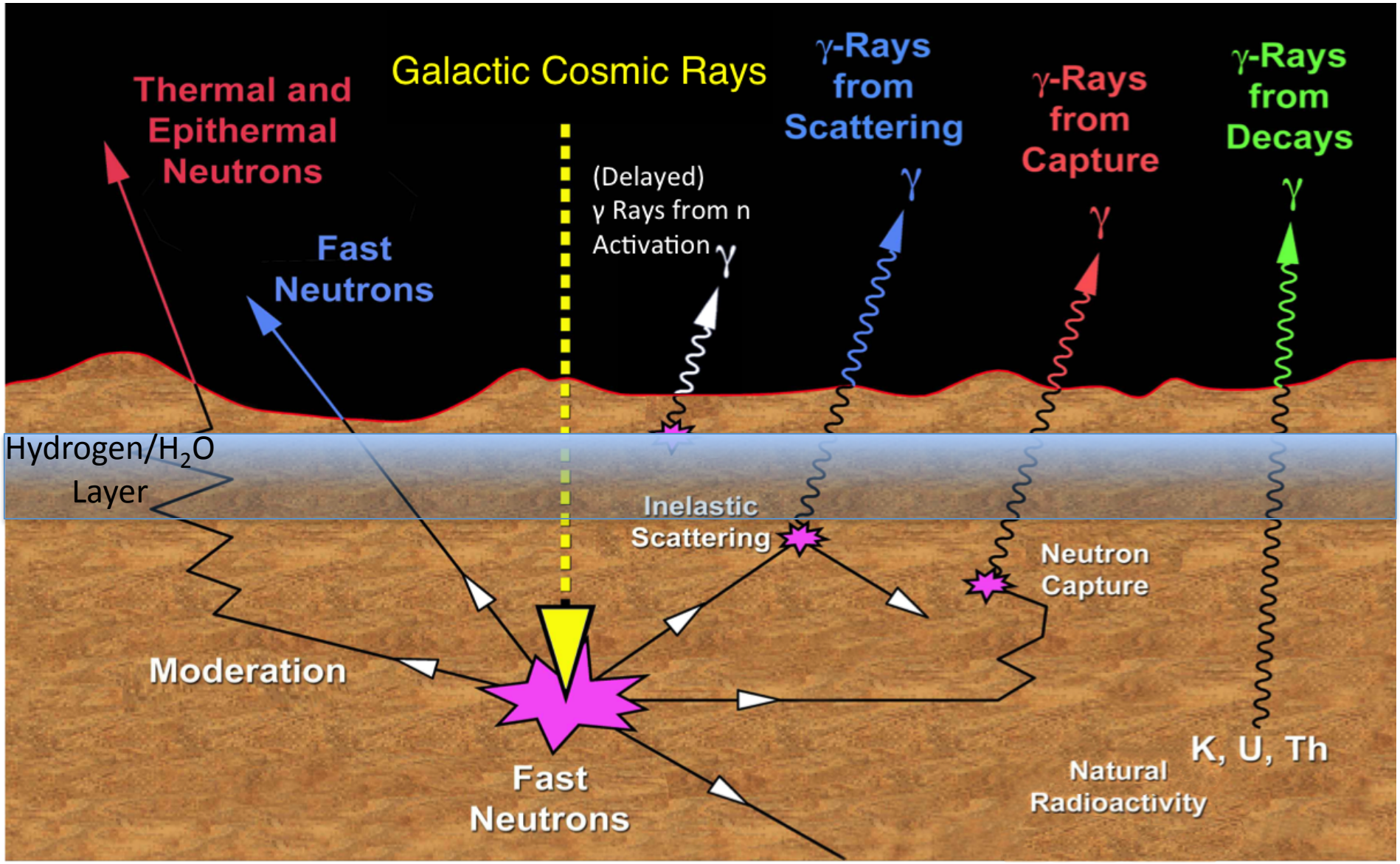


Lunar neutrons are produced within a few meters of the surface.

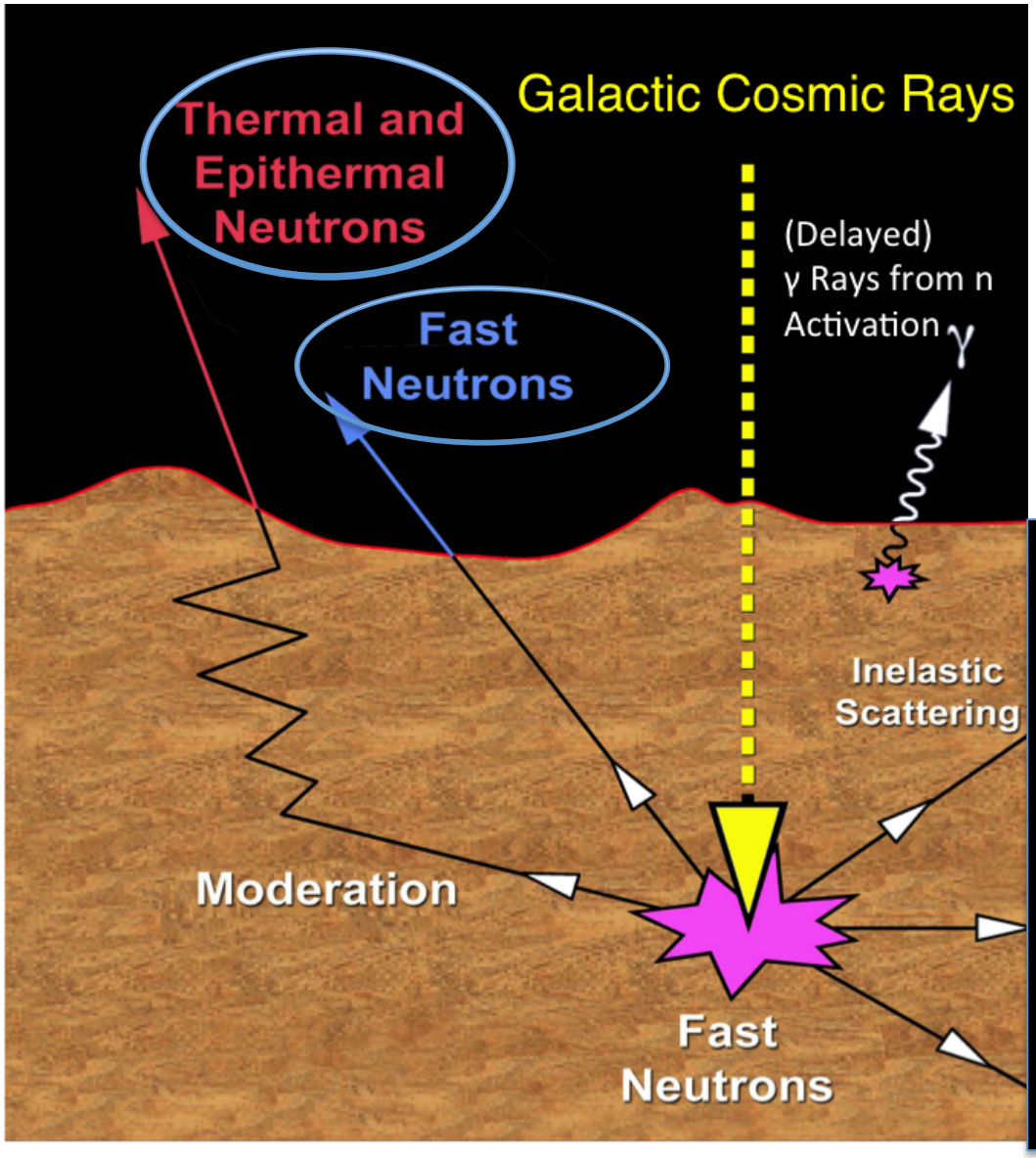
The filled color contour area shows the origin of leakage neutrons. Neutrons that originate below 1 meter deep rarely escape, but contribute to gamma ray emission from excited residual nuclei. The x-axis is the neutron initial energy and the y-axis is the depth of origin. Neutrons are mainly created with energy of a few MeV.

Depth probed by leakage neutron.

The x-axis is the energy at detection of leakage neutrons and the y-axis is the maximum depth that the leakage neutrons have reached. Leakage neutron energy varies from tens of MeV to less than 0.01 eV.


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
Fast Neutrons
Hydrogen/H_2O Layer
Inelastic Scattering
Neutron Capture
Moderation
Fast Neutrons
Natural Radioactivity
K, U, Th

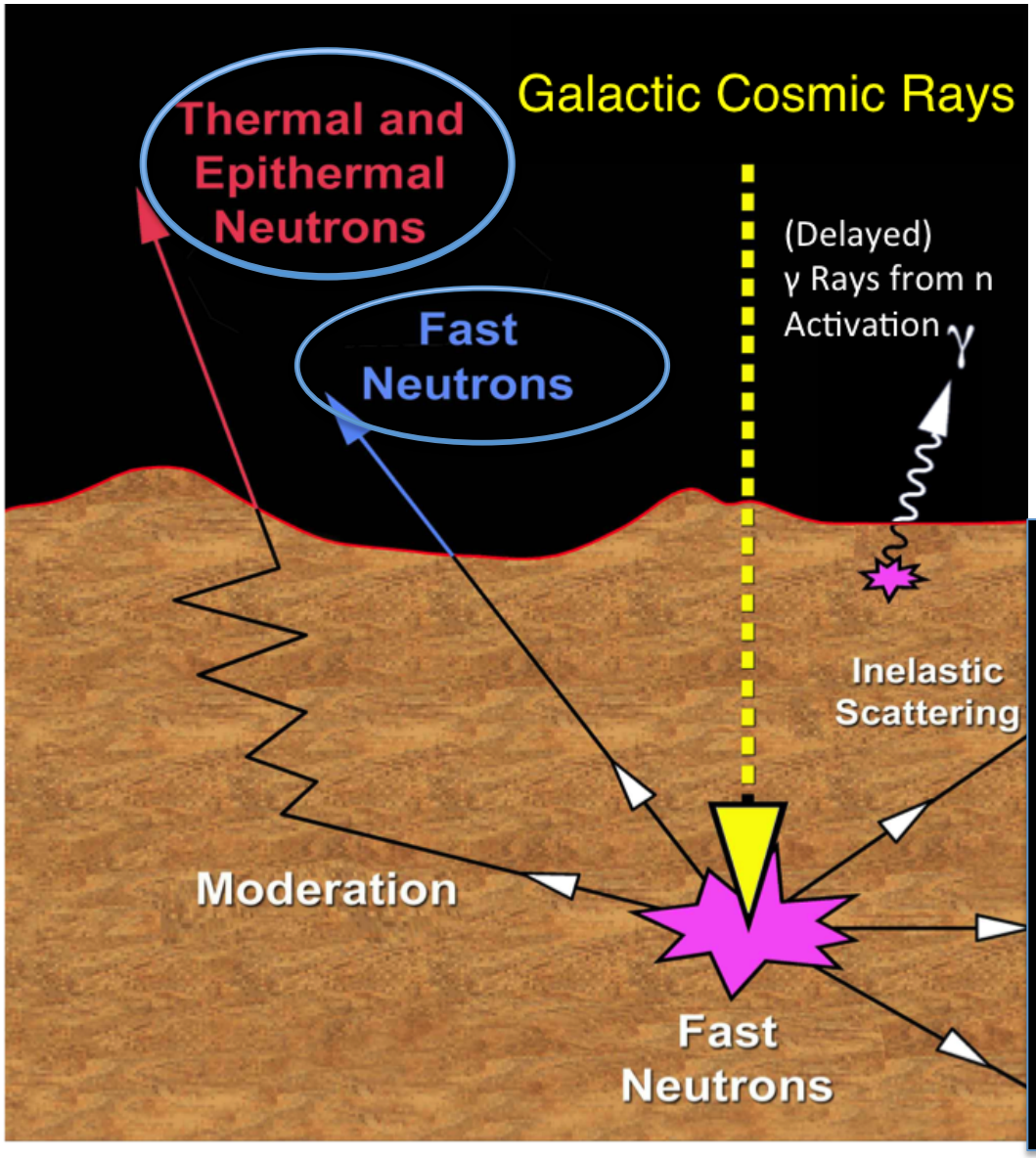
Geant4 Models of 3 Types of Subsurface Water Structure



Dry FAN 2 gm/cm^3

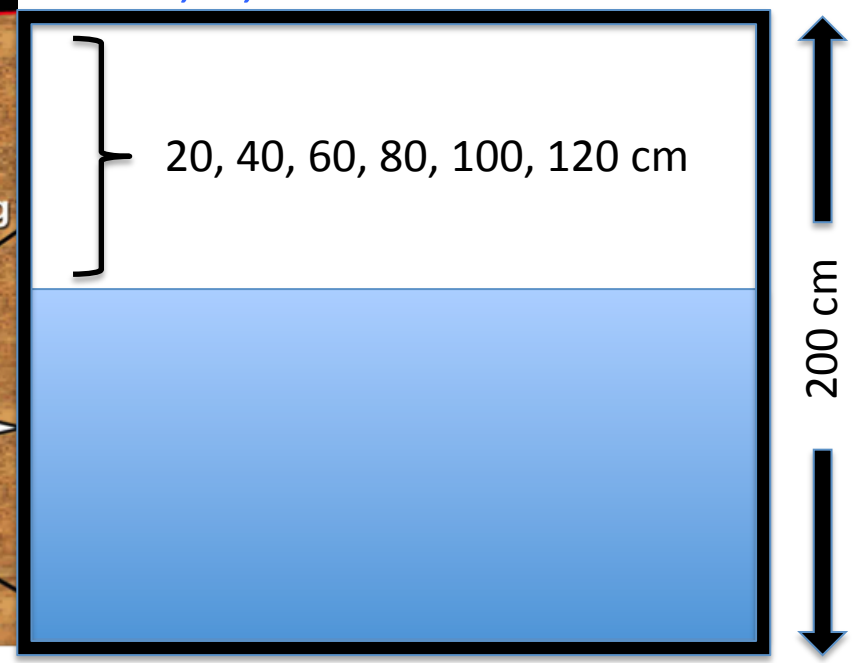
Water Structure
Single Uniform Layer
200 cm thick
Water Abundance
0.1 to 10 % Wt

Geant4 Models of 3 Types of Subsurface Water Structure

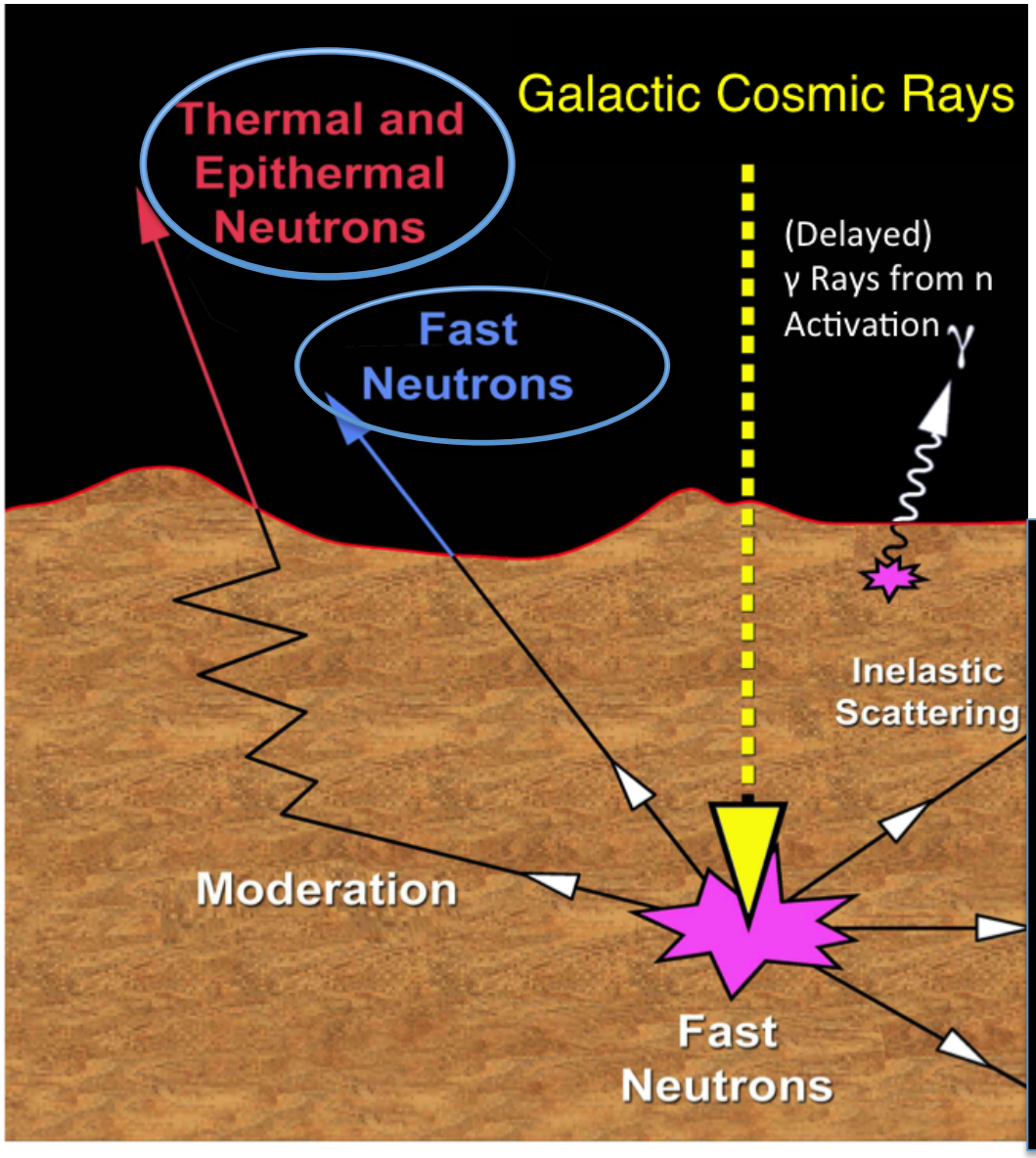


Dry FAN 2 gm/cm^3

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

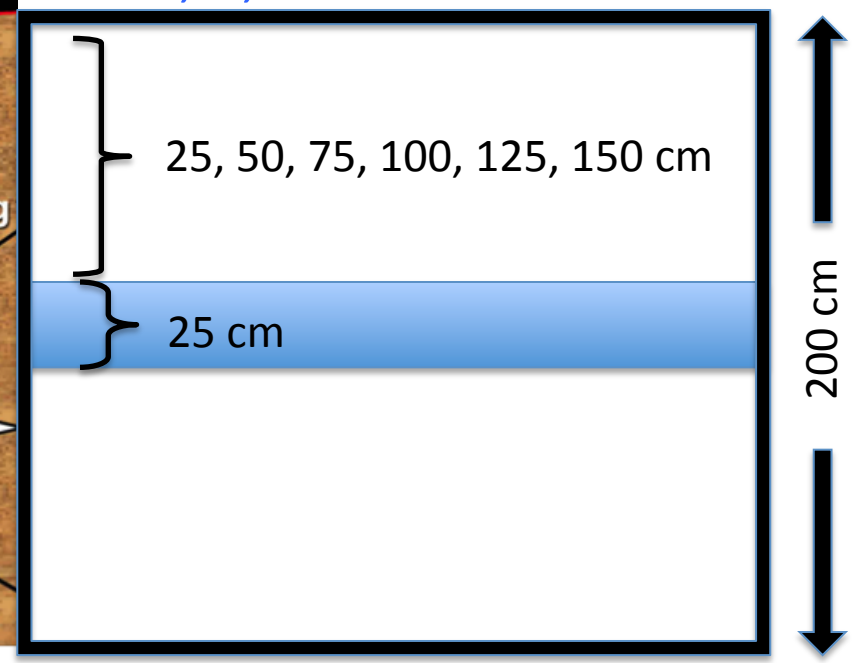


Geant4 Models of 3 Types of Subsurface Water Structure

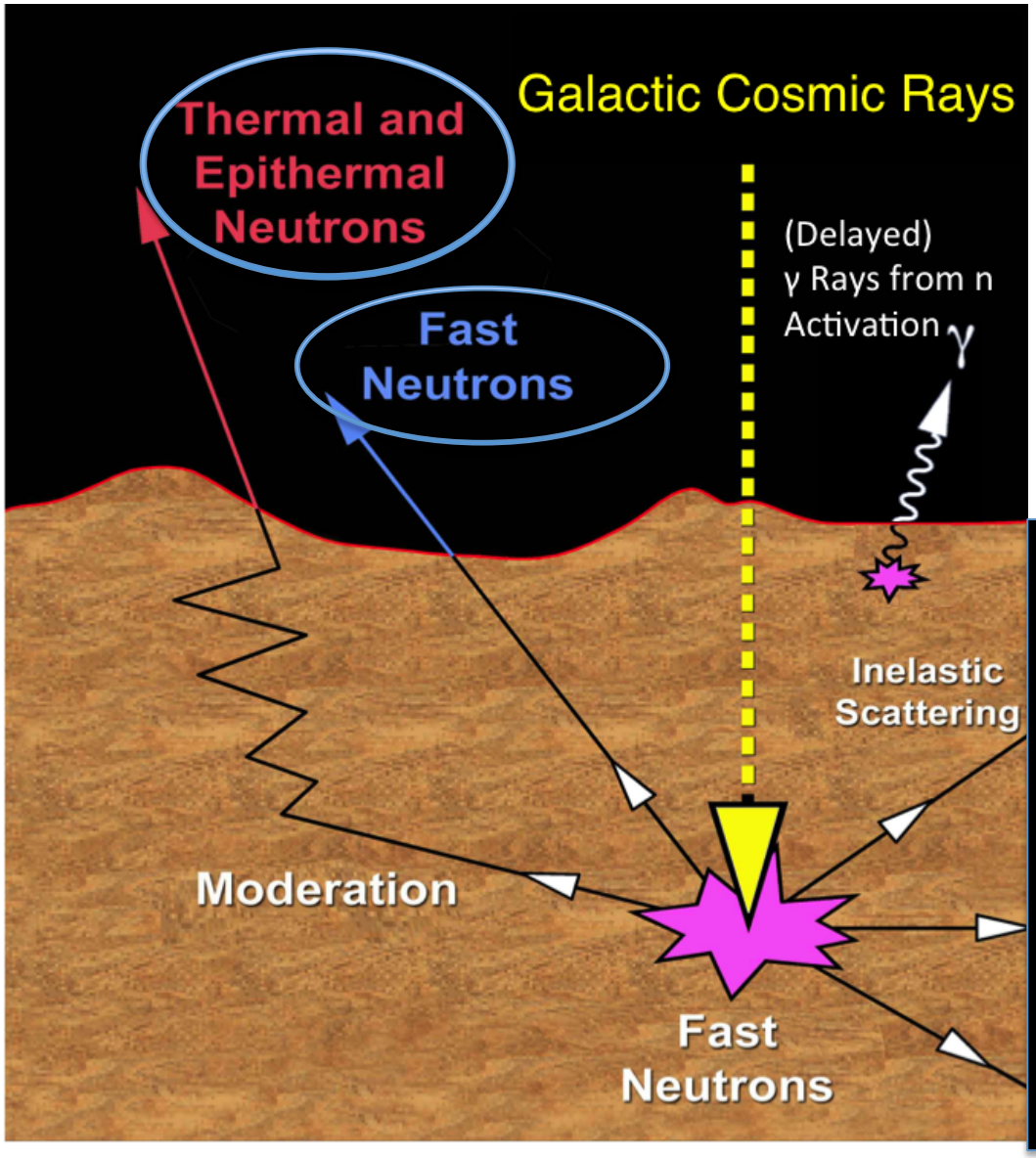


Dry FAN 2 gm/cm^3

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



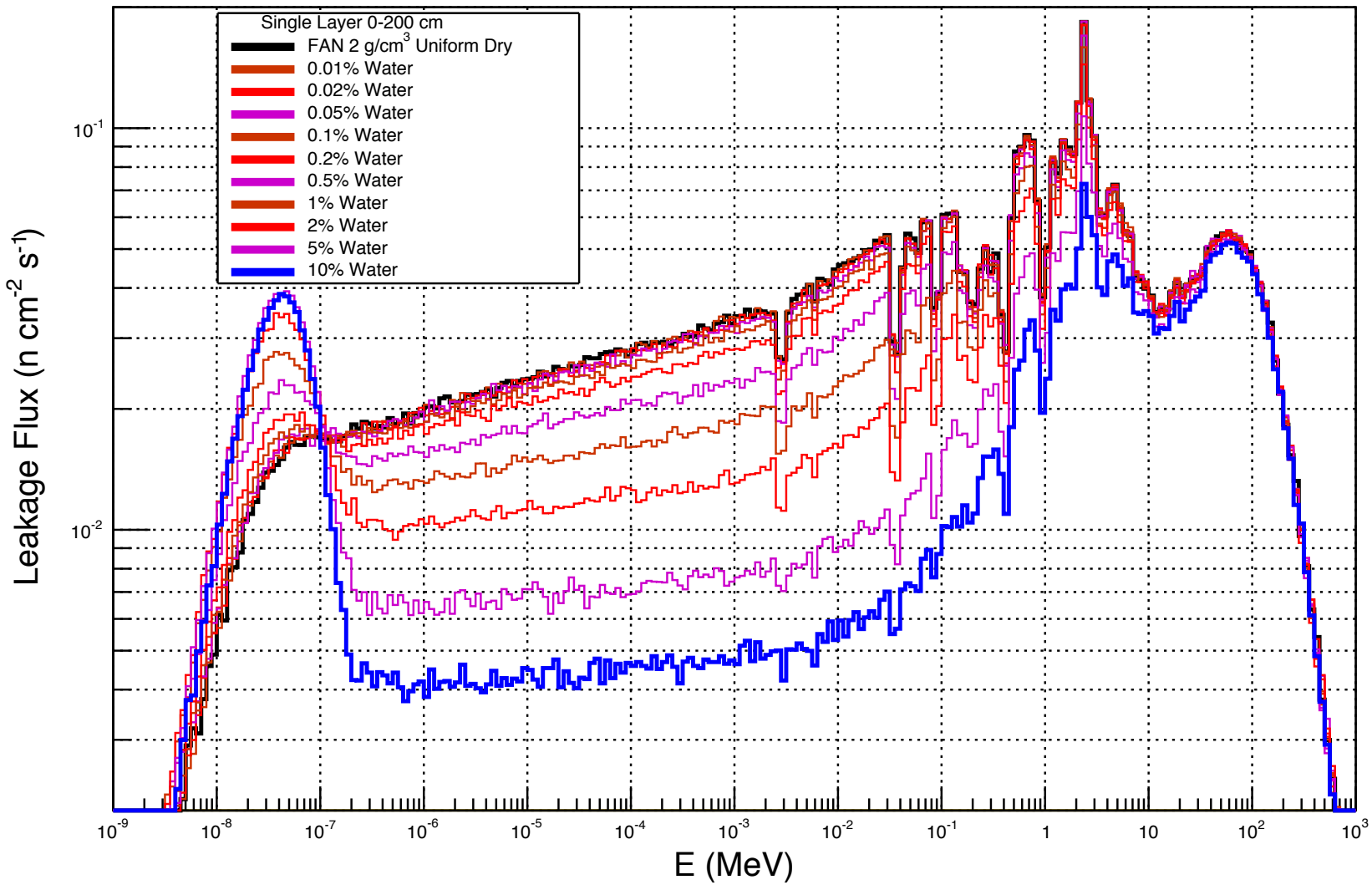
Geant4 Models of 3 Types of Subsurface Water Structure



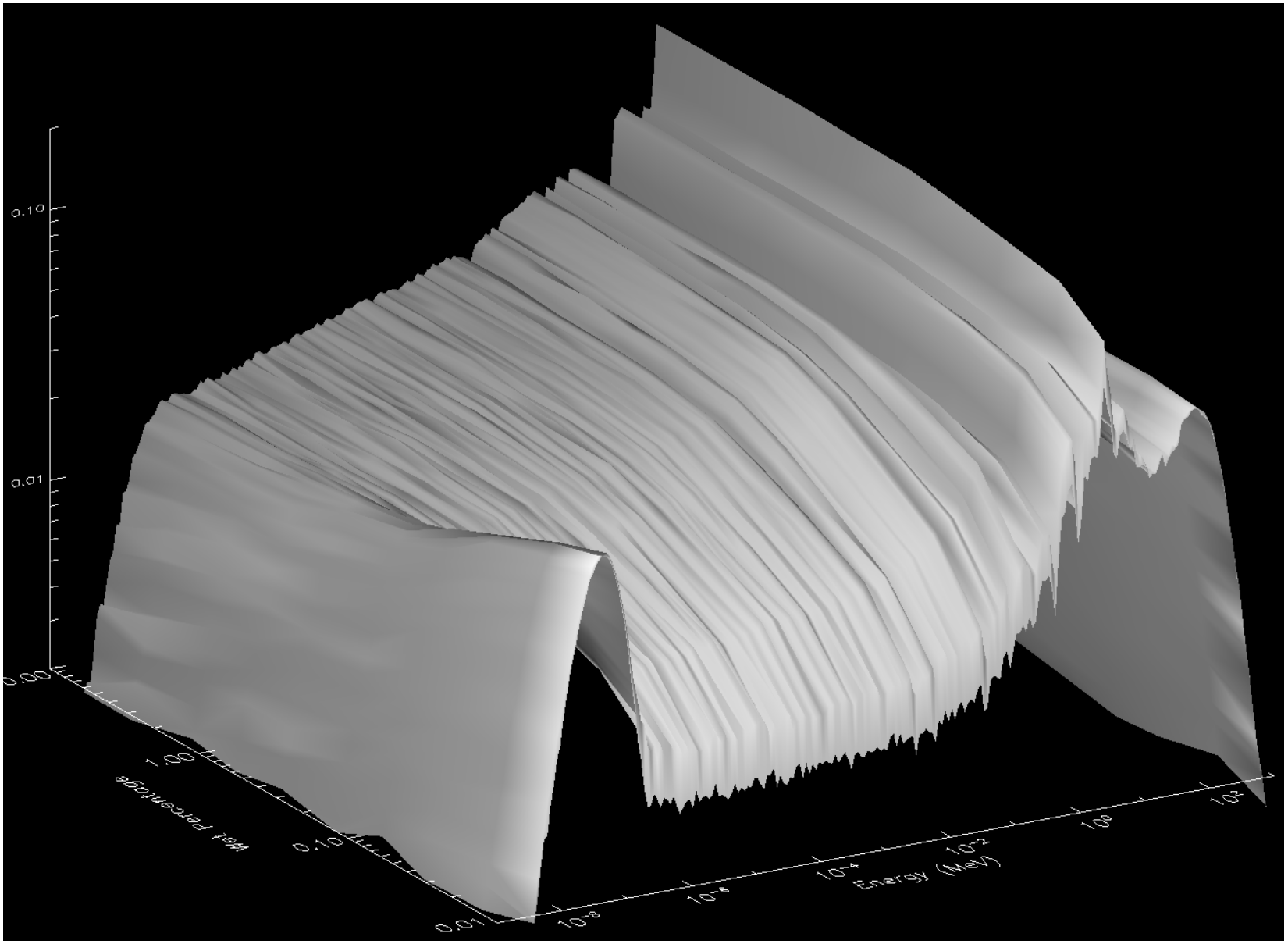
Dry FAN 2 gm/cm^3

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

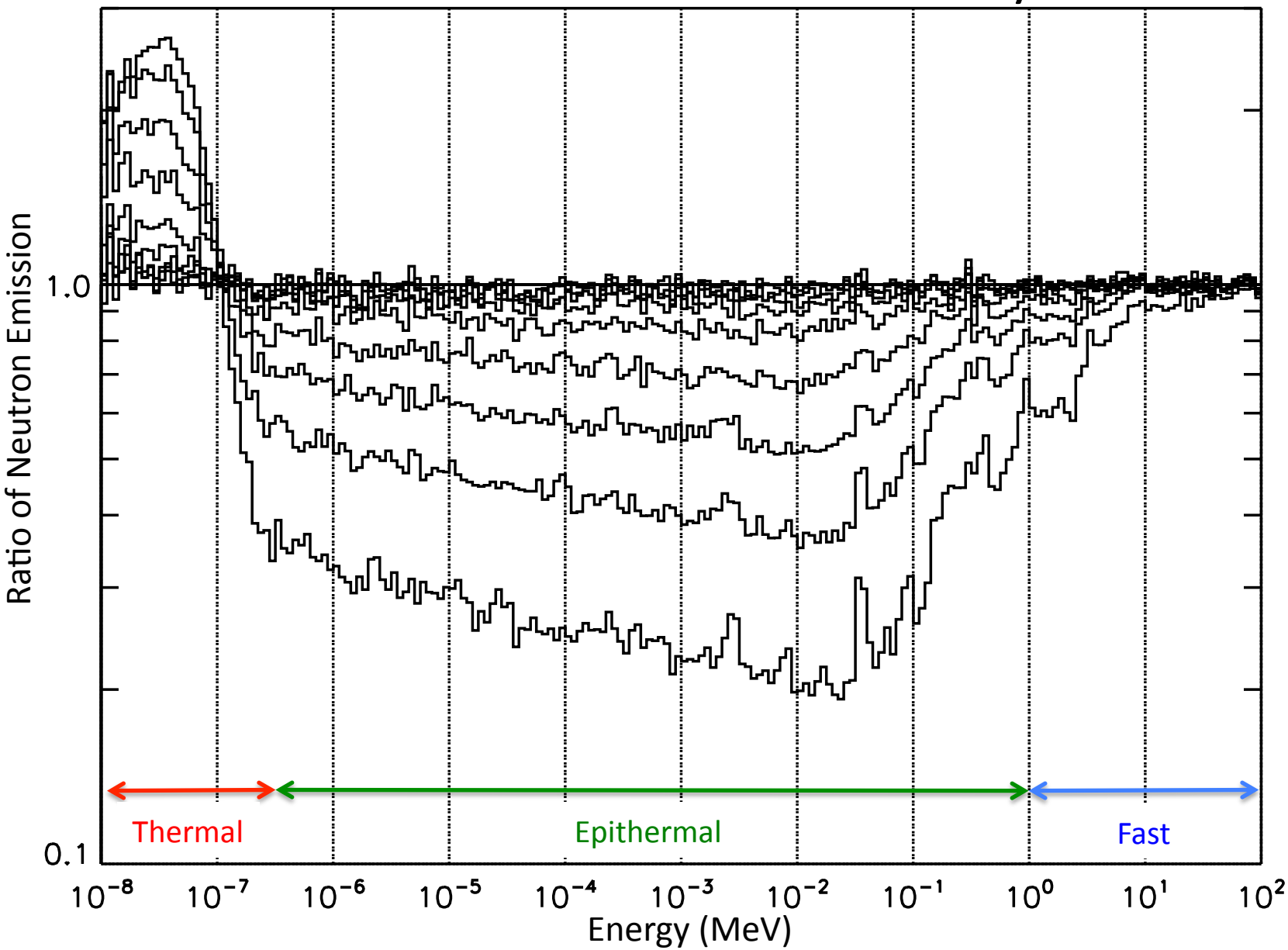
FAN Single Layer 200 cm thick 0.01 - 10% Wet



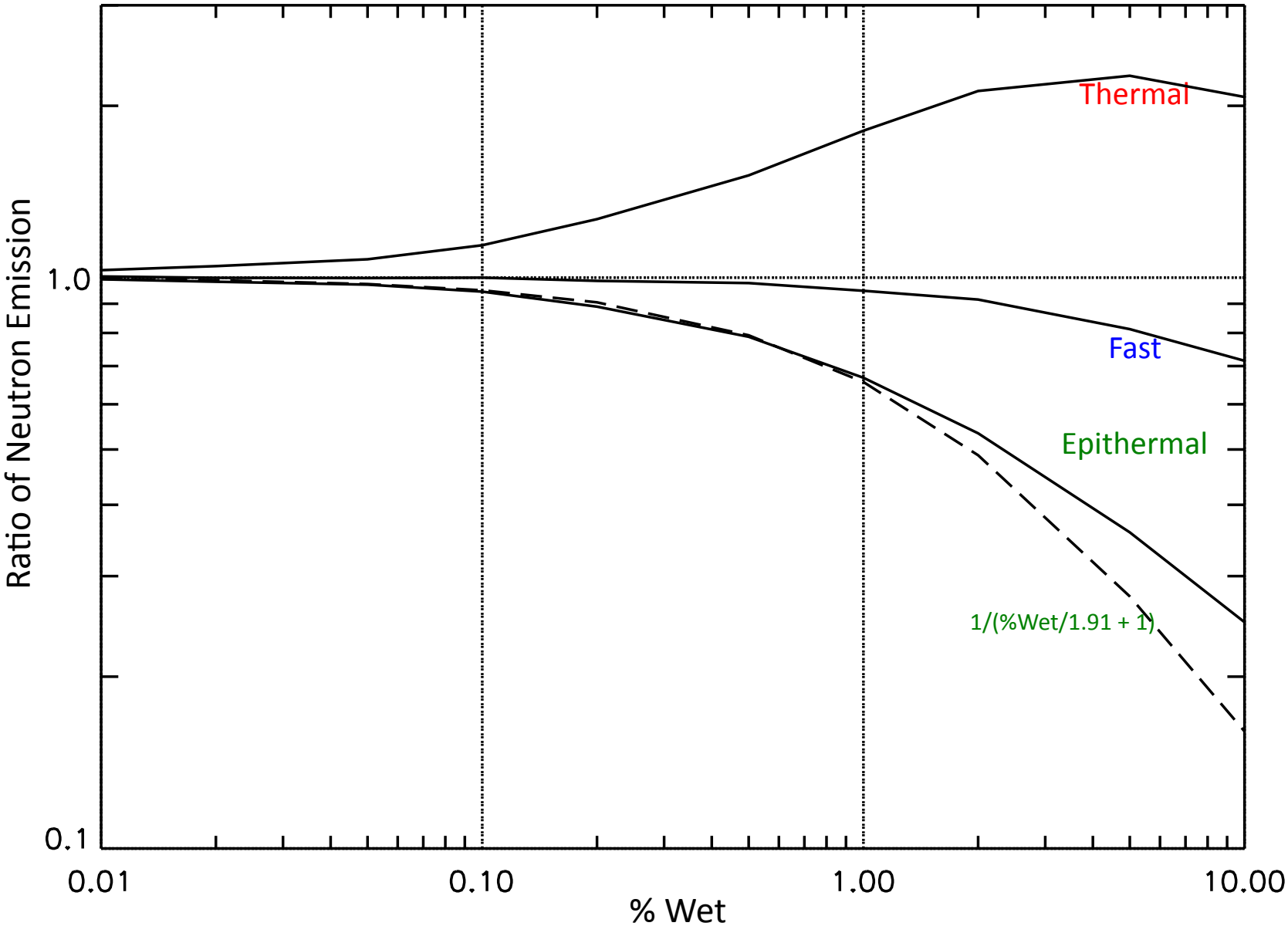
FAN Single Layer 200 cm thick .01-10% Wet



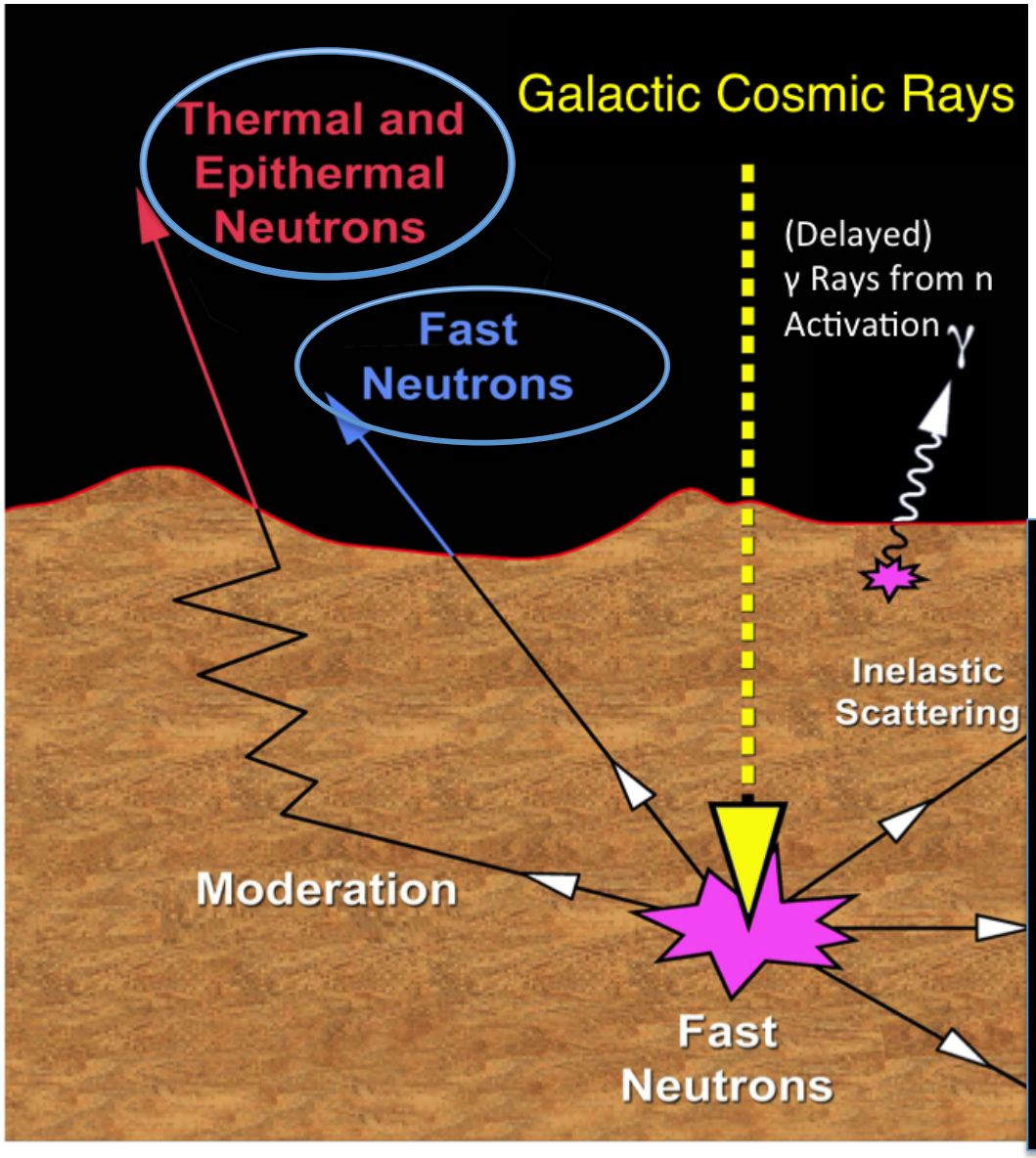
Neutron Emission Ratio from Single Layer 200 cm thick .01-10% Wet relative to Dry FAN



Abundance of water can be inferred most sensitively by the suppression of Epithermal neutrons. Thermal neutron emission is enhanced by the presence of water, but for abundances >2% the curve flattens out.

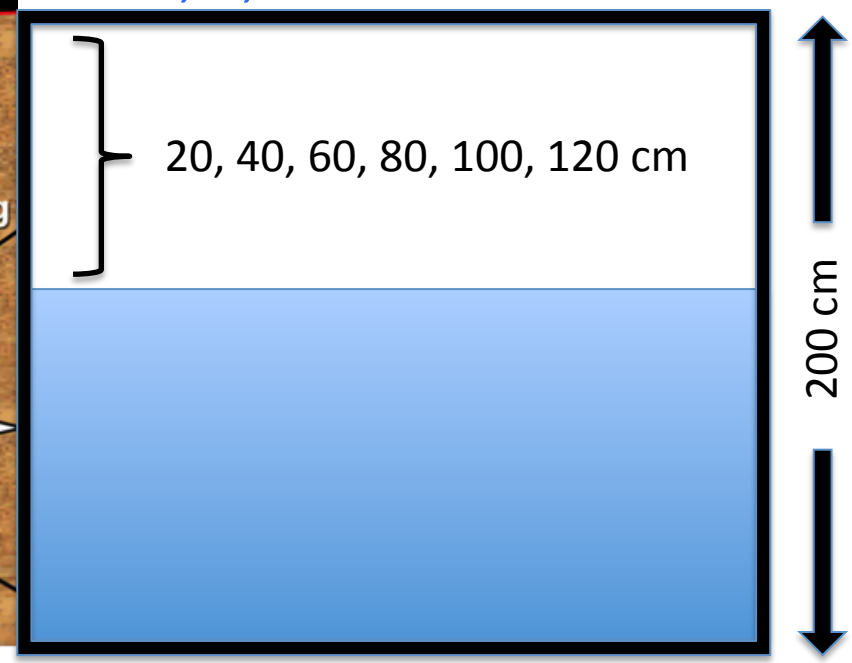


Geant4 Models of 3 Types of Subsurface Water Structure

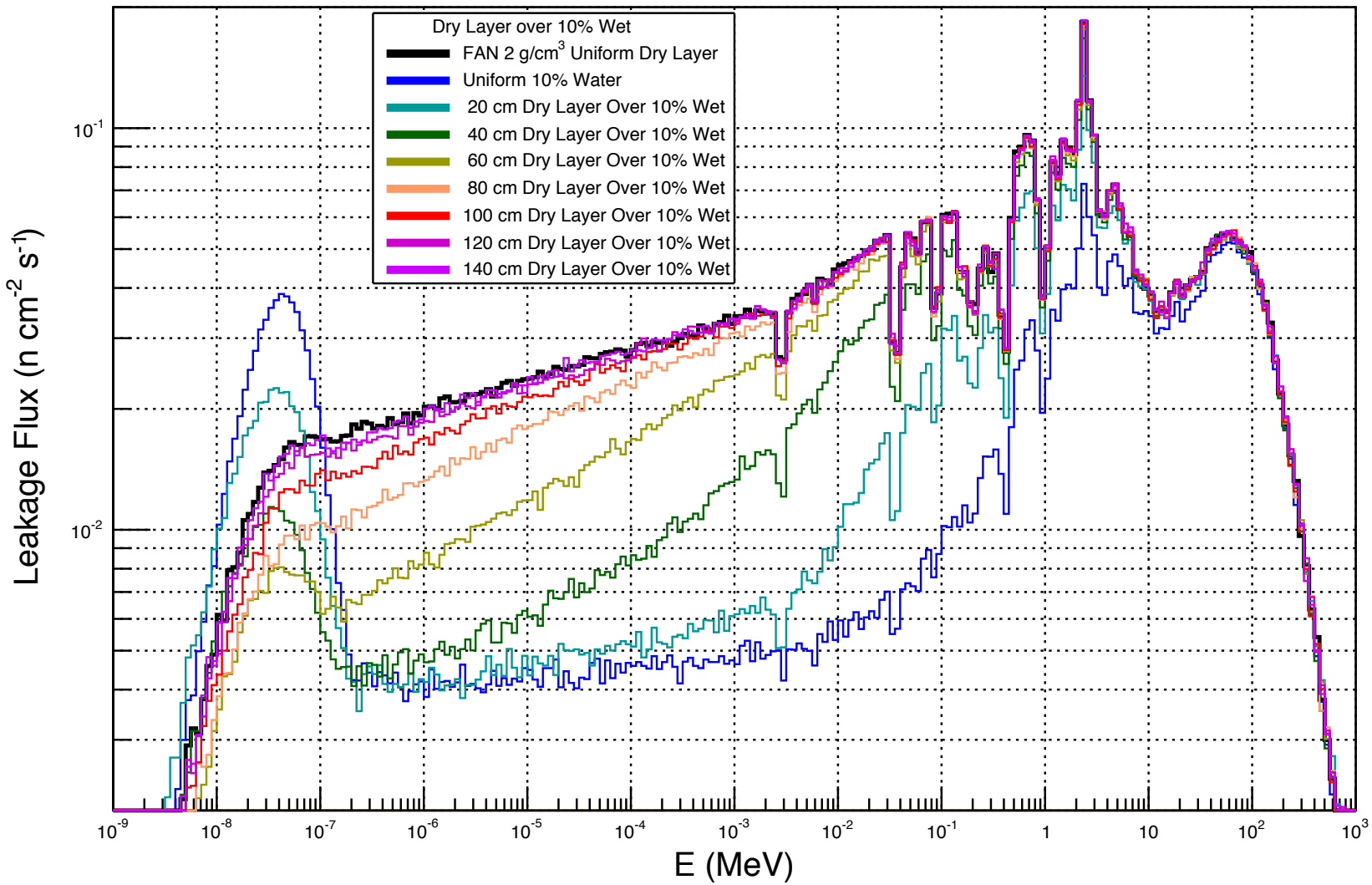


Dry FAN 2 gm/cm^3

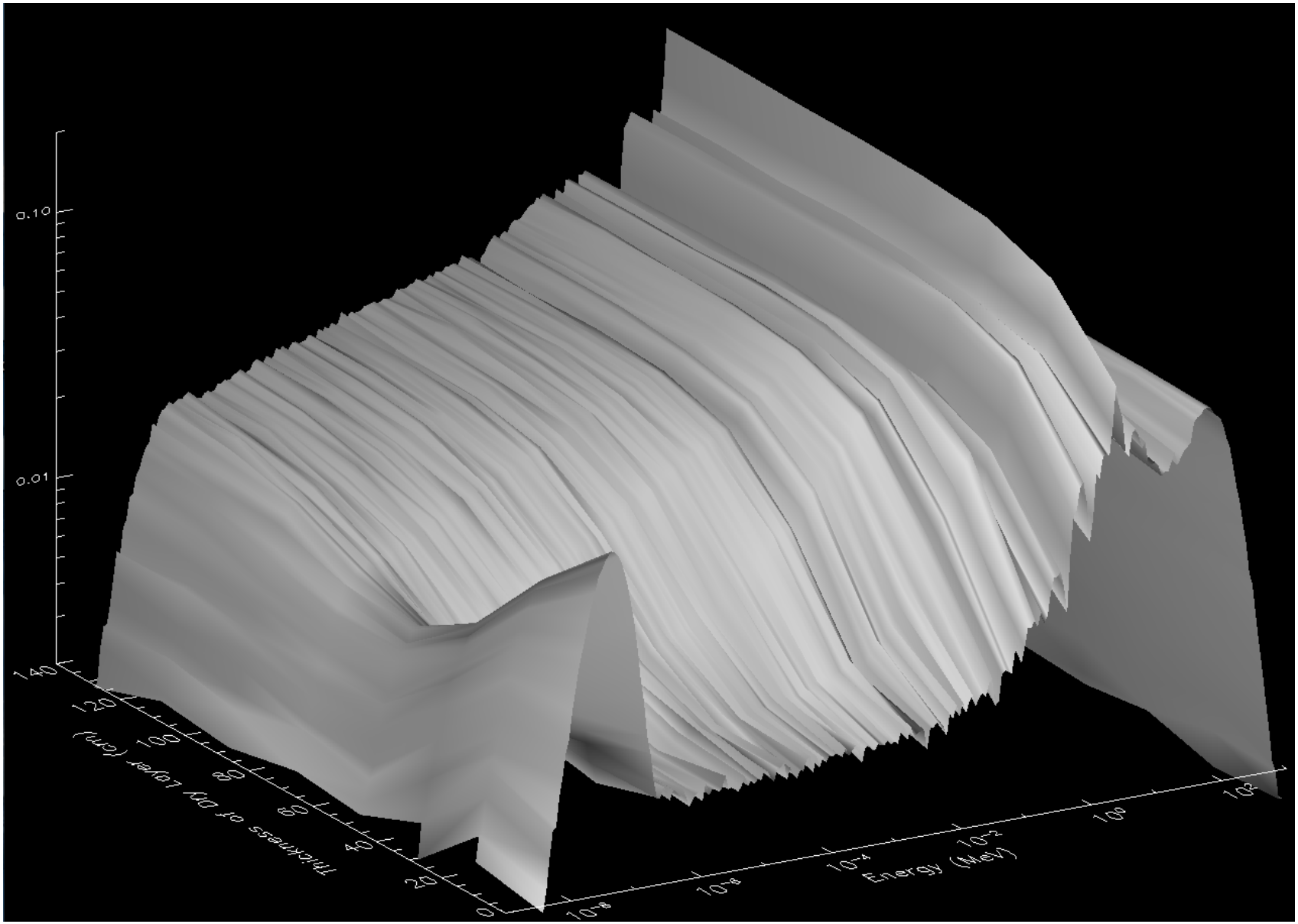
Water Structure
Single Uniform Layer
Under Dry of Varying Depth
Water Abundance
1, 2, 5 and 10 % Wt



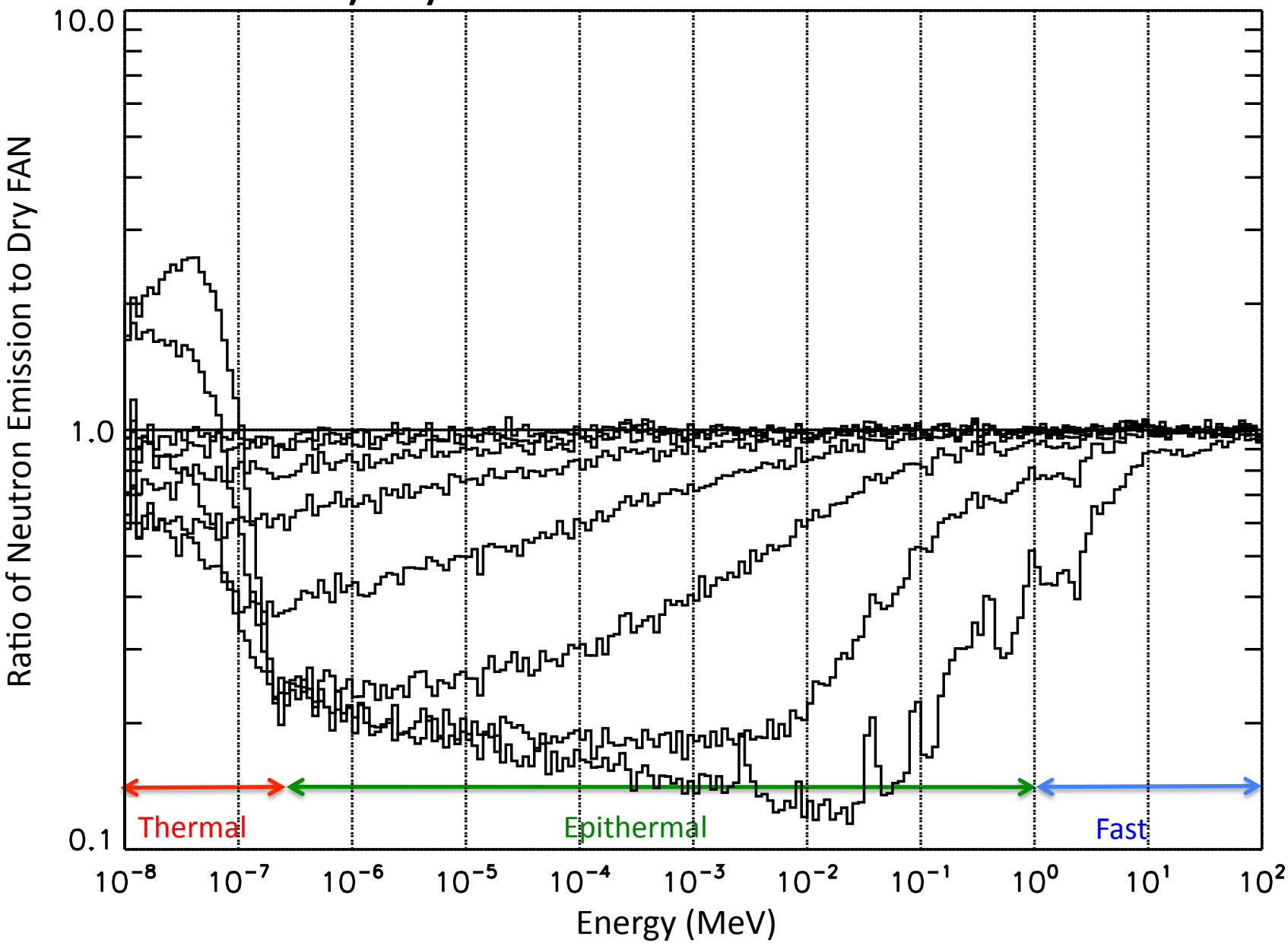
Dry FAN over 10% Wet



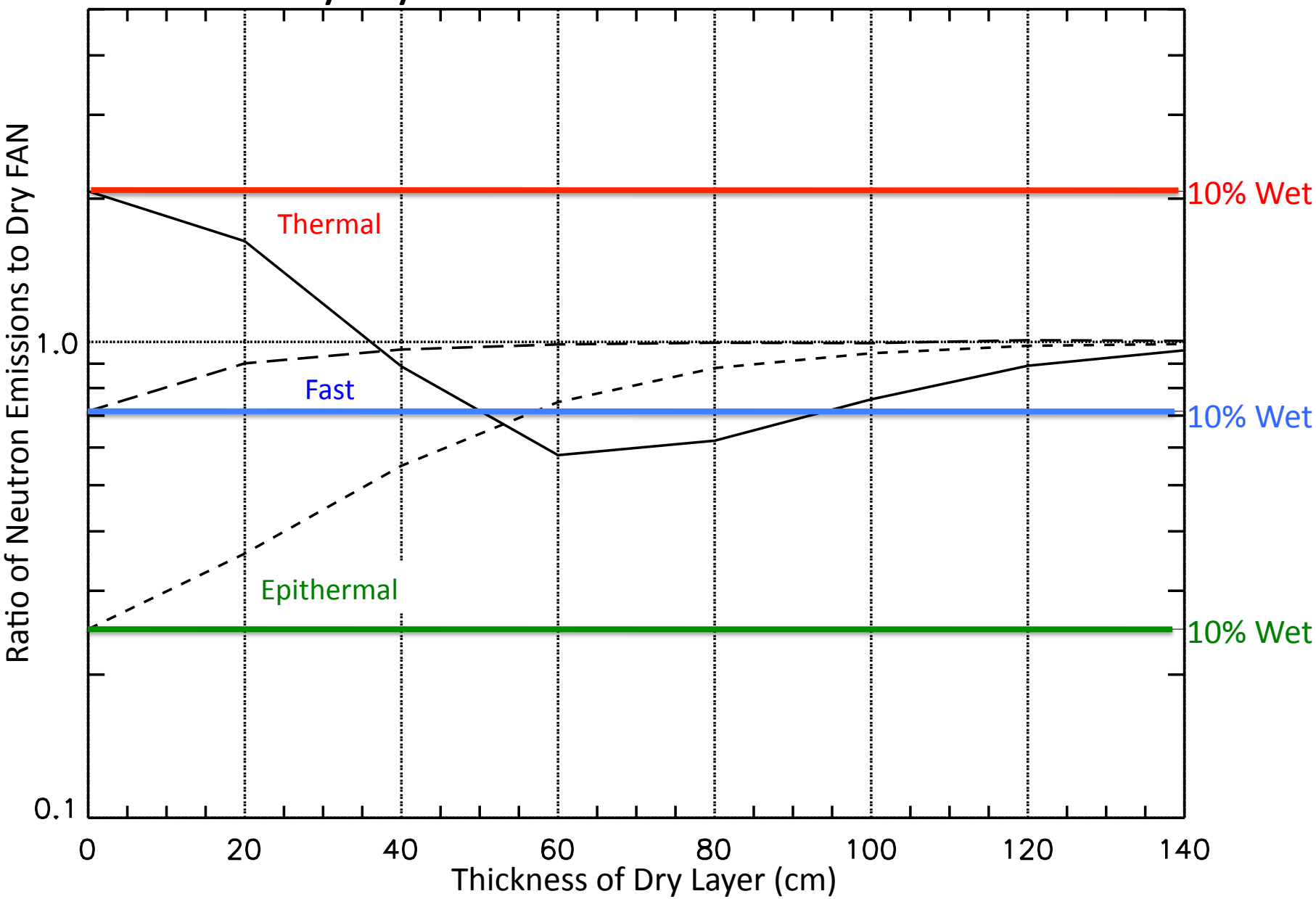
Dry FAN over 10% Wet



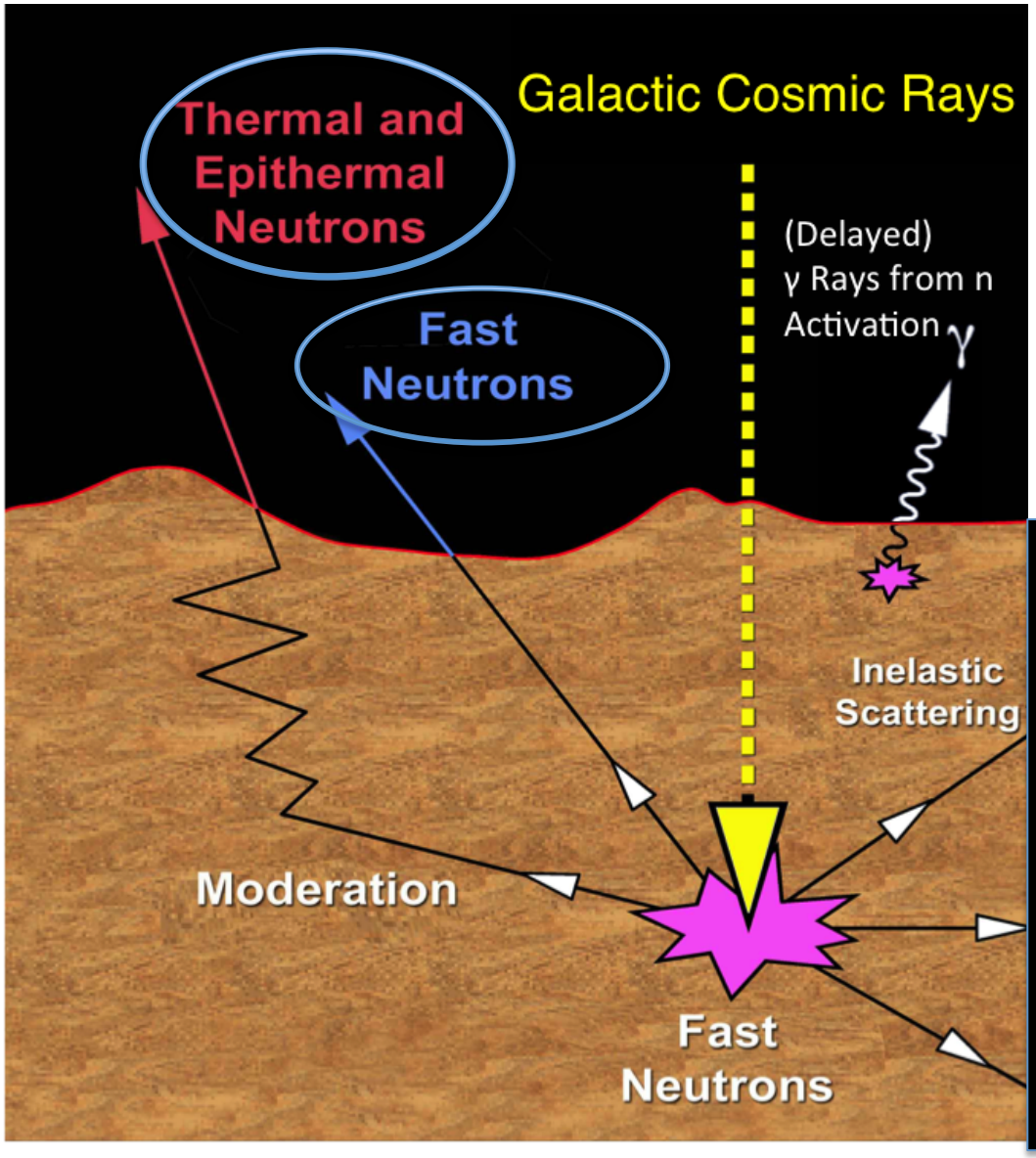
Neutron Emission Ratio
from a dry layer 0-140 cm thick over 10% Wet



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

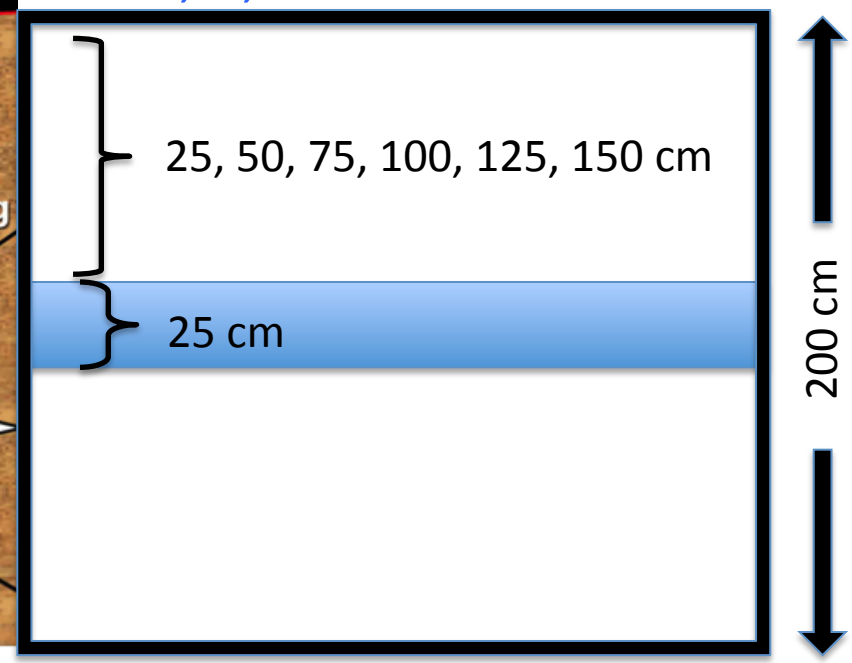


Geant4 Models of 3 Types of Subsurface Water Structure

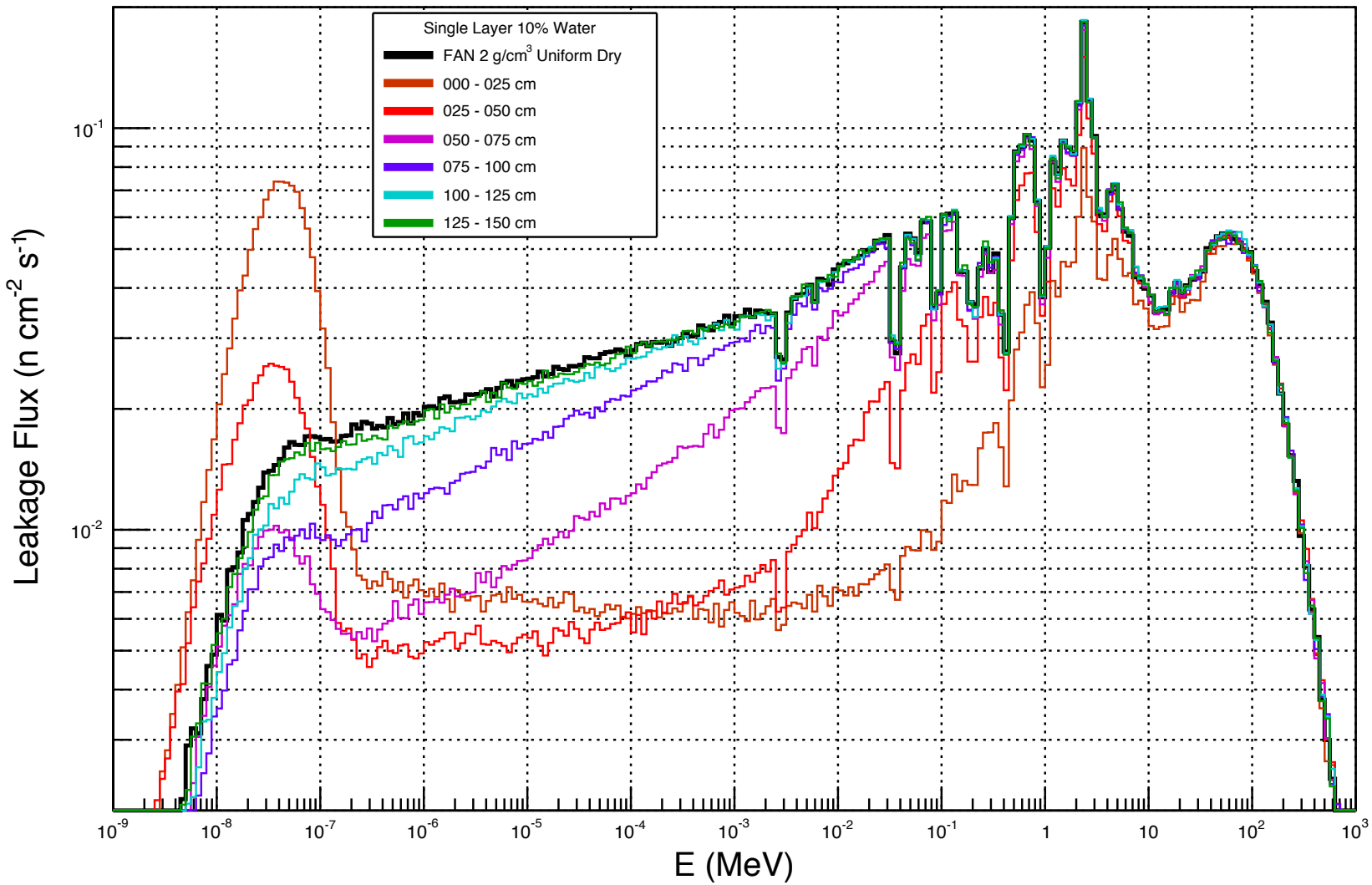


Dry FAN 2 gm/cm^3

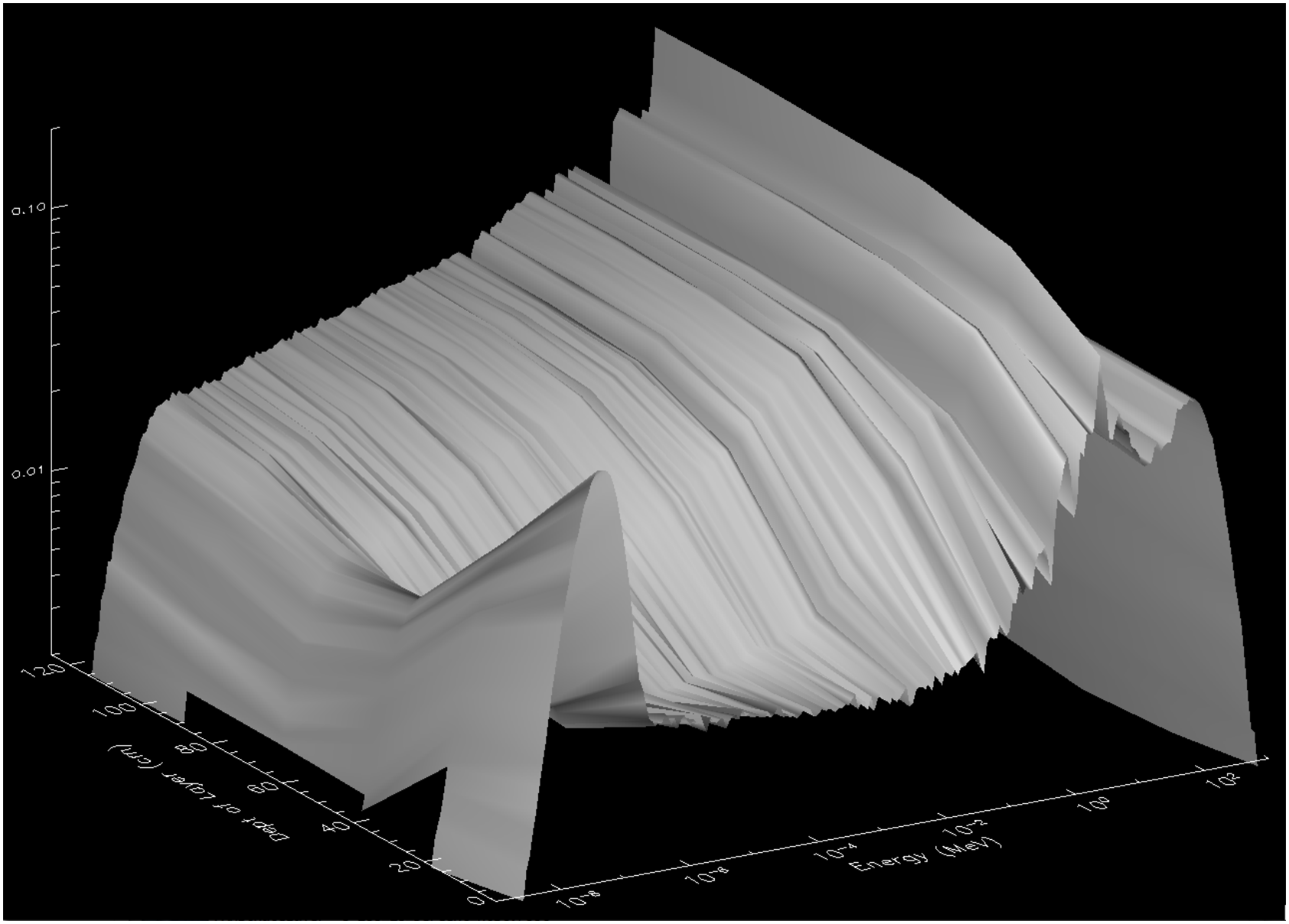
Water Structure
Single Uniform Layer 25 cm
Varying Depth
Water Abundance
1, 2, 5 and 10 % Wt



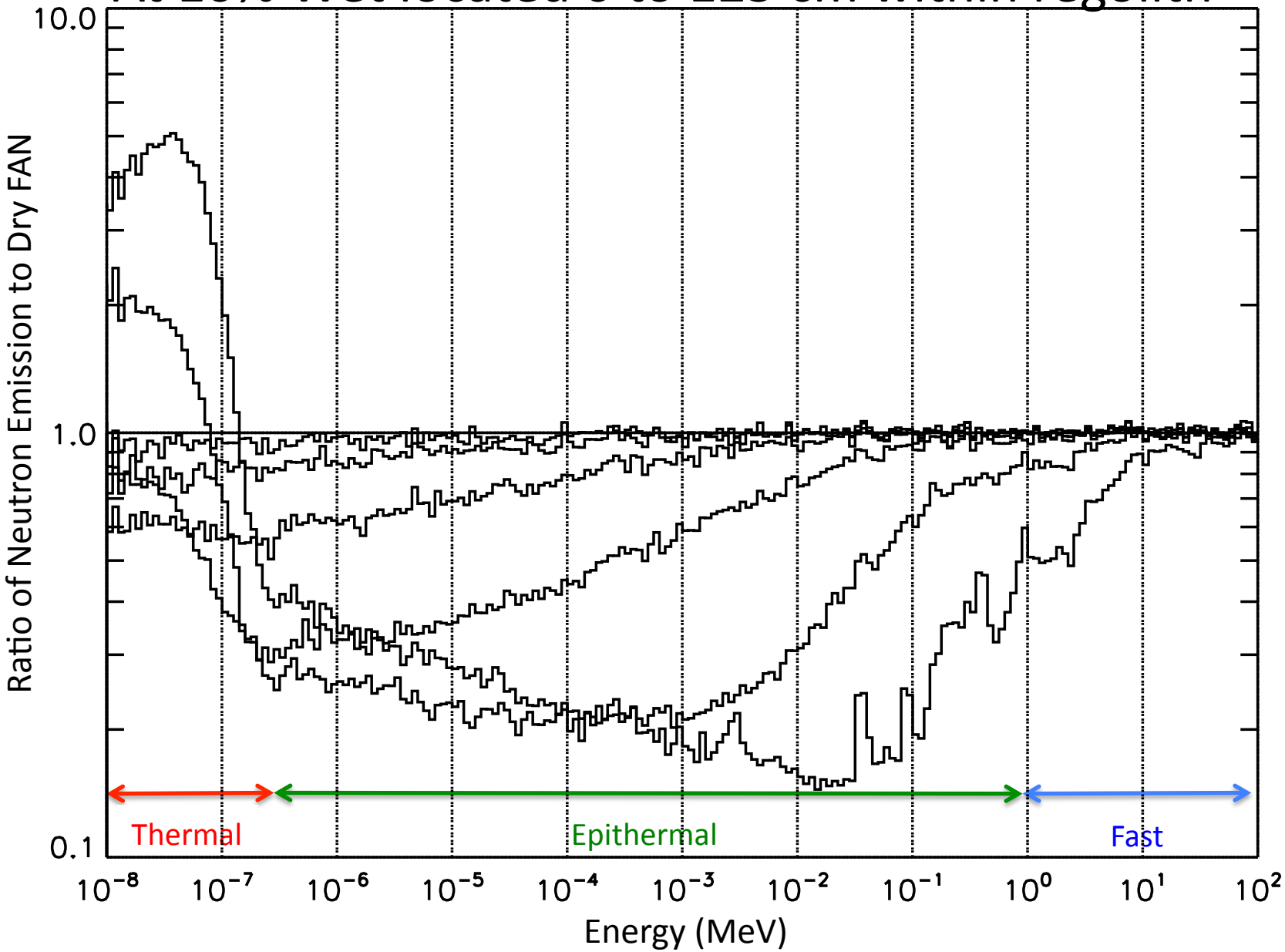
FAN Single Layer 25 cm thick 10% Wet

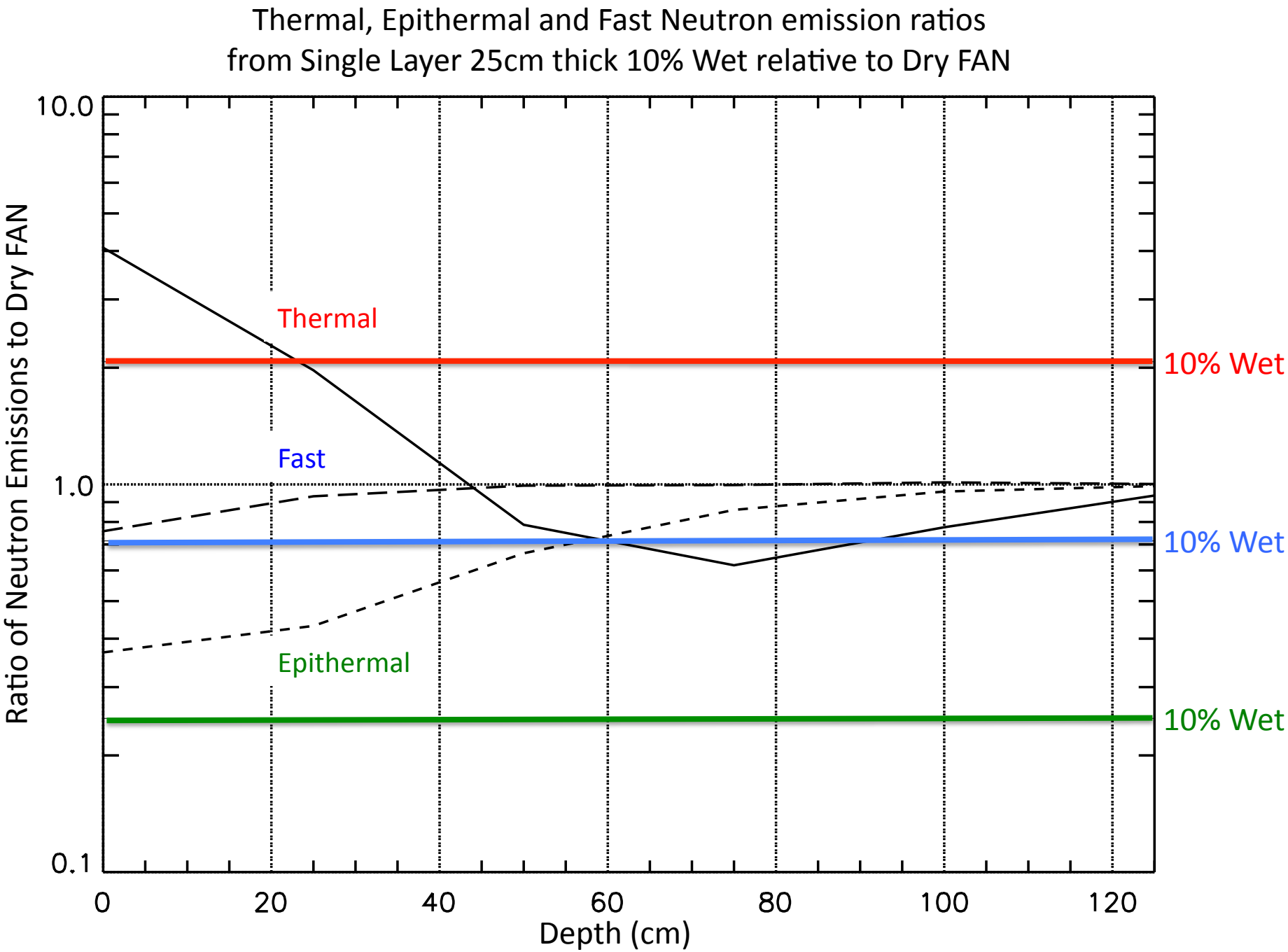


FAN Single Layer 25 cm thick 10% Wet



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
0
20
40
60
80
100
120
Depth (cm)
Thermal
Fast
Epithermal
10% Wet
10% Wet
10% Wet

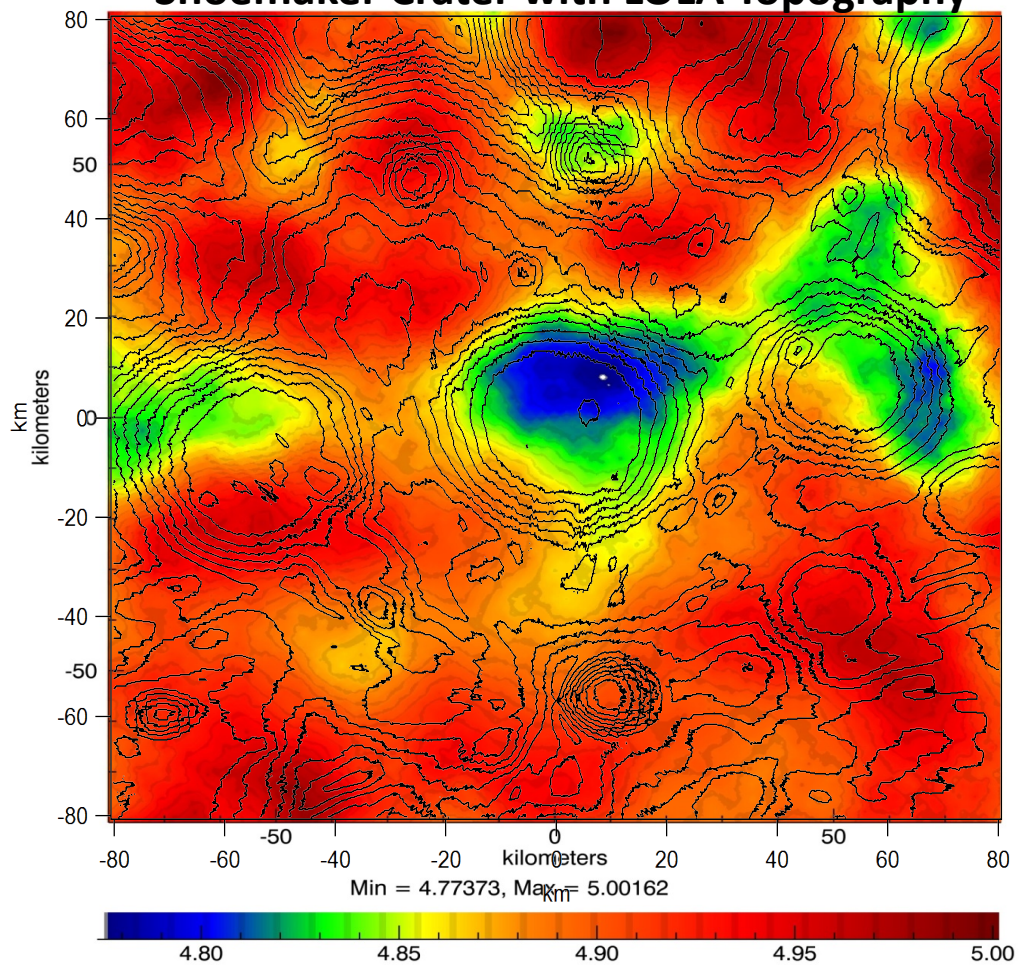
Summary

- Burial depth and structure of wet soil layer modifies the emergent neutron spectrum relative to a uniform wet structure.

- Emergent flux compared to flux from dry soil in Thermal, Epithermal, and Fast energy bins show different behavior as a function of burial depth as compared to a uniform wet distribution.

- Thermal neutron flux decreases monotonically with burial depth in layered structures and may act as a potential diagnostic of type of structure and its burial depth.

LEND Epithermal Flux at Shoemaker Crater with LOLA Topography

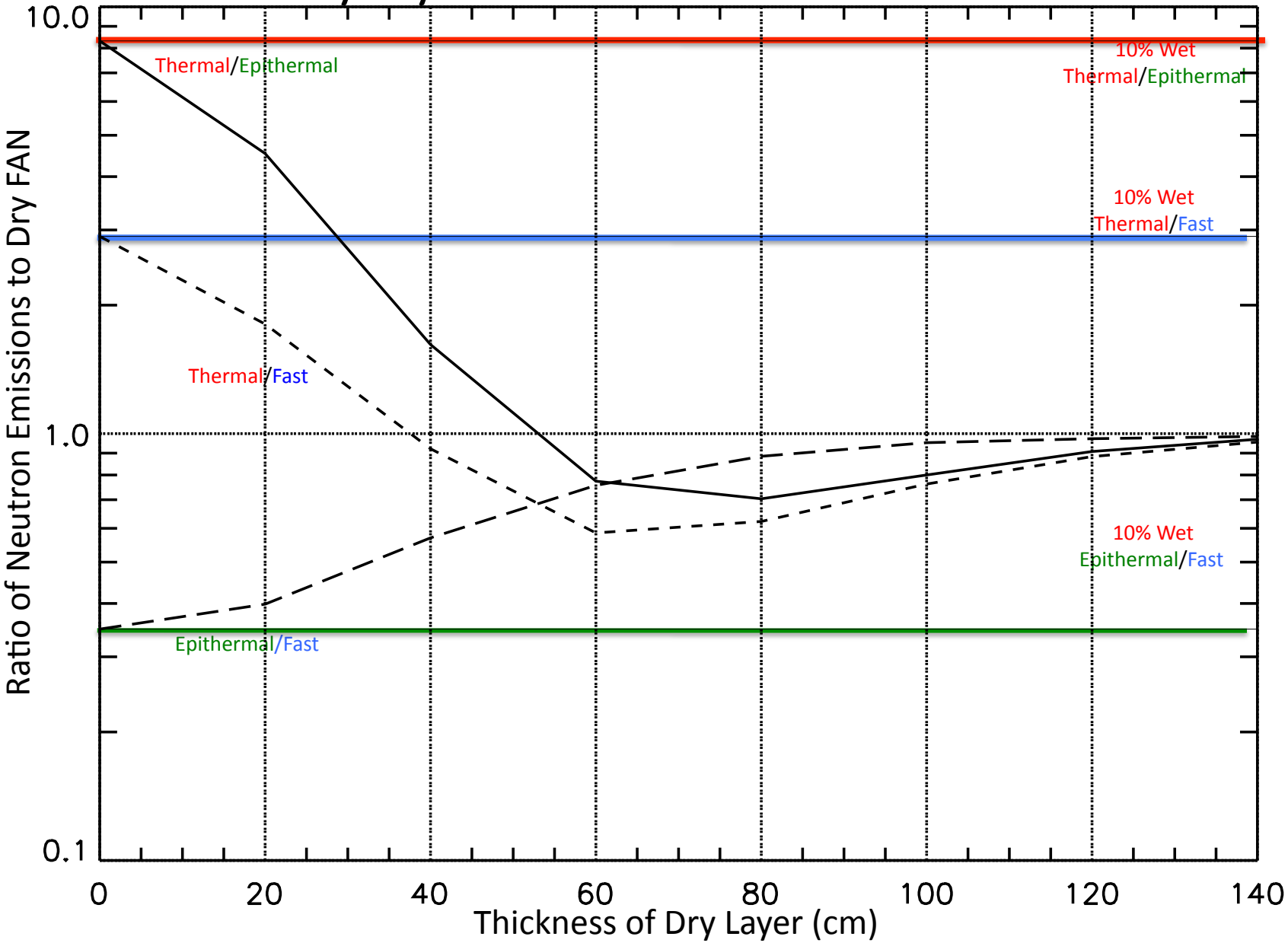


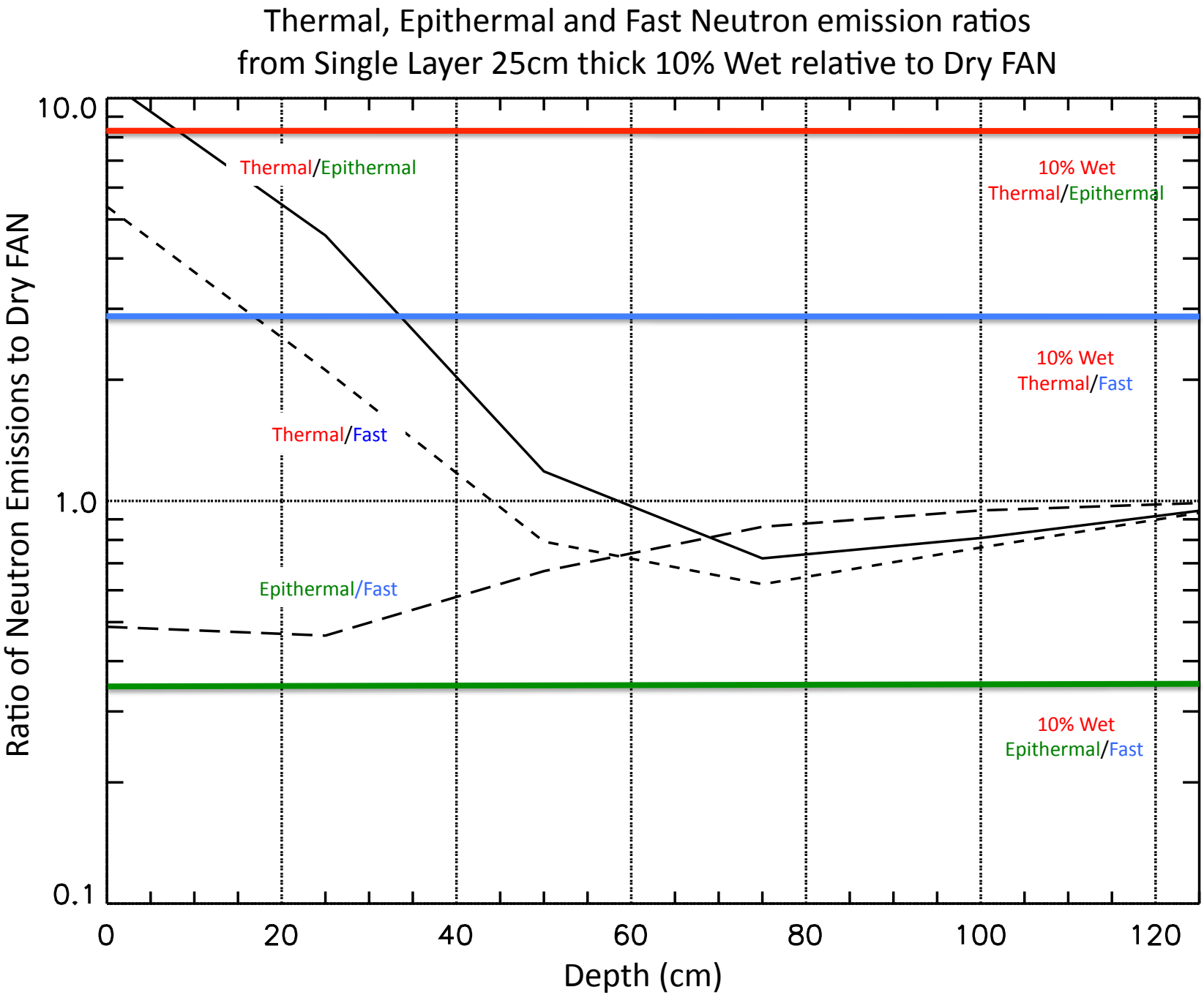
Count rate (cps)

(Boynton et al. 2015)

Backup Material

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




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
0
20
40
60
80
100
120
Depth (cm)
Thermal/Epithermal
Thermal/Fast
Epithermal/Fast
10% Wet
Thermal/Epithermal
10% Wet
Thermal/Fast
10% Wet
Epithermal/Fast