U-Pa-Th. The isotopic compositions of uranium and thorium (Table 1) have been determined on three samples from the Apollo 14 mission: 14163 (bulk fines), 14259 (comprehensive fines), and rock 14310. The Pa$^{231}$/U$^{235}$ ratio was determined in 14163 by the neutron activation technique described by Rosholt and Szabo (1969). The daughter product isotopes of uranium, thorium, and protactinium analyzed (Table 1) are in radioactive equilibrium with parent nuclides in these samples. Dissolved lunar samples from which uranium and thorium were purified were obtained from M. Tatsumoto. Neutron irradiation of a separate portion of fines for Pa$^{231}$ determination was done in the GSTR TRIGA facilities as was neutron irradiation of selected portions of highly purified thorium previously extracted from Apollo 11, 12 and 14 samples.

Clues to Existence of an Isomer of Th$^{232}$. Of more interest are observations resulting from neutron irradiation of purified thorium from both lunar and terrestrial rocks. Previous to irradiation with a total flux of approximately $5 \times 10^{18}$ neutrons, purified thorium had been electrodeposited on pure titanium or molybdenum counting discs. The purpose of this investigation is to determine if a suspected isomer of Th$^{232}$ (Th$^{232m}$) can be distinguished from Th$^{232}$ by a difference in the reaction products produced from neutron irradiation of thorium; the existence of such an isomer was suggested from interpretation of anomalous Th$^{232}$/Th$^{230}$ activity ratios in crystalline rocks from Apollo 11 and Apollo 12 missions (Rosholt and Tatsumoto, 1971).

The Th$^{232}$ (n,$\gamma$) Th$^{233}$ $\beta^-$ Pa$^{233}$ $\beta^-$ U$^{233}$ reaction will produce a measurable quantity of alpha-particle emitting U$^{233}$ on the counting disc. In addition to the expected U$^{233}$ produced, a relatively large and unexpected activity of a 5.3 MeV alpha emitter was also produced. Preliminary measurements indicate that a portion of the 5.3 MeV alpha activity decays with a half-life of approximately 40 days. A significant fraction of the activity in the alpha peak is from Po$^{210}$ (5.30 MeV, 138.4-day half-life) and a very small fraction may be from U$^{232}$ (5.31 MeV, 72-year half-life) produced by the reaction:

Th$^{232}$ (n,2n) Th$^{231}$ $\beta^-$ Pa$^{231}$ (n,$\gamma$) Pa$^{232}$ $\beta^-$ U$^{232}$ (Hyde et al., 1964). Neutron capture by bismuth impurities in the thorium or in the metal discs could produce Po$^{210}$ by the reaction: Bi$^{209}$ (n,$\gamma$) Bi$^{210}$ $\beta^-$ Po$^{210}$.

Activity at the 5.3 MeV alpha energy has been produced in all irradiated thorium that has been measured but in variable quantities from one type of thorium to the other. If indeed this unidentified alpha activity was produced
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as a reaction product from neutron irradiation of Th$^{232m}$, it will provide a very sensitive technique to estimate the abundance of Th$^{232m}$, even in very small proportion, in lunar and terrestrial thorium. The $\alpha$ activity produced can be used as an internal flux monitor in the thorium itself and the 5.3 MeV/$\alpha$ activity ratio can be used to estimate the abundance of Th$^{232m}$ in the thorium irradiated. Preliminary measurements by alpha spectrometer indicate that this ratio varied from about unity in lunar thorium from sample 12033 to about 2 in thorium from 14310 and 3633 terrestrial granite reference, to about 2.5 in thorium from terrestrial obsidian reference. Based on Th$^{230}$/Th$^{232}$ activity ratios in Apollo 12 samples (Rosholt and Tatsumoto, 1971), 12033 should have only a very small amount of Th$^{232m}$ relative to lunar crystalline rocks and data in Table 1 indicate that 14310 may also have only a small amount of isomer. Apparently our terrestrial reference samples have a slightly greater Th$^{232m}$ abundance ratio than that in most lunar fines and breccia samples that have been analyzed.

REFERENCES


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Table 1. Isotopic ratios of uranium, protactinium, and thorium.

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Sample Type</th>
<th>( \frac{U^{238}}{U^{235}} ) (atom ratio)</th>
<th>( \frac{U^{234}}{U^{238}} ) (activity ratio)</th>
<th>( \frac{Pa^{231}}{U^{235}} ) (activity ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines</td>
<td>14163</td>
<td>137.6±.3</td>
<td>1.00±.02</td>
<td>0.97±.04</td>
</tr>
<tr>
<td>Fines</td>
<td>14259</td>
<td>137.9±.3</td>
<td>0.99±.02</td>
<td>n.d.</td>
</tr>
<tr>
<td>Rock</td>
<td>14310</td>
<td>137.6±.3</td>
<td>0.98±.02</td>
<td>n.d.</td>
</tr>
</tbody>
</table>

1/ Values for \( \frac{Th^{232}}{U^{238}} \) atom ratios were furnished by M. Tatsumoto and his coworkers.

2/ Expected \( \frac{Th^{232}}{Th^{230}} \) activity ratio was calculated from
\[ \frac{(Th^{232}/U^{238})_{\text{atom}} x (\lambda_{232}/\lambda_{238})}{\text{activity ratio}} \], where \( \lambda_{232} = 4.88 \times 10^{-11} \text{ yr}^{-1} \) and \( \lambda_{238} = 1.537 \times 10^{-10} \text{ yr}^{-1} \).