ANALYTIC EXPRESSION FOR EPITHERMAL NEUTRON SPECTRA AMPLITUDES AS A FUNCTION OF WATER CONTENT: Darrell Drake. Space Science and Technology Division. Los Alamos National Laboratory. Los Alamos, NM 87545.

The epithermal portion of an equilibrium neutron spectrum in a planetary body is a sensitive function of the water content of its material. The neutrons are produced at high energies but moderate by elastic and inelastic scattering until they either are captured by surrounding nuclei or escape.

The neutron equilibrium spectrum is normally divided into three energy regions which are not precisely defined in terms of energy but in terms of the type of interactions they undergo. High energy neutrons are those whose energy is large enough to scatter inelastically from surrounding nuclei. The lower boundary of this group is usually somewhere near one to two hundred keV but is dependent on the material surrounding the neutron source.

Epithermal part of the neutron spectrum begins just below the fast neutrons where the most important reaction in earthlike materials is elastic scattering. Neutron capture leading to gamma ray emission can also occur in this energy region and can contribute to observed gamma-ray spectra. The epithermal flux is reduced by these captures, especially at the lower energies where the capture cross sections are larger and more collisions are made.

The thermal neutron spectrum is complicated by both energy gaining and energy loosing collisions due to thermal motion of the surrounding nuclei and by inelastic atomic reactions.

The epithermal part of the neutron spectrum is the most sensitive indicator of the presence of small amounts of hydrogen (presumably in the form of water), and fortunately it is the easiest to treat analytically. This work develops an expression that explicitly shows the dependence of the epithermal spectrum on the amount of water present in the medium and compares it to two codes that are frequently used to calculate neutron leakage spectra.

The expression for the amplitude of the epithermal spectrum [1] is given by

$$Epi = Q/n\sigma\xi \tag{1}$$

where Q is the neutron source, n is the atom density, σ is the elastic cross section, and ξ is the logarithmic energy decrement taken as $2/A$ for most elements and one for hydrogen. For a medium composed of several elements, the denominator of Eq. 1 can be written as

$$\sum_i n_i\sigma_i\xi_i \tag{2}$$

where i indicates the ith element of mixture. This expression can be rewritten to show the effect of a small amount of water by taking out the hydrogen component explicitly so that Eq. 1 becomes

$$E_{pi} = Q/\left((1.33fwater) + \sum_i n_i\sigma_i\xi_i\right) \tag{3}$$

where $fwater$ is the weight fraction of water in the material, 1.33 is the product of the hydrogen cross section and the number of hydrogen nuclei per cubic angstrom in water of density one. The ratio of the epithermal spectrum moderated by a dry medium to the epithermal spectrum moderated by a water containing medium can be written as

$$\frac{Epidry}{Epiwet} = 1 + \frac{1.33fwater}{\sum_i n_i\sigma_i\xi_i} \tag{4}$$

This equation shows explicitly the linear dependence implied by Feldman *et al.* [2] and also shows explicitly the slope dependence as a function of the scattering cross sections of the other elements of the medium.

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Two of the codes used to compute neutron equilibrium spectra are MCNP [3], which uses Monte Carlo methods and ONEDANT [4], which uses the Boltzman transport technique. The table below presents the results of calculations of epithermal neutron amplitude for both MCNP and ONEDANT as well as the analytic expression of Eq. 4. The moderating materials were pure silicon, pure oxygen (the main components of most soils, and a proposed lunar soil. The calculations were made with no water and 0.1% water for the three materials, infinite media, and with starting neutrons of 0.2 MeV.

EPIDRY/EPIWET

	ONEDANT	EQUATION 4	MCNP
Silicon	1.378	1.396	1.36 (high energy)
	1.17	1.20	1.18 (low energy)
Oxygen	1.0767	1.0748	1.0767
Lunar Soil	1.139	1.137	1.135

Silicon has two entries representing the high (20 keV) and low (0.5 eV) portions of the epithermal spectrum. The result for the low energy part under Eq. 4 has been corrected for neutron capture by silicon by use of an equation of Fermi [1] which accounts for the probability that a neutron is absorbed each time it collides with a silicon nucleus. The difference in the high and low energy results calculated by ONEDANT for silicon are consistent with a second part of the ONEDANT calculation shows that approximately 40% of the neutrons are captured by wet silicon and 51% are captured in the dry silicon before they reach thermal energy. The results calculated by MCNP for the lower energy epithermal neutrons agrees with those of ONEDANT and the corrected formula. Because epithermal neutrons are generally counted with cadmium covered detectors whose efficiency is proportional to the neutron velocity, most of the counted neutrons are in the energy region just above the cadmium cutoff (0.4 eV).

Oxygen has such a small capture cross section that the correction for absorbtion is unnecessary, and the agreement among the three calculations is excellent. Agreement among the three calculations for the lunar soil, ferroan anorthosite, is also excellent.

In summary, we have derived an expression that explicitly shows the dependence of epithermal neutron spectra on water content, compared its predictions to calculations done by a Boltzman transport code for infinite media for silicon, oxygen, and a possible lunar composition and have obtained very good agreement.

References: [1] Fermi, E. (1950) *Nuclear Physics*, Univ. of Chicago Press. [2] Feldman, W. C., *et al.* (1991) *Geophys. Rev. Lett.*, **66**, 2665. [3] Briesmeister, J., *et al.* Los Alamos National Laboratory report LA-9184-MS (1982).