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QUARTERLY RESEARCH REPORT TO THE NASA VANDER SPACECRAFT CENTER

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIONUCLIDE TECHNIQUES

July 6, 1970 Through October 4, 1970

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October 15, 1970

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ABSTRACT

The elemental concentrations of the fecal samples from the Apollo 12 and 13 missions are being determined by neutron activation and gamma-ray analysis of the induced radionuclides. Some samples show anomalously high concentrations of gold.

Rackets of the coated-used as the outer thermal coating of spacecraft have been proton irradiated at 100, 375, and 600 MeV. The 7Be and 212Pb excitation functions from this material are reported. The cross sections of these induced radionuclides are compared to the previously measured activities in the "skin" from the Apollo 8 and 12 mission spacecraft to yield particle fluxes of >16 p cm² sec⁻¹ and >29 p cm² sec⁻¹ incident on those spacecraft respectively.

The concentration of 211Pb in a piece of the outer thermal coating of the Apollo 12 spacecraft has been determined. The origin of the 211Pb is assumed to be the escaping decay products from the uranium in the moon. The average lunar surface uranium concentration of 0.061 ppm determined in this manner appears to be too low by a factor of 5 or 7 based on measurements of moon rocks and fines returned by the Apollo 11 and 12 missions.

The construction of a semi-portable, multipurpose gamma-ray spectrometer system is proposed. Suggested applications and a description of the high-efficiency, low-background whole-body counter and sample counter combination are given.
All aliquots of the returned feral samples from the Apollo 12 and 13 missions have been activated with thermal neutron exposures of \( 10^{-17} \) n cm\(^{-2} \) in a Savannah production reactor. Gamma-ray analyses of the induced radioisotopes are not yet complete, but results obtained to date demonstrate extraordinarily high concentrations of gold in some of the aliquots. Complete results of these analyses will appear in a later report.

A manuscript on the calcium, potassium, and iron mass balance in astronauts is currently being prepared for open literature publication. Preprints of this communication will be sent to the NASA distribution list of this report.

Several packets of the capton which is used for coating the outside of the spacecraft were proton irradiated under various conditions at the Space Radiation Effects Laboratory cyclotron and analyzed in these laboratories from seven to sixty-three days after exposure. All foil packets weighed 0.666 g and contained 64.5 cm\(^3 \) of the capton. Irradiation levels of three of the packets were \( 3 \times 10^7 \) p cm\(^{-2} \) at 600 MeV, \( 5 \times 10^7 \) p cm\(^{-2} \) at 375 MeV, and \( 1.9 \times 10^7 \) p cm\(^{-2} \) at 108 MeV. Other packets received insufficient proton exposures to measure the induced radioactivities. The measured activities are divided by the particle flux and the quantity of capton to yield the effective cross sections for the production of \(^7\text{Be} \) and \(^{22}\text{Na} \) in the spacecraft "skin." These are shown in Table 1. Extrapolation of these values to other energies cannot be accurately accomplished since the production cross sections of the radioisotopes from the different elements composing the "skin" change independently as a function of energy. However, little variation of the effective cross section is anticipated above an incident proton energy of 100 MeV for either of these radioisotopes. Below 100 MeV the cross section for the production of \(^7\text{Be} \) would be expected to drop while that for \(^{22}\text{Na} \) would be expected to increase. At very low energies both cross sections would, of course, fall to zero.

Application of these production limits to previously measured radioactivity levels in the skin from earlier missions should verify the approximations and assumptions made in the earlier calculations. Dividing the \(^{22}\text{Na} \) activity (0.027 dis/min/g "skin") observed in a piece of the capton from the Apollo 8 mission (1) by the upper limit for the production of \(^{22}\text{Na} \) at 600 MeV (a number consistent with the results at all energies) and by
the elapsed time of the mission yields a proton flux of \( >15 \, \text{p cm}^{-2} \, \text{sec}^{-1} \) incident on the spacecraft during the course of that mission. This is not contradictory to the value of \( 37 \, \text{p cm}^{-2} \, \text{sec}^{-1} \) obtained earlier by more laborious calculations even though nothing has been said about the energy of the particles. A similar calculation using the 2.06 dis/min/g "skin" observed for the \(^{7}\text{Be} \) activity in a sample from the Apollo 12 craft\(^{3}\) yields a proton flux of \( >9 \, \text{p cm}^{-2} \, \text{sec}^{-1} \) for that mission, which also does not disagree with the results previously reported.

The method of obtaining a gross effective cross section for the capton and using this value to determine radiation exposures of spacecraft is by far the best approach. However, to be truly effective, excitation functions must be measured. That is, the cross section for production of each isotope produced by proton bombardment of the capton must be accurately determined over an extensive energy range. This would involve the exposure of the packets to proton doses on the order of \( 10^{10} \, \text{p cm}^{-2} \) in order that reasonable counting statistics could be obtained for each induced radionuclide in a relatively short period of time. Exposures should be made at energies starting near the production threshold \( (\approx 20 \, \text{MeV}) \), and the packets should be analyzed as rapidly as possible to facilitate the measurement of the shorter-lived radionuclides such as \(^{210}\text{Po}\).

The concentration of \(^{210}\text{Po} \) (which can be related to \(^{210}\text{Pb} \) and \(^{226}\text{Ra} \)) has been measured in a 2.4902 g piece of the outer thermal coating of the Apollo 12 spacecraft in an attempt to determine the average uranium concentration of the moon. When \(^{238}\text{U} \) decays, one member of the decay chain is gaseous radon \( \text{(}^{222}\text{Rn} \), \( t_{1/2} = 3.8 \, \text{d} \) which diffuses out of the lunar surface and becomes, along with the solar wind, the "lunar atmosphere." Since the thermal velocity of these radon atoms is less than the escape velocity, they are trapped by the moon's gravity. The recoil velocity from the alpha decay of the radon and its daughters, however, is sufficient to exceed the escape velocity. Those recoils directed away from the lunar surface will indeed escape the moon's influence, and those striking a spacecraft in orbit around the moon will embed themselves in the outer surface and eventually decay through \(^{210}\text{Po} \).

Following the same line of reasoning used in an earlier report\(^{3}\), if the uranium concentration of the lunar surface is the same as that of the earth's crust, the saturation concentration of \(^{210}\text{Po} \) in the skin of the Apollo 12 spacecraft should be \( 0.0092 \, \text{dis/min/cm}^{2} \). This activity should arise from the successive decays of the radon daughters which have embedded themselves in the "skin" of the spacecraft while in orbit around the moon.

The chemical separation and counting of \(^{210}\text{Po} \) was as described earlier\(^{3}\) and yielded a saturation value of \( 0.0093 \, \text{dis/min/cm}^{2} \). The measured value is 0.034 times the calculated value, which, although still low, is much higher than the 0.0047 ratio determined for the Apollo 6 mission skin.\(^{3}\) Assuming that the ratio of the measured and calculated activities represents the ratio of the uranium concentrations of

\[ \frac{\text{measured}}{\text{calculated}} = \frac{0.0093}{0.0092} = 1.01 \]
surfaces of the moon and the earth and that the average uranium concentration in the earth's crust is 1.5 ppm, the average uranium concentration on the lunar surface would be 0.061 ppm. This calculated concentration again appears to be too low when compared to an average value of 0.40 ppm measured in some lunar rocks and fines from the Apollo 11 and 12 missions. Possible reasons for this discrepancy have been discussed elsewhere.

A second "milking" of the 218Po activity from the 218Po parent in the separation solution is presently in progress. Arrangements have been made to receive 430 cm$^2$ of the solar wind composition experiment foil which was exposed to the lunar atmosphere during the Apollo 12 lunar landing. It is anticipated that this well-documented sample will eliminate the possible sources of error involved in trying to measure the 218Po activity in the spacecraft skin. The SWC foil should be received within a few days, and the 218Po will be separated shortly thereafter.

The construction of a semi-portable, multipurpose gamma-ray spectrometer is proposed for use during Project Skylab with completion in time for some testing and evaluation during the last of the Apollo series missions. Basic design features of the spectrometer incorporate two large (about 9" dia. x 8" thick) NaI(Tl) scintillation detectors mounted face to face in a vertical assembly which permits the separation distance to be varied from a fraction of an inch to about eighteen inches. Both detectors would be integrally mounted with a NaI(Tl) anticoincidence shield and a pure NaI light pipe. A 4096 channel multiparameter analyzer or a small computer would be best suited for data storage with sufficient peripheral electronics to allow data to be taken in a variety of modes such as (1) gamma-gamma coincidence between the primary detectors with the outer annulus in anticoincidence, (2) the sum of the single events in both detectors with anticoincidence shielding, (3) the sum of the single events in each detector and its annulus (effectively about 15" dia. by 11" thick crystals), or (4) the single events in either crystal with or without anticoincidence.

The detectors and electronics would be shock mounted in a framework designed to permit the center detectors to be brought close together for low-level sample counting or separated sufficiently to allow a motor-driven pallet to pass between the detectors for use as a whole body counter. Worm gear drive systems would allow the change-over between sample counter and whole body counter to be effected in minutes. The detector assembly in its supporting skeleton and the electronics would be mounted in a reinforced, climate-controlled truck or trailer which would render the entire assembly truly portable. Floor space requirements would be about 4' x 15', which
The system could be used as a whole body counter to measure changes in the natural $^{40}$K and $^{14}$C in the astronauts' bodies by starting at the Manned Spacecraft Center before a mission, moving the counter along with the astronauts to Cape Kennedy prior to lift-off, moving the counter to the recovery vessel to count the astronauts immediately upon their return, and finally back to the Manned Spacecraft Center for the final terrestrial reinstallation. Using the same counter for all measurements would increase the sensitivity of the experiment by eliminating the uncertainties involved in the calibration of different counters. When used as a whole body counter, any radionuclides injected in the astronauts for medical studies to be performed under space environment conditions could also be determined. In addition, these radionuclides could be measured in the urine, feces, or blood by the same counter when used in the appropriate sample counter mode.

Correlations between the injected quantities and those excreted or those in the body serum can then be drawn. In the event of a solar excursion or uninduced cosmic radiation dose, a whole body counter measurement on the astronauts could be used to determine the extent of radiation activation of the astronauts' bodies. Again, sample counter measurements could be made to determine the quantities of induced radionuclides excreted in the feces or urine or those still present in the blood or body serum.

Use of the counter as a sample detector is almost unlimited. The design permits the measurement of radionuclides at concentrations as low as 0.1 dpm/min in sample geometries from point sources up to about 10" cubes. By measurement of the induced activities in parts of the spacecraft or equipment, the cosmic-ray exposure can be determined. Studies similar to those performed on moon rocks, meteorites, or returned space "junk" can be accomplished with all the sensitivity and accuracy of existing equipment and, in addition, with the tremendous advantage of being able to measure short-lived spallation products which have heretofore been indeterminable due to their decay before radioactivity measurements could be made. An additional experiment which could be best carried out with a spectrometer system located at the point of splashdown is the determination of the cosmic-ray activation products in pure elemental samples exposed to the space environment. This experiment, which is the basis for all conclusions regarding cosmic-ray activation of extraterrestrial materials, has never been carried out in silico. Theoretical calculations and simulation experiments have thus far been used to interpret the quantities of cosmic-ray spallation products present in meteorites, lunar materials, and space "junk" by actually exposing pure elemental foils.
to the space environment and determining the quantities of all the activation products in them, better mappings of the cosmic-ray spectrum and intensity and a better basis for evaluation of activation product concentrations in elemental mixtures, such as moon rocks, will be obtained. Determination of the activation products in similar foil on both the inside and outside of a spacecraft would elucidate the type and degree of radiation shielding provided by the spacecraft and the quantity and type of secondary particles produced within the hull.

In summary, a multipurpose, portable, highly sensitive gamma-ray spectrometer is proposed which will have the capability of being applied to almost any existing or conceivable program requiring the use of a whole body counter or a high-efficiency, low-background sample counter. The system will be truly portable and will have sensitivities comparable to the best equipment presently available anywhere.

The following table documents the expenditures according to task and total cost incurred from July 6, 1970, through October 4, 1970, for the work reported herein.

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**Table 1**

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<th>Energy (MeV)</th>
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<th>Sig. 7pm</th>
<th>Sig. 7+7pm</th>
<th>Sig. 1pm</th>
<th>Sig. 7pm</th>
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<tr>
<td>100</td>
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<td>3.3 × 10^7</td>
<td>5.6 × 10^7</td>
<td>5.6 × 10^7</td>
<td>5.6 × 10^7</td>
</tr>
<tr>
<td>275</td>
<td>3.6 × 10^7</td>
<td>3.6 × 10^7</td>
<td>5.7 × 10^7</td>
<td>5.7 × 10^7</td>
<td>5.7 × 10^7</td>
</tr>
<tr>
<td>600</td>
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<td>1.4 × 10^7</td>
<td>2.9 × 10^7</td>
<td>2.9 × 10^7</td>
<td>2.9 × 10^7</td>
</tr>
</tbody>
</table>

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**Note:** The table above shows the proton spallation yields of 7pm and 77pm in Apollo spacecraft thermal coating (CAPTOR).