THE GRADIENT OF COSMOGENIC RADIONUCLIDES TO A DEPTH OF 400 g/cm² IN THE MOON: R. C. Finkel, M. Wahlen, J. R. Arnold, C. P. Kohl, M. Imamura, University of California, San Diego, La Jolla, California, 92037.

We have extended our investigation of cosmic ray bombardment effects in the lunar regolith, placing the main emphasis in this work on understanding those effects produced by galactic cosmic rays. Results for $^{53}$Mn, $^{22}$Na, $^{55}$Fe, $^{26}$Al, $^{60}$Co and $^7$Be are reported.

The most sensitive isotope available to us for this study was $^{53}$Mn. Using a neutron activation technique we were able to determine $^{53}$Mn in samples of 200 mg or less. We measured this isotope in a series of samples taken from the ends of the various sections of the Apollo 15 drill stem and from a sample of trench soil (15031) from about 60 g/cm² depth. The results are given in Table 1, and these measurements along with measurements from earlier samples are plotted in the figure. The solid line in the figure is a theoretical estimate of the galactic cosmic ray production profile using the model of REEDY and ARNOLD, with the curve normalized at the deepest point. The unnormalized curve, using the recent cross section of HONDA et al (priv. comm.) lies about 25% below the measurements.

The $^{53}$Mn profile illustrates the complete range of effects produced by spallation reactions in the lunar regolith. The surface samples show the high activities associated with solar cosmic ray bombardment. This region of the depth profile has been extensively discussed elsewhere [1]. At about 20 g/cm² the gradient becomes rather flat as galactic cosmic ray induced production begins to predominate. Deeper than 20-30 g/cm², where production is caused only by galactic cosmic ray bombardment, the activity level decreases slowly with depth due to the slow attenuation of the incident galactic cosmic rays. For $^{53}$Mn, below about 60 g/cm², the production decreases exponentially with a mean length of 220 g/cm². It is clear from the general nature of the profile and the good agreement with the theoretical shape that the lunar surface, at the site where the Apollo 15 long core was collected, has been undisturbed on a meter scale for the last 5 million years or so.

$^{22}$Na, $^{55}$Fe and $^{26}$Al were also measured in samples from the Apollo 15 drill core and in the trench soil 15031 (60 g/cm²). These measurements required larger samples and were therefore carried out at only three depths: 100 g/cm², 200 g/cm² and 350 g/cm². The techniques used have been reported previously. These cosmogenic radioisotopes also clearly show a decrease in activity with increasing depth below about 60 g/cm².

In order to study neutron effects in the regolith the $(n,\gamma)$ produced isotope, $^{60}$Co, was measured in samples from different Apollo missions at various depths from the surface down to 360 g/cm². The results are given in Table 2. By comparing the data obtained to calculated production rates (based on the work of LINGENFELTER et al [2]) we determined the present
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day lunar neutron production rate to be \((21 \pm 5)\) neutrons/cm\(^2\) sec \((E < 10\) MeV). As the result of a continuing program of high sensitivity detector development we were able to measure \(^7\)Be \((t_{1/2} = 53\) d) in samples returned by Apollo 17. The results will be reported at the Conference.

REFERENCES


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Measured $^{53}$Ar Concentrations in the Lunar Surface. The error bars on the experimental points include all known sources of error. The solid line is a calculated galactic cosmic ray production profile (NEEY-_ARHOLD model) normalized to the deepest experimental point.

TABLE 2

$^{53}$Ar in Various Lunar Samples

| No. | Sample       | Weight g | Depth g/cm² | Co content ppm | Co counted mg | Co sample | Co sample | Date of collection
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soil 10084.19</td>
<td>94.4</td>
<td>0-5</td>
<td>35 (1)</td>
<td>2.27</td>
<td>17/8</td>
<td>0.57±0.70</td>
<td>July 21, 1971</td>
</tr>
<tr>
<td>2</td>
<td>Rock 15031.123</td>
<td>42</td>
<td>&lt;20</td>
<td>25 (2)</td>
<td>0.94</td>
<td>26±18</td>
<td>0.92±0.92</td>
<td>Feb. 6, 1971</td>
</tr>
<tr>
<td>3</td>
<td>Soil 15031.37</td>
<td>19.4</td>
<td>60</td>
<td>45 (3)</td>
<td>0.61</td>
<td>60±12</td>
<td>4.0±1.0</td>
<td>Aug. 2, 1971</td>
</tr>
<tr>
<td>4</td>
<td>Soil 15005.67-70</td>
<td>9.38</td>
<td>98-106</td>
<td>45 (4)</td>
<td>0.248</td>
<td>11±4±1</td>
<td>5.1±1.8</td>
<td>Aug. 2, 1971</td>
</tr>
<tr>
<td>5</td>
<td>Soil 15001.69-133</td>
<td>14.0</td>
<td>349-386</td>
<td>45 (5)</td>
<td>0.263</td>
<td>7±6±3</td>
<td>3.5±1.5</td>
<td>Aug. 2, 1971</td>
</tr>
<tr>
<td>6</td>
<td>Soil and Rocks, combined sample of 15031, 10084, 12000</td>
<td>239.9</td>
<td>0-20</td>
<td>--</td>
<td>10.4</td>
<td>13±6 (6)</td>
<td>Sept. 20, 1969</td>
<td></td>
</tr>
</tbody>
</table>

1) SHEEHY et al. (1969), 2) Morgan et al. (1970), 3) Kelley et al. (1972), 4) Kelley et al. (1972), 5) Assumed identical to 15031.

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