NEUTRONS IN THE MOON,

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The neutron flux in the moon was calculated by using the discrete ordinate method of solution to the transport equation by means of the ANISN[1] code. Scattering cross sections were taken from the ENDF/B III[2] library and were processed into the 99 group structure by the SUPERTOG code, except for Ti, which was taken from the GAM II library.[2] The standard GAM II 99 group structure from 14.98 MeV to 0.414 eV was used, and a thermal group was added. The chemical composition used by Armstrong and Alsmiller[3] for Apollo 11 D fines was adopted. Isotropic scattering (P_0) was assumed, and eight angular directions (S8) were used. On the assumption that the moon is a slab, calculations were carried out at 1-cm intervals to a depth of 200 cm. A density of 1.5 g/cm^3 was assumed. A group-dependent albedo was used, together with isotropic reflection at 200 cm. The source function was modified from Lingenfelter.[4] Degraded high-energy neutrons contribute only about 6% of the total source. An exponential decay of the source with an attenuation length of 155 g/cm^2 was used. The ANISN code normalized the source to 1 n/cm^2/sec over the depth considered.

Activities were calculated for the following reactions: $Ca^{40}(n, \alpha)Ar^{37}$, $K^{39}(n, p)Ar^{39}$, $Ca^{40}(n, p)K^{40}$, $B^{10}(n, \alpha)Li^7$, $Li^6(n, \alpha)H^3$, $Li^7(n, n, \alpha)H^3$, $U^{235}(n, f)$, and Gd^{255}, Gd^{157}, Sm^{149}, Co^{59}, Cl^{35}, and $I^{127}(n, \gamma)$. Activation cross sections were taken from the ENDF/B III library, except for Cl and I, which were taken from the GAM II library.

A comparison of our neutron flux above thermal energy with that of Armstrong and Alsmiller[3] shows significant differences in that our flux peaks ~50 g/cm^2 earlier than theirs. This is due to their having used a flat source distribution out to ~150 g/cm^2. The agreement shown in Fig. 1 between the experimental Ar^{37} activities of Fireman et al.[5] and Stoenner et al.,[6] mainly produced by 1-10 MeV neutrons, and our calculations supports our assumed depth dependence. The agreement between the depth dependence at our thermal flux and that of Armstrong and Alsmiller[3] and of Lingenfelter et al.[7] indicates that the thermal flux may not depend strongly on the source-function depth dependence for about the first 350 g/cm^2.

From a comparison of the Ar^{37} measured production rate with the calculated $Ca^{40}(n, \alpha)Ar^{37}$ production rate, the neutron production rate could be determined if the contribution of high-energy spallations to Ar^{37} could be estimated. If all Ar^{37} is due to neutrons, then the upper limit for the neutron production rate is 57 n/cm^2/sec. According to Ar^{39} measurements of Fireman et al.[5] and Stoenner et al.,[6] the Ar^{39} production rate at the Apollo 16 site is 0.04 Ar^{39}/cm^2/sec. If the Ar^{37} spallation rate is equal to the Ar^{39} production rate, then 6/7 of the Ar^{37} activity is caused by the action of neutrons. The neutron production rate is then 48 n/cm^2/sec.

As the moon is a very absorbing medium, the thermal flux can be expected to deviate from the Maxwellian distribution peaked at 0.025 eV that was used in the calculation of the thermal group absorption cross sections. If the correct thermal-flux energy distribution was known, the absorption cross section could be numerically integrated over the flux to give corrected average absorption cross sections. From the conservation of neutrons, the corrected thermal flux could be determined, and

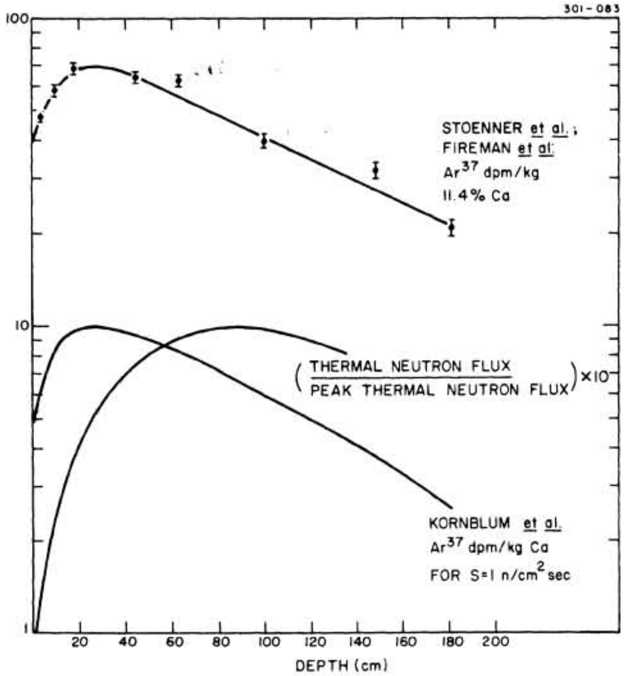

Fig. 1. Ar^{37} versus depth and thermal neutron flux versus depth.

then the calculated activities corrected. Since the leakage is small, the thermal flux is nearly inversely proportional to the total thermal cross section. Hence, it is simple to correct the activations for spectral effects when the changes in the cross sections due to those effects are known. This procedure was carried out for three different thermal-flux distributions. The 1/v activities did not change very much. The depth dependence of the thermal flux is independent of the above considerations and can be used to give the neutron-flux depth dependence shown in Fig. 1. This can be compared to the measured values of Russ et al.,[8] who obtained a surface value 60% of the peak at 190 g/cm^2. The comparison supports the idea of irradiated material being added to the surface.

References

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