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QUARTERLY RESEARCH REPORT TO THE NASA MANNED SPACECRAFT CENTER

THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

April 8, 1969, Through June 30, 1969

DETERMINATION OF THE RADIONUCLIDE CONTENT OF FECES AND URINE FROM ASTRONAUTS ENGAGED IN SPACE FLIGHT

by

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July 15, 1969

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INTRODUCTION

Astronauts engaged in space flight are subject to cosmic radiation which does biological damage to, and induces radioactive isotopes in, their bodies. The radiation dose received from the cosmic particles can be determined from the quantities of induced radionuclides.[1,2] The amounts of these induced activities can be determined by direct measurement, i.e., whole body counting of the astronaut, or by indirect measurement, such as counting the radionuclides excreted in the feces and urine. The latter approach was used for evaluation of radiation activation during the course of the Apollo 7, 8, 9, and 10 missions.

The principal gamma-ray-emitting radioisotopes produced in the body by cosmic-ray bombardment are ^{7}Be ($t_{\frac{1}{2}}$=53 day), ^{11}C ($t_{\frac{1}{2}}$=20.5 min), ^{13}N ($t_{\frac{1}{2}}$=9.96 min), ^{22}Na ($t_{\frac{1}{2}}$=2.60 yr), and ^{24}Na ($t_{\frac{1}{2}}$=15.0 hr). Of these, ^{11}C and ^{13}N are too short-lived to be measured by any method other than a direct determination, and this direct counting would have to be done as soon as possible after recovery. This is unfortunate since these radioisotopes are produced in the largest abundance. The radionuclides ^{7}Be, ^{22}Na, and ^{24}Na are, however, sufficiently long-lived to facilitate their use in making dose estimates from indirect measurement of their quantities in urine and fecal samples.

Other radioisotopes were also expected to be present in the bioassay samples. In addition to the aforementioned cosmogenic radionuclides, measurements of naturally present ^{40}K, normally occurring ^{7}Be, ^{22}Na, and ^{137}Cs, and injected

^{51}Cr and ^{59}Fe were also made. Another radioisotope, ^{60}Co, was detected and quantitatively measured in some of the specimens. Corrections to the cosmogenic ^{7}Be and ^{22}Na must be made to account for the quantities of these radioisotopes normally occurring in the body because of fallout, food intake, and other ingestion processes. The quantities of the naturally occurring ^{40}K and the injected ^{51}Cr and ^{59}Fe in the bioassay samples could serve as biological tracers of various changes of metabolic processes during the course of a mission.

EXPERIMENTAL

Preflight and postflight urine and feces and those feces specimens collected in flight were analyzed from the Apollo 7, 8, 9, and 10 missions. Urine specimens were treated by repeatedly boiling to dryness with nitric acid to destroy the organic matter present. The remaining salts were counted in large crystal multidimensional gamma-ray spectrometers[3,4,5] for determination of ^{22}Na, ^{24}Na, ^{40}K, ^{51}Cr, ^{59}Fe, ^{60}Co, and ^{137}Cs. The salts were then redissolved in a weak HCl solution and diluted to known volume. An aliquot of this solution was taken for neutron activation analysis to determine the amount of inert sodium in the sample. The remainder of the solution was reduced in volume to approximately 15 ml and transferred to a 100 ml polyethylene centrifuge tube. Approximately 5 mg of Be^{++} carrier and 20 mg of Fe^{+++} carrier were added, and the solution was neutralized with concentrated NH_4OH. After centrifugation the supernatant solution was discarded. Thirty-five ml of 3N NaOH were added to the remaining precipitate and stirred vigorously until well mixed. After centrifugation the supernatant liquid was transferred to a clear centrifuge tube, saturated with NH_4Cl, and heated in a water bath. If necessary, additional NH_4Cl was added until a $Be(OH)_2$ precipitate settled from the solution. The solution was then centrifuged, and the supernatant fraction was discarded. The resulting precipitate containing the ^{7}Be activity was counted in an all NaI(Tl) anticoincidence shielded, 7-inch

diameter scintillation well crystal in the absence of all interfering activities. This was necessary in order to measure the relatively small quantities of ^{7}Be present.

Fecal samples were thoroughly mixed in their collection bags to ensure homogeneity of the specimens. A small corner was cut off each bag and aliquots were squeezed out for the various experiments. Aliquots of raw feces were counted on multidimensional gamma-ray spectrometers to measure the radioisotopes ^{22}Na, ^{40}K, ^{51}Cr, ^{59}Fe, ^{60}Co, and ^{137}Cs. Separate aliquots were wet ashed with nitric acid and hydrogen peroxide to destroy the organic matter present. The resulting salts were dissolved in dilute nitric acid, and the same procedure as above was followed for separation of the ^{7}Be activity. In addition, for the Apollo 9 and 10 missions, approximately 10 mg of mixed rare earths were added to the feces prior to wet ashing. These were to serve as carriers for ^{147}Pm, which could possibly have been ingested by the crew members from some faulty switch tips in the Lunar Excursion Module. This rare earth fraction was separated from the beryllium fraction after the initial NH_4OH precipitation by dissolving the precipitate in approximately 8 ml of 3M HCl and adding 2 ml of 49 percent HF. Centrifugation separated the rare earth precipitate from the beryllium in the supernatant solution. The rare earth fraction was then dissolved in two parts concentrated HNO_3 and three parts saturated boric acid solution and reprecipitated with NH_4OH. After centrifugation and decantation, the precipitate was dissolved in dilute HCl, and saturated oxalic acid solution was added to precipitate the rare earth oxalates. The solution was centrifuged, the supernatant solution was decanted, and the precipitate was washed with alcohol, transferred to a 1-inch diameter stainless steel dish, and counted in an end window, gas flow beta counter for the measurement of ^{147}Pm.

RESULTS AND CONCLUSIONS

The results of the various determinations are given in Tables I through VIII. The data for the fecal samples have all been normalized by dividing by the weight of material. The urine data have been normalized to fluid volume and in a few select cases the weight of inert sodium in the sample. All data for the Apollo 7 mission have been corrected for radioactive decay to October 22, 1968, the day of splashdown of that mission. Similarly, the data for the Apollo 8 mission have all been corrected to December 27, 1968, for the Apollo 9 mission to March 13, 1969, and for the Apollo 10 mission to May 26, 1969.

Analysis of the ^{51}Cr data given in Table I indicates that inflight samples S/N 2278, S/N 2280, S/N 2292, S/N 2299, and S/N 2312 are all from the same astronaut, and comparison with the two postflight specimens further indicates that this was Astronaut C. Similarly, from a comparison of the postflight specimen data, samples S/N 2277 and S/N 2282 appear to be from Astronaut A. Samples S/N 2276 and S/N 2300 would then be from Astronaut B by the process of elimination. Sample S/N 2270 was not counted for any radioisotopes other than ^{7}Be because of the small quantity of material.

Analysis of the ^{59}Fe data tends to substantiate the above allocations. The anomalously high value for ^{59}Fe observed in the Astronaut C postflight specimen appears to be real but remains unexplained. Indeed, the value observed for ^{60}Co in this sample is also real but unconfirmed in any other sample. The ^{40}K and ^{137}Cs activities appear natural and excreted normally. The ^{22}Na activities observed were so low that large uncertainties exist. However, this activity appears to be increasing as a function of time within each of the two astronauts in which it was observed. Similarly, the ^{7}Be activity increased from 1.39 dis/min/g before the flight to an average of 1.51 dis/min/g during the flight for Astronaut B and from 0.843 dis/min/g before the flight to an average of 1.14 dis/min/g during the flight to 1.75 dis/min/g after the flight for Astronaut C. The uncertainties in these numbers, however, are large enough to eliminate the implications at the present time.

Since ^{7}Be and ^{22}Na are cosmogenic radionuclides produced in man, they will be treated here to see what, if any, conclusions can be drawn regarding the cosmic-ray exposure of the astronauts. Several assumptions will be required and will be explicitly stated. First it is necessary to determine the average effective proton bombarding energy incident on the astronauts. This can be done by determining the production ratio of $^{7}Be/^{22}Na$ in their bodies. The average of the ratio of the increase in fecal excretion of these radioisotopes in Astronauts B and C from preflight levels to inflight levels is 67. The ratio of the percentage of the body burden of ^{7}Be excreted to that of ^{22}Na excreted is estimated to be 2/7 based on the assumption that the body excretion pattern of beryllium is the same as that for magnesium.[6] Dividing by this excretion percentage ratio yields a body burden ratio of 235. This ratio corresponds to an average effective proton energy of 38 MeV incident on the astronauts.[1] The large uncertainties which arise when taking the differences of the ^{7}Be and ^{22}Na values preclude the possibility of making accurate dose calculations from these data. Suffice it to say, however, that the dose was relatively low and certainly within tolerance levels.

Analysis of the urine data given in Table II confirms the anomalously high values for ^{59}Fe and ^{60}Co observed in the postflight fecal sample from Astronaut C. These data also indicate that ^{51}Cr and ^{60}Co are excreted primarily in the urine as the concentrations are considerably higher than in the feces. The higher levels of the ^{51}Cr and ^{60}Co activities observed in the preflight specimen from Astronaut A than in his postflight specimen demonstrate that he had received an injection of the radioisotopes prior to taking the preflight specimen but did not receive any subsequent injections. Conversely the low levels of ^{51}Cr, ^{59}Fe, and ^{60}Co present in the preflight specimen from Astronaut C compared to the extremely high levels in the postflight specimens from Astronauts

B and C indicate that these astronauts had not received an injection closely preceding the preflight specimen but had received an injection between the time the preflight and postflight specimens were taken. These two observations also demonstrate that the ^{60}Co is coming from the injection as opposed to any other possible source. Assuming all three astronauts were exposed to the same conditions, ate the same food, drank the same water, etc., the only source for the ^{60}Co observed in Astronauts B and C and not observed in Astronaut A is the injections received by Astronauts B and C but not received by Astronaut A. Again the ^{40}K and ^{137}Cs activities appear to be quite natural and normally excreted, and the low activities observed for ^{22}Na and ^{24}Na lead to large uncertainties.

The observed ratio of the increase in ^{7}Be activity to the increase in ^{22}Na activity from preflight to postflight specimens from Astronaut A is 155. Again correcting for the excretion percentages yields a whole body burden ratio of 541. This value corresponds to an average effective proton energy of 40 MeV incident on the astronaut,[1] which is in excellent agreement with the value derived from the fecal data. A dose estimate can be attempted based on the one measurement of ^{24}Na in the postflight urine of Astronaut A. First, since ^{24}Na is short-lived compared to the duration of the mission, a correction must be applied to account for decay during flight. Assuming that the incident proton flux is reasonably constant during the flight, the 20 dis/min/g Na of ^{24}Na observed in the urine at the end of the flight is equivalent to 240 dis/min/g Na from an equivalent instantaneous dose of radiation. It is then necessary to find its equivalence at an incident proton energy of 107 MeV in order to compare experimental data[7] with flight data. This can be done by a multiplication factor obtained from the ratio of ^{24}Na production rates in muscle tissue at 107 MeV and 40 MeV.[14] Utilization of this factor yields an equivalence of 290 dis/min/g Na from an instantaneous dose of 107 MeV protons. This corresponds to a radiation dose of 480 millirads integrated through the course of the mission.[7] It should again be pointed out that the large uncertainties in the measured values for ^{22}Na and ^{24}Na make this

dose estimate unreliable. The uncertainty is at least 310 millirads at the 65 percen confidence level. Much more precise dose estimates would be possible if the samples could be received much sooner after splashdown before any significant fraction of the short-lived ^{24}Na will have decayed.

Analysis of the fecal data (see Table III) from Apollo 8 shows that Astronauts B and C were given an injection of ^{51}Cr between the preflight samples and liftoff. The same observation is apparently true for the ^{59}Fe data, and it appears that the inflight specimens are not from Astronaut A since there was no measurable ^{59}Fe in his postflight specimen. Based on the ^{59}Fe and ^{40}K concentrations in the inflight and postflight specimens, the inflight specimens appear to be from Astronaut C. The values for ^{60}Co are insignificant with respect to the large uncertainties, and the ^{137}Cs values are quite normal. There is no apparent increase in the ^{7}Be activity, although there is the suggestion of an increase in the ^{22}Na levels. This would indicate that the average effective proton energy incident on the astronauts is less than the threshold for production of ^{7}Be or less than about 38 MeV. Reliable dose estimates are not possible from these figures, although the dose is probably lower than in the Apollo 7 mission.

Analysis of the data in Table IV bears out the conclusion that Astronauts B and C received preflight injections of ^{51}Cr, ^{59}Fe, and ^{60}Co, while Astronaut A did not. No other conclusions can be drawn from these data at this time because of the lack of preflight specimen data for comparison.

Analysis of the fecal data from Apollo 9 (see Table V) is a rather uneventful task. Of foremost importance are data not given in the table. No ^{147}Pm was observed in any of the fecal samples. The possible existence of this radioisotope was incurred when some switch tips containing ^{147}Pm and a scintillator were broken in the Lunar Excursion Module. Had any microspheres of ^{147}Pm been ingested by the astronauts, it most probably would have appeared in the feces. Since none ($< 6 \times 10^{-10}$ ci) was observed, it is likely that none was ingested.

Those samples in the table numbered 1, 3, 4, 6, and 8 had no identification marks or time written on the bags, and these numbers simply reflect the order in which the samples were handled and labeled. It may be assumed that all these samples are from the third astronaut although their time of collection is unknown. The ^{40}K and ^{137}Cs are quite normal in all samples. The levels of ^{60}Co activity are rather low and uniform except for sample number 1, where it is an order of magnitude higher than elsewhere. This anomaly is unexplained. The ^{51}Cr activity is in the same range as previous flights, and though it tends to be erratic for the numbered samples it is remarkably constant for the D.R.S. samples. Similarly, the ^{59}Fe activity is on the same level as previous flights and tends to demonstrate an increase in excretion rate as a function of time in the D.R.S. samples. The complete lack of observed ^{22}Na activity and the sparse and rather uncertain ^{7}Be activity again indicate that an extremely low radiation dose was received by the astronauts.

Examination of the urine data from Apollo 9 in Table VI yields several interesting observations. The ^{51}Cr and ^{59}Fe results are some of the more unusual data presented. Comparing these values for the four time periods covered demonstrates that the astronauts received injections of these radioisotopes between the fourteenth and the fourth day prior to flight. The lower activities of ^{51}Cr observed in the specimens collected immediately after the mission compared to the activities measured in samples collected four days before the flight indicate a normal decay. However, the very large increase in the quantities of this radioisotope observed in the first twenty-four-hour collection period postflight can only be explained by a further injection of ^{51}Cr after the mission or by some drastic metabolic change in the astronaut's system occasioned by the space environment. The ^{59}Fe data, conversely, do not demonstrate the decay trend or the subsequent abrupt huge increase. The two measurements of ^{60}Co activity are incidental and subject to large error. The naturally present ^{137}Cs activity also

appears to be somewhat higher in the postflight rather than in the preflight specimens although this difference may be insignificant. The naturally occurring ^{40}K activity, on the other hand, demonstrates a definite decrease in the postflight specimens compared to the preflight. This phenomenon may be caused by a reduced potassium content in their inflight diet or, again less likely, to some disruption of biological processes induced by the rigors of the mission. The ^{7}Be and ^{22}Na activities are low, have large uncertainties, and are apparently all naturally present. No ^{24}Na was observed in the postflight urine specimens, which were collected immediately on splashdown and counted about three days later, indicating a very low cosmic radiation dose. An upper limit for the dose can be calculated on the basis of the sensitivity for determining this radioisotope and an assumption about the energy of the cosmic particles incident on the astronauts. If it is assumed that the astronauts were subjected to the same average effective proton flux of 40 MeV as in Apollo 7 and 8, that the flux was constant throughout the course of the mission, and that the urine salts are composed of 13 percent sodium by weight (activation analysis of the samples is not yet complete, therefore, this previously determined average value is used), then an upper limit of 315 millirad can be set for the cosmic radiation dose received by the Apollo 9 astronauts (McDivitt).

Analysis of the fecal data from Apollo 10 (see Table VII) is again a difficult task because of the lack of preflight and postflight samples. The one ^{7}Be value reported is representative of a typical concentration based on previous flights, however, the ^{22}Na activities are higher than any observed in the three previous missions for inflight specimens. These ^{22}Na values would indicate that the radiation dose received by Apollo 10 astronauts is about a factor of three higher than that received on any other manned Apollo mission assuming that the ^{22}Na levels prior to flight were about the same for all missions. The ^{59}Fe and ^{60}Co data are quite comparable with the previous missions and the ^{40}K and ^{137}Cs activities appear natural and normally excreted. The complete absence of ^{51}Cr

activity would indicate that these astronauts did not receive a preflight injection of this radioisotope as did previous Apollo astronauts. Again, no ^{147}Pm (< 5×10^{-12} Ci) was observed in the feces.

The urine data from Apollo 10 (see Table VIII) illustrate the normal excretion rates of ^{40}K, ^{59}Fe, and ^{137}Cs found in the previous missions. The ^{51}Cr activities are extremely low and support the absence of a recent ^{51}Cr injection; however, the ^{22}Na activities do not show a particularly large increase in the urine in contrast to the increase demonstrated in the fecal samples. This discrepancy may be accountable in the large uncertainties and small sample sizes. Increases in the levels of ^{7}Be and ^{22}Na are, however, definitely indicated in the urine specimens. A calculation of the radiation dose based on the ^{24}Na activity will follow the same pattern as that used for the Apollo 7 mission. First, since ^{24}Na is relatively short-lived compared to the duration of the mission, a decay correction factor must be applied to the recorded data. From the known total volumes and the weight of salts in the two postflight specimens and again assuming the salts are composed of 43 percent sodium, the average ^{24}Na activity in the urine at the time of splashdown was 50 dis/min/g Na. If it is assumed that the incident proton flux is constant throughout the course of the mission, then this value is equivalent to 530 dis/min/g Na from an equivalent instantaneous radiation dose. The flux is, of course, not constant throughout the flight, however, if it is reasonably symmetric as a function of time about the midpoint of the flight, the same results arise. Again making the energy correction in order to compare experimental data[7] with flight data, this becomes 610 dis/min/g Na from an equivalent dose of 10^7 MeV protons, which corresponds to a radiation dose of 870 millirads[8] received by the Apollo 10 astronauts. Again, it should be emphasized that the error values on this number are quite substantial.

SUMMARY

A study of the quantities of radionuclides present in the feces and urine of the astronauts from the Apollo 7, 8, 9, and 10 missions has been completed. Observed radioisotopes were ^{7}Be, ^{22}Na, ^{24}Na, ^{40}K, ^{51}Cr, ^{59}Fe, ^{60}Co, and ^{137}Cs. The ^{51}Cr, ^{59}Fe, and ^{60}Co are from preflight injection, the ^{40}K and ^{137}Cs are naturally occurring or normally present, the ^{7}Be and ^{22}Na are both of normally occurring and cosmogenic origins, the ^{24}Na is cosmogenic. Evaluation of the data indicates that the Apollo 7 mission astronauts were exposed to protons with an average effective energy of 38 to 40 MeV. The Apollo 8 mission astronauts were exposed to protons of less than 38 MeV. The radiation dose received by Apollo 7 mission astronauts was 480 ± 310 millirads at the 65 percent confidence level. The radiation dose received by the Apollo 9 mission astronauts was less than 315 millirads. The radiation dose received by the Apollo 10 mission astronauts was 870 ± 550 millirads.

NEUTRON ACTIVATION ANALYSIS OF FECES AND URINE FROM ASTRONAUTS ENGAGED IN SPACE FLIGHT

The conditions of weightlessness and prolonged inactivity of astronauts during extended space flight have raised some questions concerning possible metabolic changes which may occur. The phenomenon of osteoporosis, the loss of skeletal calcium, is of primary concern but the changes in the body content of other essential elements are also important. The microconstituents such as cobalt, iron, and selenium and the alkali metals which act as electrolytes play an important part in the metabolic processes of the body. Radical changes in their excretion rates may result in physical and mental disparities which could alter the course of a mission. Other elements such as bromine and chromium with as yet unspecified biological functions may also be important in this respect.

A study to establish the excretion rate of these elements would be an important step in determining possible losses during a space flight. Although a complete mass balance of each constituent would require the study of the intake of each element from the food, changes in the excretion rate could still be determined if serious losses occur over a prolonged period of time. A sensitive multielement technique of instrumental neutron activation analysis developed specifically for the measurement of trace and ultratrace elements in biological systems[8] has been employed to measure the elemental concentrations of the feces and urine excreted by astronauts during extraterrestrial activity.

The fecal samples were thoroughly mixed in their collection bags and an aliquot weighing a few hundred milligrams was transferred directly to preweighed polyethylene irradiation capsules, freeze dried to a constant weight, and sealed in their polyethylene containers. The samples, together with their comparative standards, were irradiated in a Hanford Production Reactor to an integrated thermal neutron exposure of $\sim 2 \times 10^{17}$ n/cm^2. The samples were permitted to decay several days prior to gamma-ray analysis.

All samples and standards were thoroughly mixed in 2 percent solutions of agar agar and transferred quantitatively to standard counting geometries consisting of 1/2-inch thick by 2-inch diameter polyvinylchloride rings. After the agar agar solution solidified, the samples and standards were counted for ten minutes on a 20 cm^3 Ge(Li) diode for determination of the neutron-induced radioisotopes ^{24}Na ^{42}K, ^{47}Ca, ^{47}Sc, ^{76}As, ^{82}Br, and ^{198}Au. The samples and standards were then allowed to decay for approximately one month before being counted for 1000 minutes on the same diode for determination of the following radionuclides: ^{46}Sc, ^{51}Cr, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{75}Se, ^{86}Rb, ^{124}Sb, ^{134}Cs, and ^{203}Hg. After a further decay period of approximately one month, the samples and standards were counted on the large volume NaI(Tl) multiparameter spectrometers[3,4,5] for 1000 minutes to quantitatively determine ^{46}Sc, ^{60}Co, ^{65}Zn, ^{110m}Ag, and ^{124}Sb.

The concentration of each element was calculated by direct comparison of the activity of each radionuclide in the samples with those in the standards. Agreement between the two detection methods for a few common radioisotopes is typically within a few percent, overall accuracy of the data is ± 10 percent.

The quantitative results which have been completed to date are presented in Table IX. These data are so limited as to preclude drawing conclusions as yet, however, some observations can be made. The sodium concentrations must not be considered seriously at any time since the preservative added to the feces while in flight is a sodium salt of an organic compound, and the concentration of it will vary between each sample. This fact is illustrated by considering the elemental composition of the preservative presented in Table IX. Bromine, zinc, and iron tend to be lower in the postflight specimens when compared to the preflight samples. This may be due either to the fact that the body is retaining these elements to a higher degree during flight or that lower than normal amounts of these elements are taken in during the flight. Chromium, scandium, and antimony tend to show an increased excretion rate during flight. The chromium value may also be affected by the preflight injection of chromium received by the astronauts. The increased excretion rate of scandium and antimony, on the other hand, which are typically low in biological systems (parts per billion levels), is almost certainly due to a higher intake of these elements during the mission.

The postflight fecal samples from the Apollo 8 and 9 missions have been activated and counted on a Ge(Li) spectrometer, but the results can be discussed only in qualitative terms at this time. Most samples were found to contain large amounts of ^{198}Au with detectable quantities of ^{76}As. The presence of arsenic and gold is a significant departure from the results obtained for the excreta samples from the Apollo 7 mission.

GLASS FIBERS IN ASTRONAUT FECAL SAMPLES

During the course of the Apollo 7 mission, it was observed by the astronauts that significant amounts of glass fibers were present within the atmosphere of the spacecraft. In order to determine the amount and origin of the fibers ingested by the astronauts, the fecal samples which were collected and stored on board the spacecraft during the flight were analyzed for glass fiber content according to the following procedure.

The samples were thoroughly mixed in their collection bags to ensure homogeneity. A corner was cut off each bag, and aliquots of the sample were squeezed out for the various experiments being performed. The aliquot to be examined for glass fibers was squeezed directly into a 500 ml Erlenmeyer flask. Nitric acid was added, and the sample was wet ashed on a hot plate with additions of nitric acid and hydrogen peroxide as required to destroy the organic matter present. Only the insoluble silicates and glass fibers survive this procedure.

After wet ashing, the solutions were filtered through a 0.45 μ Millipore filter, and the eluent was saved for subsequent radiochemical separations. The filter containing the silicates and glass fibers was again dissolved in nitric acid and hydrogen peroxide and wet ashed to destroy the filter paper. The resulting solution was diluted to 400 ml, thoroughly mixed to ensure homogeneity of the insoluble material, and a measured volume of the solution corresponding to 3 to 6 grams of fecal material was again filtered through a 0.45 μ Millipore filter. This dilution was necessary to reduce the quantity of insoluble silicates on the filter paper to a point where they do not interfere with the identification of glass fibers. The remainder of the solution was filtered on a separate paper, and the insoluble material was stored for future reference.

Appropriate blanks were carried through the above procedure using samples of fiber glass which were the same as those used within the spacecraft. Fibers were identified as to type and number by visual examination of the black, gridded

filter paper through a Zeta-Meter microscope under 60X magnification. The average length of the fibers was estimated to be approximately 0.3 to 0.5 mm with a range of approximately 0.05 to 3 mm. The results of the measurements are given in Table X. A photomicrograph of three beta fibers on the filter paper from a 3.25 g aliquot of sample S/N 2312 is shown in Figure 1 under 200X magnification. Figure 2 is a photograph of the filter containing the insoluble silicates and glass fibers from a 137.2 g aliquot of sample S/N 2282.

A procedure similar to that described for the Apollo 7 mission fecal samples was used to determine the quantities of glass fibers in the feces from the Apollo 8 mission. The samples were numbered arbitrarily upon receipt for identification purposes only, and weighed aliquots of each were used for the measurements. In addition to the results as given in Table XI, 41 clusters of beta fibers where many fibers were still held together by the bonding agent were observed in sample number 3.

Four of the fecal samples from the Apollo 9 mission which were marked with the elapsed time into the mission were analyzed for glass fiber content by the same procedure as used for Apollo 8 specimens. The results of the observations are presented in Table XII. In addition, two clusters of beta fibers were observed in the D.R.S.-190 25 aliquot.

These results show a definite increase in the amount of ingested glass as a function of time into the flight. Dividing the total weight of glass in each defecation by the elapsed flight time since the last defecation, the amount of ingested glass becomes 0.19 μg/hr for the 113 00 sample, 0.48 μg/hr for the 168 00 sample, 6.5 μg/hr for the 190 25 sample, and 16 μg/hr for the 235 00 sample. This constitutes an exponential increase in the quantity of glass being ingested although the 235 00 sample begins to show some indication of leveling off.

Only three fecal samples were returned from the Apollo 10 mission. All three were particularly small samples, and aliquots for fiber glass analysis were obtained from only two of them. No identification other than the manufacturer's serial number appeared on any of the collection bags. Analysis was completed by the same procedure used in the previous missions.

Although great concern was displayed by the astronauts during the course of the mission about the quantity of fiber glass present in the capsule environment, no particular increase in the amount of excreted fiber glass over that of previous missions was observed, as is evidenced by the data in Table XIII. Only three fibers were observed in the aliquot from sample S/N 3512 which could not be identified and, hence, attributed to a different source than those from previous missions. A portion of the observed fibers reported as beta fibers may actually be alpha fibers, as no control sample was available until after the determinations were made. However, the total number of observed fibers will not change.

INDUCED RADIONUCLIDES IN SPACECRAFT

A 17.8 g piece of the outer "skin" of the Apollo 8 spacecraft was peeled off shortly after splashdown and counted for induced radioactivities in these laboratories seven days later. The only radioisotope observed was ^{22}Na, which was present at a concentration of 0.027 ± 16.4% dis/min/g "skin." This skin is an aluminized capton with a silicon monoxide coating. In order to draw any conclusions regarding the flux of incident particles which produced this activity, it is necessary to know the composition of the skin. The supplier of the skin (Schjeldahl Company, Northfield, Minnesota) was unable to furnish such an analytical composition of the skin, knowing only that it is made of a polyimide base (capton) coated with aluminum and an oxide of silicon (SiO_x) and utilizing a silicon base adhesive. Thus, only two elements, aluminum and silicon, are present which could give rise to ^{22}Na by cosmic-ray spallation.

These two elements were measured analytically by fast neutron activation techniques. One and one-half inch diameter foils were cut from the skin, from 1 mil thick aluminum foil, and from a silicon "foil" composed of pure silicon powder sandwiched between two pieces of cellulose acetate adhesive tape. These three foils and a blank "foil" of tape were irradiated with 14 MeV neutrons from a (d,t) reaction. Deuterons were supplied by a 2 MeV Van de Graaff accelerator. Beam currents, irradiation time, and number of neutrons were recorded for each sample in order to make valid comparisons. The irradiated foils were each counted on a 3 inch diameter by 3-inch thick NaI(Tl) scintillation crystal within one minute after bombardment for the short-lived induced activities ^{27}Mg and ^{28}Al produced by the (n,p) reactions on ^{27}Al and ^{28}Si, respectively. A small correction was required for the ^{28}Al produced by the (n,γ) reaction on ^{27}Al. No ^{27}Mg was observed from the (n,α) reaction on ^{30}Si. Intercomparison of these induced activities yields a mass composition of the skin of 7.7 percent aluminum, 51 percent silicon, and the balance carbon, hydrogen, nitrogen, and oxygen.

The number of particles incident on the spacecraft from liftoff to splashdown can now be calculated by assuming a typical shape for the incident cosmic particle spectrum and normalizing the excitation functions for production of ^{22}Na from aluminum and silicon to it. The excitation function from aluminum is well known over all energies, while that from silicon is known above 100 MeV only. The production cross section from silicon was therefore estimated to be 10.5 mb from 30 MeV to 100 MeV for the purposes of this calculation. The weighted average cross sections thus obtained for production of ^{22}Na by cosmic protons are 10.6 mb and 21.2 mb from silicon and aluminum, respectively. These cross sections, along with the measured activity and chemical composition of the skin, yield a flux of 37 protons cm^{-2} sec^{-1} above 30 MeV incident on the outside of the spacecraft. This value is certainly in accordance with all measured and calculated values for the cosmic proton flux and is indeed somewhat lower than the long-term average. This low flux is further substantiated by the low radiation dose received by the astronauts.

A 5.3 g piece of the outer skin from Apollo 9 was counted a little less than three days after splashdown of the mission. The only observed radioisotope was ^{24}Na present at the level of 0.4 ± 80% dis/min/g skin, decay corrected to the time of splashdown. Assuming the same composition of the skin as determined for Apollo 8 the ^{24}Na would be produced from the aluminum and silicon. Again, the excitation function for the production of this radioisotope from silicon is not well known and a reasonable estimate of this cross section was made. Using the same typical cosmic proton spectrum shape as for Apollo 8 and normalizing the excitation functions to it, the weighted average cross sections are 9.26 mb and 3.25 mb for the production of ^{24}Na fomm aluminum and silicon, respectively. Using these values of the cross sections, the activity of the ^{24}Na as a saturation value, and the same percentages of aluminum and silicon in the skin as used for Apollo 8, an incident proton flux of 130 protons cm^{-2} sec^{-1} above 40 MeV can be calculated. Though this value may be a little higher than would normally be expected, its uncertainty is large because of the large uncertainty in the ^{24}Na activity. In addition, this value is not a time integrated number through the course of the mission but is only representative of the last day of the flight.

PROMETHIUM-147 IN THE SPACE CAPSULE ENVIRONMENT

A luminous material composed of ^{147}Pm microspheres mixed with a scintillator is used extensively in the spacecraft in acrylic switch tips and sighting figures used in orbiting maneuvers. Because of the high rejection rate of switch tips caused by promethium leaks, there is some concern about the possibility of the presence of ^{147}Pm in the weightless environment in the space capsule. In order to check this possibility, approximately 3-inch by 3-inch squares of the inlet and outlet filters from the air purification cannister used in the Apollo 10 flight were digested with concentrated HNO_3 and 30 percent H_2O_2 in the presence of approximately 10 mg of mixed rare earth carriers. The eluent from this

digestion was treated in a similar manner to that described for the separation of ^{147}Pm from fecal material. No ^{147}Pm (< 1×10^{-12} ci) was observed in the solution from either filter, thus indicating its presence in the capsule environment is minimal.

CALIBRATION OF THE NASA MANNED SPACECRAFT CENTER WHOLE BODY COUNTER

The whole body counter located in the Counting Room of the Lunar Receiving Laboratory was calibrated by using solid phantoms in lieu of liquid phantoms or human subjects which were considered unadvisable because of the possibility of contamination. Phantoms were constructed of rectangular cardboard boxes, 2 inches by 3 inches by 4 inches, filled with Delrin 500* plastic in the form of 1/8-inch pellets. Bulk density of each box was 0.96 g/cm^2. Phantoms constructed for the calibration weighed 141, 164, and 206 pounds. Each box in the phantom had an equivalent source of the radioisotope being calibrated attached to it in order to allow optimum distribution of the radioisotope through the solid phantom. Equivalent point sources were made by micropipetting standardized solutions of the radioisotopes ^{7}Be, ^{22}Na, ^{24}Na, and ^{137}Cs on 3/8-inch diameter discs of absorbent paper. The discs were allowed to air dry, double sealed in cellulose acetate adhesive tape, and taped to the outside of the phantom boxes. Equivalent sources of ^{40}K were made by filling one dram glass vials with dried KCl. The activity in each vial was determined from the weighed quantity of KCl plus the measured activities in the glass vial itself. These ^{40}K sources were placed inside each box of the phantom for calibration. A photograph of a phantom in place in the whole body counter appears in Figure 3.

Data were accumulated with a Nuclear Data 50/50 multichannel analyzer which has a teletype readout using an energy calibration of 10 keV per channel. The number of channels chosen to represent each peak was selected to give the maximum

* DuPont Chemical Company, Plastics Department, Los Angeles, California

sensitivity for each radioisotope according to the expression $S = E^2/B$, where S = Sensitivity, E = Efficiency, and B = Background. Similarly, the 2.75 MeV gamma ray was chosen to represent ^{24}Na instead of the 1.37 MeV gamma ray on the basis of the above expression. The 1.27 MeV rather than the 0.511 MeV gamma ray of ^{22}Na was chosen because of the uncertainties concerning the positron annihilation in the phantom. All calibrations were accomplished with ten-minute counting periods using a total activity of approximately one microcurie in each phantom. All gamma-ray energies and branching ratios were taken from a recent compilation.[9]

The results of the calibrations are presented in Table XIV. The Compton correction factors listed refer to the fraction of a higher energy peak which is Compton scattered and recorded in the energy region of the other standardized radioisotopes. For example, if 10,000 counts were observed in the ^{137}Cs peak channels in the 141 pound phantom, there would be 1379 Compton events in the ^{7}Be peak channels. These Compton correction factors are plotted in Figures 4 through 7 as a function of phantom weight so that the appropriate correction factor can be determined for any size of subject. Figures 8 and 9 are plots of the counter efficiencies as a function of phantom weight and gamma-ray energy, respectively. The numbers plotted on the ordinate of both figures are, in fact, the reciprocal of the absolute efficiency; therefore, one need only multiply the number of counts determined in any measurement by the appropriate value in order to obtain the number of gamma rays of that energy emitted in that measurement. For example, from Figure 8, if 1000 counts appeared in the ^{137}Cs peak channels from a 191-192 pound man, then there would have been 125,000 ^{137}Cs gamma rays emitted. Figure 9 is used to find the efficiency of any radioisotope not used in the calibration. For example, if there are 1000 counts in a peak centered at 1.95 MeV from a 164 pound man, then there would have been 180,000 gamma rays of that peak energy emitted. By interpolating between the curves, either Figure 8 or 9 can be used to find the efficiency of any gamma-ray energy from any weight of subject.

Prior to transporting the phantom to Houston, it was counted containing ^{137}Cs at Battelle-Northwest in a shadow shielded whole body counter which had been standardized by using human subjects. As was expected, the phantom counted more efficiently than did a living man. It is felt that the correction factor to be applied to the phantom data for the NASA Manned Spacecraft Center whole body counter is 9 percent for ^{137}Cs, that is, to arrive at the number of gammas per count for a human subject, multiply the number of gammas per count for the phantom as given in Figure 8 or 9 by the factor 1.09. This factor is probably less for higher energy gamma rays and perhaps more for lower energy gamma rays and serves to illustrate the necessity of calibrating the counter with human subjects to attain the highest possible degree of accuracy. It is recommended that such a calibration be undertaken at the earliest possible time.

A list of useful conversion factors for whole body counting appears in Table XV.

RECOMMENDATIONS FOR WHOLE BODY COUNTING OF ASTRONAUTS

To provide assistance in the evaluation of the radiation dose received by astronauts from the cosmic radiation of the space environment, it is necessary to whole body count the astronauts on return from a space mission. The dosimetry techniques ordinarily employed (thermoluminescent dosimeters, ionization chambers etc.) have a limited sensitivity to large variations in particle energy such as found in the space environment and are designed only to record a surface dose rather than a whole body radiation dose. It is generally recognized that the best indicator of whole body radiation dose from higher energy particles is the quantity of radionuclides induced in the body since they are representative of the energy and flux of particles throughout the entire body where the radiation damage occurs. The only direct method of measuring these induced radionuclides is by whole body counting of the astronaut, although they can be measured indirectly by determining

their concentrations in bioassay (urine and feces) samples. The indirect method is much simpler but needs to be calibrated against the direct method to establish the degree of correlation.

The basic radioisotopes of interest are ^{7}Be, ^{22}Na, and ^{24}Na, which are produced in high enough abundances and which have long enough half-lives to be observed on return to earth. Of these, ^{24}Na is the most sensitive for recent exposure history because of its comparatively short half-life (15 hr) and its high specific activity. In order to measure this radioisotope by either whole body counting or by bioassay analysis, it is necessary to make the determination within a few days after return to earth. Similarly, because of the 11-day effective half-life of ^{22}Na in the body, it is necessary to measure this radioisotope by whole body counting within a few weeks. These time limits do not apply to the determination of ^{22}Na in bioassay samples or the determination of ^{7}Be by either whole body counting or bioassay measurements.

The Apollo Series G missions have the unique possibility of crew quarantine associated with them which would render the determination of ^{22}Na by whole body counting and ^{24}Na by whole body or bioassay counting impossible unless the measurements can be made during the quarantine period. This would require installation of a whole body counter and a low-level sample counter in the Crew Reception Area of the Lunar Receiving Laboratory at the Manned Spacecraft Center. After inspection of the Crew Reception Area and discussions with technical personnel at NASA, the following recommendation is made.

A multipurpose, low-level, portable counting assembly should be temporarily installed in the Crew Reception Area for at least one of the lunar landing missions. Equipment should include a multidimensional gamma-ray spectrometer system composed of two 9-inch diameter by 8-inch thick NaI(Tl) center detectors with 15-inch diameter by 11-inch thick annular NaI(Tl) anticoincidence shields and 9-inch diameter by 3-inch thick pure NaI light pipes. These opposing crystal assemblies can be shielded with 4 or 8 inches of lead and are designed for both whole body

counting and low-level sample analysis with a sensitivity on the order of that of the low-level counter already in place in the Lunar Receiving Laboratory Counting Room. Such a crystal system is available as portable equipment at Battelle-Northwest and can be installed and operational within a few days.

Two principal areas are suggested for location of this counter assembly. The prime area would be the Spacecraft Room in the Crew Reception Area, particularly if the spacecraft itself is not going to be housed there. Not only would there be adequate room available, but the floor strength would be sufficient to withstand almost any reasonable load. A secondary location for the facility, in the event that the spacecraft is housed in the Crew Reception Area and that no space would be available in the Spacecraft Room, would be in the Minor Surgery or Examining Room. Adequate space is available in this room, and the installation would not interfere in any way with the stated purpose of the room.

The advantages of the availability of such a system are: (1) whole body counting of the astronauts to aid and assist in the determination of cosmic radiation dose through the additional possibility of measuring the ^{22}Na and ^{24}Na radioisotopes present in their bodies, (2) low-level counting of the bioassay samples from the astronauts with the possibility of measuring the ^{24}Na activity before it has decayed significantly, and (3) low-level counting of the induced activities in the astronaut's gear, parts of the spacecraft, etc., for determination of the cosmic-ray exposure of these items and the astronauts. All these possibilities are available at a bare minimum in expense and utilization of space. Personnel requirements are flexible depending on the quantity of information to be developed. The operation of the counter never requires more than one man, and once the count period is started, he is free to do something else until another count is required. Battelle-Northwest will, if desired, furnish a man to operate the counter system in the Crew Reception Area full time, thereby assuring maximum possible data retrieval. If the spacecraft itself is not to be housed in the Crew Reception Area, temporary living quarters for a Battelle-Northwest employee could be established with the

counter in the Spacecraft Room. If, because of personnel restrictions in the Crew Reception Area, the counter is to be operated by NASA personnel, they could be completely instructed in its operation in a few hours.

Total estimated cost for installation of such a portable counter assembly in the Crew Reception Area is $9,200.

EXPENDITURES

The following table illustrates the expenditures according to task and total costs incurred as of June 30, 1969, for all work reported herein except the calibration of the whole body counter. None of the costs for calibration of the whole body counter nor for unreported research in progress are included.

Task	Expenditures
Determination of the Radionuclide Content of Feces and Urine From Astronauts Engaged in Space Flight	$ 13,584
Neutron Activation Analysis of Feces and Urine From Astronauts Engaged in Space Flight	2,030
Glass Fibers in Astronaut Fecal Samples	2,562
Induced Radionuclides in Spacecraft	468
^{147}Pm Analysis in Air Filters and Feces	593
Total Costs	$ 19,237

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TABLE I

RADIONUCLIDES IN FECES FROM APOLLO 7 ASTRONAUTS

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/g on 10-22-68) ^{7}Be	^{22}Na	^{40}K	^{51}Cr	^{59}Fe	^{60}Co	^{137}Cs
B	Pre	1.39 ± 15.3%	0.003 ± 95%	5.20 ± 4.0%	19.0 ± 1.3%	0.117 ± 23.8%		0.167 ± 16.9%
C	Pre	0.843 ± 23.3%		6.85 ± 5.5%	18.0 ± 2.4%			
S/N 2270	In	6.01 ± 19.2%						
S/N 2276	In	0.921 ± 12.1%		5.75 ± 3.9%	16.0 ± 3.0%	0.295 ± 15.5%		0.179 ± 17.0%
S/N 2277	In	0.581 ± 18.1%		8.14 ± 2.1%	20.1 ± 2.5%			0.147 ± 15.8%
S/N 2278	In	0.916 ± 9.6%	0.0039 ± 73%	10.5 ± 2.3%	55.6 ± 1.0%	0.169 ± 28.4%		0.136 ± 23.2%
S/N 2280	In	0.503 ± 35.1%	0.0055 ± 53%	8.82 ± 2.8%	55.1 ± 0.9%	0.122 ± 45.4%		0.090 ± 35.1%
S/N 2282	In	0.600 ± 9.3%		7.61 ± 2.3%	19.6 ± 2.7%			0.151 ± 16.1%
S/N 2292	In	1.53 ± 14.6%		4.81 ± 4.1%	53.1 ± 1.2%			0.042 ± 68.7%
S/N 2299	In	1.07 ± 14.5%		9.51 ± 2.6%	42.5 ± 1.3%	0.590 ± 8.2%		0.388 ± 8.4%
S/N 2300	In	2.10 ± 10.7%	0.0047 ± 53%	3.96 ± 4.8%	16.7 ± 3.8%	0.204 ± 21.8%		0.295 ± 9.8%
S/N 2312	In	1.69 ± 14.2%		8.91 ± 2.0%	45.8 ± 1.2%	0.146 ± 24.6%		0.132 ± 18.4%
A	Post	4.12 ± 5.6%	0.0052 ± 53%	10.8 ± 2.2%	24.8 ± 1.6%	0.464 ± 8.5%		
C	Post	1.75 ± 13.8%		7.73 ± 2.4%	49.2 ± 0.9%	4.85 ± 0.9%	0.376 ± 3.5%	0.398 ± 6.6%

TABLE II

RADIONUCLIDES IN URINE FROM APOLLO 7 ASTRONAUTS

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/ml on 10-22-68) ^{7}Be	^{22}Na	^{40}K	^{51}Cr	^{59}Fe	^{60}Co	^{137}Cs
A	Pre	0.105 ± 14.6%		7.10 ± 0.3%	2610 ± 0.4%		0.00501±8.3%	0.250 ± 0.8%
C	Pre	0.212 ± 17.8%		0.763 ± 4.5%	0.155±26.2%			0.00961±48.5%
A	Post	0.723 ± 27.9%	0.0040 ± 56%	3.47 ± 5.2%	123 ± 0.3%			0.154 ± 16.2%
B	Post	0.808 ± 30.6%	0.0073 ± 32%	6.84 ± 2.5%	12300±0.8%	2.79 ± 1.2%	2.79 ± 1.2%	0.607 ± 4.2%
C	Post	0.786 ± 26.0%		3.17 ± 4.4%	16900±0.7%	16.7 ± 0.3%	1.00 ± 1.9%	0.166 ± 14.0%

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/g Na on 10-22-68 @ 0710 EDT) Na^{22}	Na^{24}	K^{40}	Cs^{137}
A	Post	1.4 ± 56%	20 ± 65%	1180 ± 5.2%	52.4 ± 16.2%
B	Post	4.9 ± 32%		4570 ± 2.5%	405 ± 4.2%

TABLE III

RADIONUCLIDES IN FECES FROM APOLLO 8 ASTRONAUTS

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/g on 12-27-68) ^{7}Be	^{22}Na	^{40}K	^{51}Cr	^{59}Fe	^{60}Co	^{137}Cs
B	Pre	2.63 ± 9.7%	0.049 ± 36%	5.21 ± 3.3%	3.42 ± 6.1%	0.134 ± 23.8%	0.006 ± 92%	0.147 ± 11.3%
C	Pre	3.87 ± 9.8%		9.32 ± 2.4%	4.34 ± 6.2%	0.211 ± 19.3%	0.013 ± 61%	0.245 ± 8.6%
1	In	3.72 ± 30.0%		6.80 ± 2.7%	34.2 ± 1.6%	0.172 ± 24.9%		0.249 ± 10.4%
2	In	1.04 ± 15.9%		7.04 ± 3.2%	39.0 ± 1.3%	0.286 ± 18.8%		0.359 ± 8.3%
3	In	0.612 ± 30.9%	0.0043 ± 79%	7.67 ± 3.1%	22.0 ± 2.2%	0.306 ± 18.3%		0.228 ± 13.7%
A	Post	0.420 ± 46.5%		10.4 ± 0.8%	81.8 ± 0.2%		0.0025 ± 58%	0.105 ± 6.6%
B	Post	3.81 ± 21.3%	0.029 ± 27%	4.35 ± 8.5%	38.2 ± 1.1%	1.80 ± 3.7%		
C	Post	2.75 ± 17.6%	0.091 ± 35%	7.84 ± 4.8%	27.0 ± 1.5%	0.344 ± 17.7%		0.070 ± 54%

TABLE IV

RADIONUCLIDES IN URINE FROM APOLLO 8 ASTRONAUTS

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/ml on 12-27-69) ^{7}Be	^{22}Na	^{40}K	^{51}Cr	^{59}Fe	^{60}Co	^{137}Cs
A	Post	0.492 ± 16.5%		2.63 ± 4.1%	83.5 ± 0.4%	0.139 ± 14.8%	0.0037 ± 60%	0.179 ± 9.1%
B	Post	1.16 ± 10.8%	0.0026 ± 73%	2.84 ± 5.6%	1450 ± 0.1%	8.66 ± 0.5%	0.201 ± 4.3%	0.148 ± 15.3%
C	Post	1.95 ± 17.7%		7.10 ± 5.6%	9010 ± 1.5%	7.46 ± 1.2%	0.237 ± 11.1%	0.211 ± 19.5%

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/g Na on 12-27-68) Na^{22}	K^{40}	Cs^{137}
B	Post	1.6 ± 73%	1780 ± 5.6%	93.0 ± 15.3%

TABLE V

RADIONUCLIDES IN FECES FROM APOLLO 9 ASTRONAUTS

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/g on 3-13-69)						
		^{7}Be	^{22}Na	^{40}K	^{51}Cr	^{59}Fe	^{60}Co	^{137}Cs
1	In			8.57 ± 7.3%	7.29 ± 23.0%	0.637 ± 23.3%	0.081 ± 20.3%	
3	In	0.33 ± 93.5%		9.73 ± 2.3%	23.6 ± 1.9%	0.373 ± 13.9%	0.0065 ± 53.0%	0.323 ± 9.3%
4	In			13.2 ± 2.4%	37.2 ± 1.8%	0.656 ± 11.7%	0.004 ± 99.0%	0.623 ± 6.6%
6	In			12.0 ± 4.9%	17.6 ± 6.6%	1.04 ± 13.8%		0.639 ± 12.7%
8	In	9.6 ± 31.4%		3.54 ± 41.4%		1.50 ± 24.8%	0.049 ± 63.9%	
Schweickart	168:00	1.11 ± 52.2%		10.9 ± 1.7%	36.5 ± 1.5%	0.255 ± 14.5%	0.0075 ± 47.8%	0.216 ± 11.8%
D.R.S.	113:00			11.0 ± 1.8%	9.77 ± 4.7%	0.109 ± 32.7%	0.0066 ± 56.2%	0.171 ± 14.7%
D.R.S.	190:25			11.9 ± 1.5%	10.9 ± 4.0%	0.246 ± 13.5%	0.0062 ± 53.0%	0.161 ± 14.7%
D.R.S.	235:00	0.239 ± 31.5%		11.1 ± 1.6%	10.2 ± 4.3%	0.350 ± 9.5%	0.0099 ± 34.8%	0.286 ± 8.2%

TABLE VI

RADIONUCLIDES IN URINE FROM APOLLO 9 ASTRONAUTS

SAMPLE # OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/ml on 3-13-69)						
		^{7}Be	^{22}Na	^{40}K	^{51}Cr	^{59}Fe	^{60}Co	^{137}Cs
Scott	F-14		0.00046±46.1%	5.14 ± 0.5%				0.0524 ± 4.5%
Schweickart	F-14		0.00051±37.9%	4.32 ± 0.5%				0.0335 ± 6.2%
McDivitt	F-14	0.0146 ± 80.4%	0.00086±25.1%	2.65 ± 0.7%				0.0352 ± 6.0%
McDivitt	F-4		0.00028±73.1%	3.33 ± 0.7%	147 ± 0.1%	0.00953±47.7%		0.0568 ± 4.2%
Schweickart	F-4	0.0414 ± 29.0%		6.66 ± 0.4%	146 ± 2.9%	0.0214 ± 17.9%	0.00053±50.3%	0.0544 ± 3.8%
Scott	F-4	0.0272 ± 44.4%	0.0002±95.6%	4.40 ± 0.5%	93.2 ± 0.1%	0.0162 ± 30.5%		0.0404 ± 5.7%
McDivitt	Immed. Post			1.26 ± 2.2%	19.0 ± 0.3%			0.0132 ± 18.4%
Schweickart	Immed. Post			3.69 ± 5.1%	119 ± 0.3%	0.131 ± 26.7%		0.150 ± 17.1%
McDivitt	24-hr. Post			2.28 ± 2.8%	1570 ± 1.6%	0.058 ± 28.0%		0.0881 ± 9.7%
Schweickart	24-hr. Post			2.93 ± 1.8%	5580 ± 0.9%	0.0226 ± 53.3%	0.0012 ± 81.2%	0.0717 ± 10.3%
Scott	24-hr. Post	0.274 ± 16.3%	0.00084±86.6%	2.90 ± 2.2%	4610 ± 0.9%	0.0381 ± 42.8%		0.122 ± 6.8%

TABLE VII

RADIONUCLIDES IN FECES FROM APOLLO 10 ASTRONAUTS

SAMPLE NO. OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/g on 5-26-69)					
		^{7}Be	^{22}Na	^{40}K	^{59}Fe	^{60}Co	^{137}Cs
S/N 3512	Pre		0.0061 ± 66%	10.8 ± 2.2%	0.144 ± 25.5%	0.01 ± 50%	0.174 ± 12.3%
S/N 3527	Pre	0.721 ± 53.1%	0.023 ± 68%	14.5 ± 4.3%	0.306 ± 32.8%		0.332 ± 18.2%

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TABLE VIII

RADIONUCLIDES IN URINE FROM APOLLO 10 ASTRONAUTS

SAMPLE NO. OR ASTRONAUT	FLIGHT PERIOD	ACTIVITY (d/m/ml on 5-26-69 @ 0952 PDT)						
		^{7}Be	^{22}Na	^{24}Na	^{40}K	^{51}Cr	^{59}Fe	^{137}Cs
Cernan	Pre				2.71 ± 3.1%			
Stafford	Pre		0.0012 ± 75%		1.99 ± 3.6%		0.126 ± 9.8%	0.0157 ± 67.1%
Young	Pre				2.67 ± 3.1%	1.24 ± 10.9%	0.0606 ± 24.0%	0.0575 ± 16.2%
Cernan	Post	0.19 ± 17.9%		0.05 ± 75%	3.27 ± 2.0%		0.018 ± 53%	0.0447 ± 19.2%
Stafford	Post	0.0415 ± 77.0%			0.421 ± 10.4%	0.626 ± 14.1%	0.0189 ± 39.9%	0.0354 ± 19.1%
Young	Post		0.0026 ± 37%	0.06 ± 50%	2.62 ± 2.1%	0.315 ± 26.2%	0.0458 ± 20.0%	0.048 ± 12.4%

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TABLE IX

LUNAR MATERIAL CONTAMINATION IN FECES FROM APOLLO 7 ASTRONAUTS

ASTRONAUT	FLIGHT PERIOD	CONCENTRATION IN PARTS PER MILLION DRY WEIGHT BASIS								
		Ba	Sr	I	Pb	Zn	Sn	Fe	Mg	Cr
B	Pre	3,160	23	14,400	26.2	690	1.7	580	1.7	1.4
C	Pre	1,290	18	16,400	43.6	1490	2.9	900	1.2	1.3
A	Post	2,920	6.0	21,000	46.7	660	10.1	420	2.7	2.5
C	Post	3,960	6.9	16,700	43.0	670	2.4	420	1.4	3.7
Preservative*		45,000	16.5	--	0.44	9.0	<0.2	5.0	0.03	0.17

ASTRONAUT	FLIGHT PERIOD	CONCENTRATION IN PARTS PER BILLION DRY WEIGHT BASIS				
		Cs	Co	Sc	Sb	Ag
B	Pre	63	430	24.0	150	440
C	Pre	120	860	31.0	300	2350
A	Post	97	480	39.0	460	880
C	Post	85	600	37.5	450	850
Preservative†		6.7	12	0.5	32	<1

* Concentrations are in micrograms per milliliter (10^{-6} g/ml)
† Concentrations are in nanograms per milliliter (10^{-9} g/ml)

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TABLE X

QUANTITIES OF GLASS FIBERS IN ASTRONAUT FECAL SAMPLES FROM APOLLO 7

SAMPLE #	ALIQUOT (grams)	OBSERVED FIBERS		DEFECATION WT.† (grams)	FIBERS/g FECES		FIBERS/DEFECATION		(μg GLASS/ g FECES)‡	(μg GLASS/ DEFECATION)‡
		BETA	DE*		BETA	DE*	BETA	DE*		
S/N 2270	5.3	54	11	81.3	10	2.1	830	170	0.15	12.4
S/N 2276	3.23	41	4	119.8	13	1	1,500	150	0.13	16.4
S/N 2277	3.58	1038	34	229.8	290	9.5	66,600	2,200	2.42	555
S/N 2278	3.09	579	18	326.2	187	5.8	61,100	1,900	1.54	505
S/N 2280	5.98	506	58	240.2	84.6	9.7	20,300	2,300	0.97	232
S/N 2282	3.84	590	30	236.0	154	7.8	36,300	1,800	1.39	326
S/N 2299	2.97	796	3	228.1	268	1	61,600	200	1.93	440
S/N 2300	2.76	271	4	96.1	98.2	1	9,440	100	0.73	70.6
S/N 2312	3.25	199	9	233.7	61.2	3	14,300	600	0.55	124

* Due to the difficulty in distinguishing type G fibers from type DE fibers, and due to the observance of only a few fibers which were definitely type G, these two categories have been combined.

† Total weight of defecation determined by subtracting weight of blank collection kit from weight of returned samples and bag.

‡ Weight of glass based on average fiber length of 0.4 mm and density of 2.5 gm cm^{-3}.

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TABLE XI

QUANTITIES OF GLASS FIBERS IN ASTRONAUT FECAL SAMPLES FROM APOLLO 8

SAMPLE #	ALIQUOT (grams)	OBSERVED FIBERS BETA	DE	DEFECATION WT. (grams)	FIBERS/g BETA	FECES DE	FIBERS/DEFECATION BETA	DE	(μg GLASS/ g FECES)	(μg GLASS/ DEFECATION)
1	2.115	405	16	186.5	191	7.6	35,700	1,400	1.64	307
2	2.013	8	1	85.6	4	0.5	340	40	0.05	4
3	4.578	2,207	47	198.6	482.1	10	95,740	2,000	3.79	754

TABLE XII

QUANTITIES OF GLASS FIBERS IN ASTRONAUT FECAL SAMPLES FROM APOLLO 9

ASTRONAUT	TIME OF FLIGHT	ALIQUOT (grams)	OBSERVED FIBERS BETA	DE	DEFECATION WT. (grams)	FIBERS/g BETA	FECES DE	FIBERS/DEFECATION BETA	DE	(μg GLASS/ g FECES)	(μg GLASS/ DEFECATION)
D.R.S.	113:00	4.8286	84	0	168.0	17	0	2,900	0	0.12	21
D.R.S.	190:25	7.2075	2,491	33	190.7	345.6	4.6	65,910	870	2.619	499.4
D.R.S.	235:00	4.7453	1,446	14	317.5	304.7	3.0	96,750	940	2.267	719.9
R.L.S.	168:00	3.9579	112	1	385.1	28.2	0.3	10,900	100	0.210	80.8

TABLE XIII

CALIBRATION OF GIACC FIBERS IN ASTRONAUT FECAL SAMPLES FROM APOLLO 10

SAMPLE NO.	ALIQUOT (g)	CONTENTS FIBERS Beta	DE	DEFECATION WT. (g)	FIBERS/g FECES Beta	DE	FIBERS/DEFECATION Beta	DE	(μg GLASS/ g FECES)	(μg GLASS/ DEFECATION)
D/B 3512	0.9904	1157	38	76.3	386.9	13	29,520	970	3.235	246
D/B 3527	0.8033	69	1	40.9	78	1	3,200	50	0.59	25

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TABLE XIV

CALIBRATION FACTORS FOR THE NASA MANNED SPACECRAFT CENTER WHOLE BODY COUNTER

Phantom Height	Phantom Weight	Isotope	Energy (MeV)	No. of Peak Channels	Location of Peak	Bkgd. (c/m)	(Gammas/Count)	(Dis/Count)	Compton Correction Factor ^{7}Be	^{137}Cs	^{22}Na	^{40}K
68"	141#	^{7}Be	0.4774	6	45-50	69.67	98.35	954.9				
68"	164#	^{7}Be	0.4774	6	45-50	69.67	98.90	960.2				
73"	206#	^{7}Be	0.4774	6	45-50	69.67	115.1	1117				
68"	141#	^{137}Cs	0.6616	8	63-70	56.85	113.0	120.9	0.1379			
68"	164#	^{137}Cs	0.6616	8	63-70	56.85	115.1	123.1	0.1408			
73"	206#	^{137}Cs	0.6616	8	63-70	56.85	132.3	141.5	0.1667			
68"	141#	^{22}Na	1.2746	10	123-132	19.46	151.7	151.8	1.459	0.2388		
68"	164#	^{22}Na	1.2746	10	123-132	19.46	151.1	151.2	1.463	0.2434		
73"	206#	^{22}Na	1.2746	10	123-132	19.46	168.1	168.2	1.471	0.2581		
68"	141#	^{40}K	1.460	13	139-151	43.48	156.1	1419	0.1578	0.1646	0.09924	
68"	164#	^{40}K	1.460	13	139-151	43.48	163.9	1490	0.1656	0.1663	0.1052	
73"	206#	^{40}K	1.460	13	139-151	43.48	175.2	1593	0.2084	0.1812	0.1095	
68"	141#	^{24}Na	2.7539	20	262-281	5.94	200.2	200.4	0.3475	0.3168	0.4336	0.5241
68"	164#	^{24}Na	2.7539	20	262-281	5.94	205.7	205.9	0.3596	0.3347	0.4737	0.5235
73"	206#	^{24}Na	2.7539	20	262-281	5.94	218.2	218.4	0.3963	0.3621	0.4622	0.4923

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TABLE XV

CONVERSION FACTORS

To Convert From	To	Multiply By
gammas/min of ^{7}Be (0.4774 MeV)	dis/min of ^{7}Be	9.709
gammas/min of ^{22}Na (1.2746 MeV)	dis/min of ^{22}Na	1.001
gammas/min of ^{24}Na (2.7539 MeV)	dis/min of ^{24}Na	1.001
gammas/min of ^{40}K (1.460 MeV)	dis/min of ^{40}K	9.091
gammas/min of ^{137}Cs (0.6616 MeV)	dis/min of ^{137}Cs	1.070
dis/min	microcuries	4.505×10^{-7}
dis/min of ^{40}K	Grams of K	5.429×10^{-4}
gammas/min of ^{40}K (1.460 MeV)	Grams of K	4.935×10^{-3}

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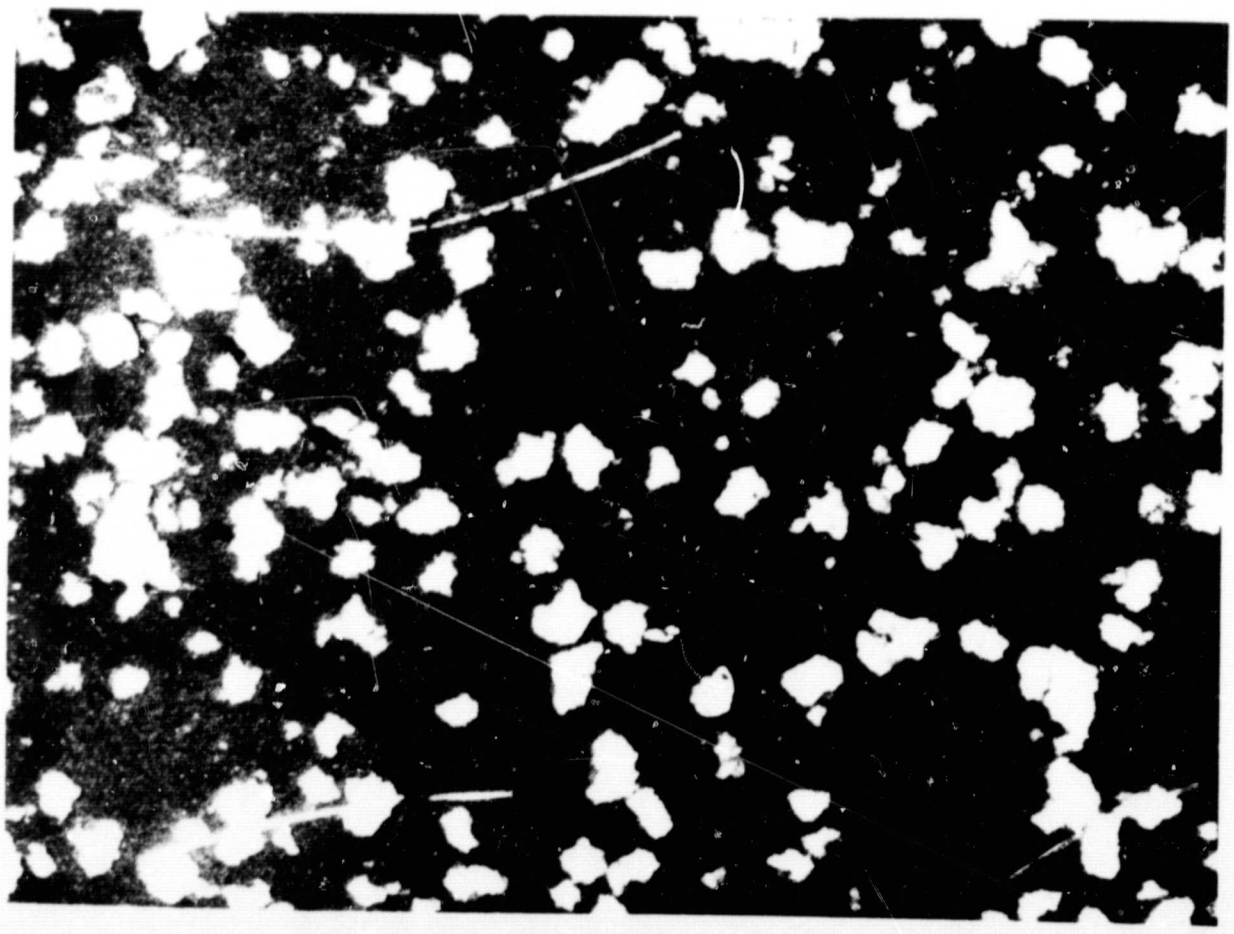

FIGURE 1
Three Beta Fibers in an Astronaut Fecal Sample Under 200X Magnification

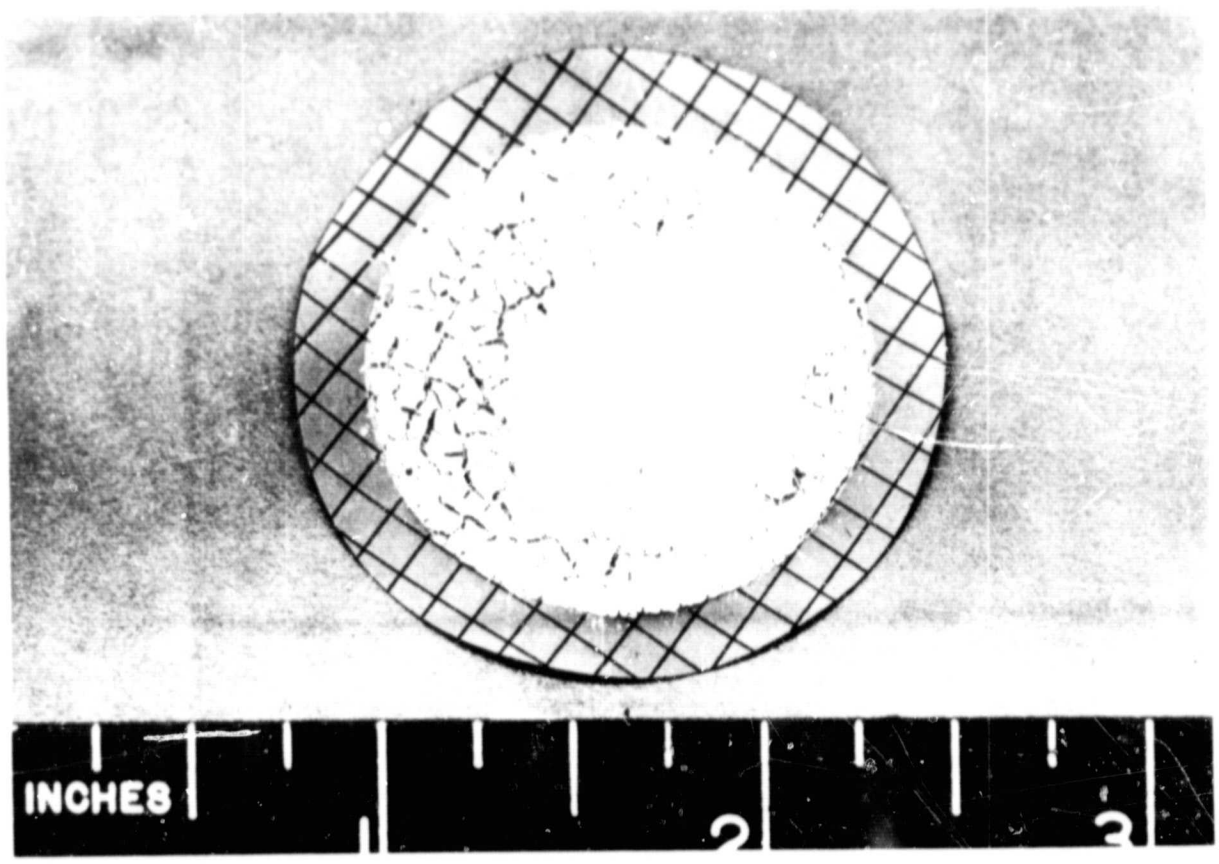

FIGURE 2
The Insoluble Silicates and Glass Fibers from a 137.2 Gram Sample of Astronaut Feces

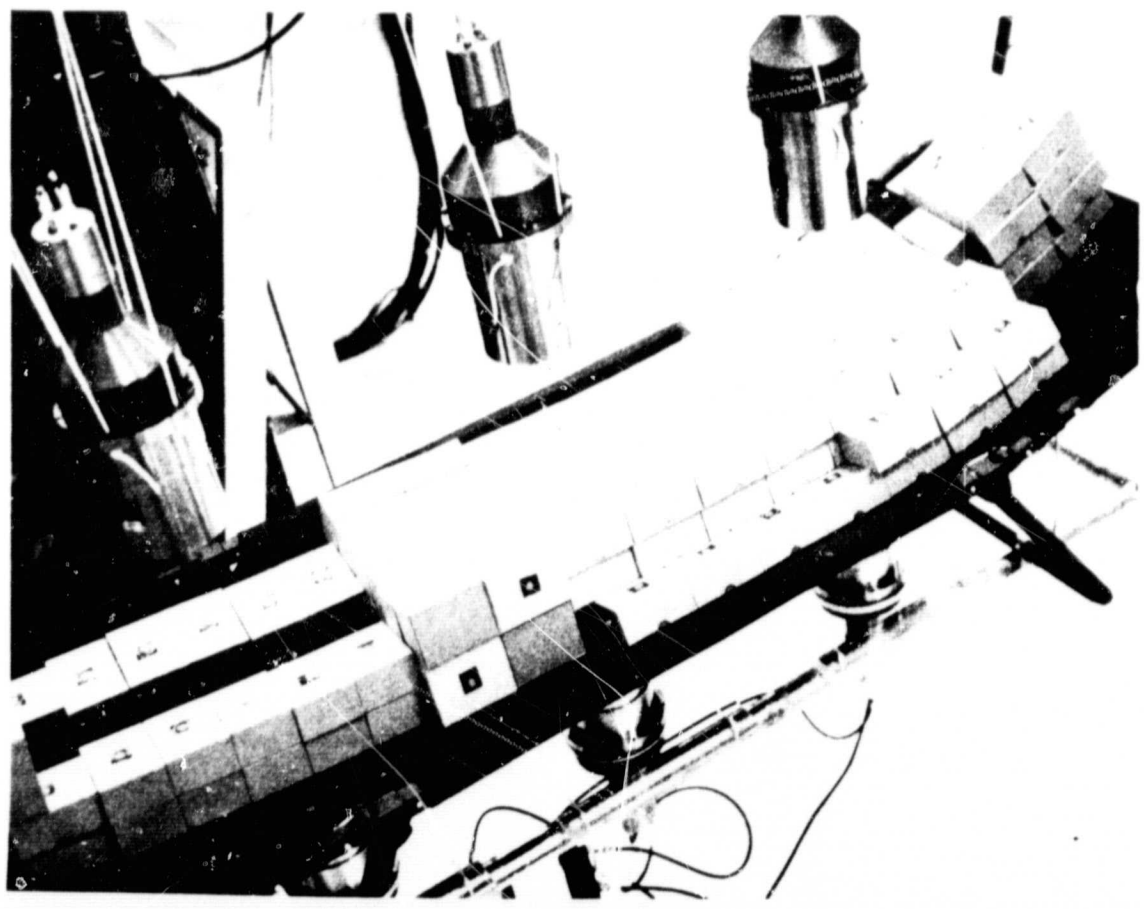

FIGURE 3
141 Pound Phantom in Place in the NASA-MSC Whole Body Counter

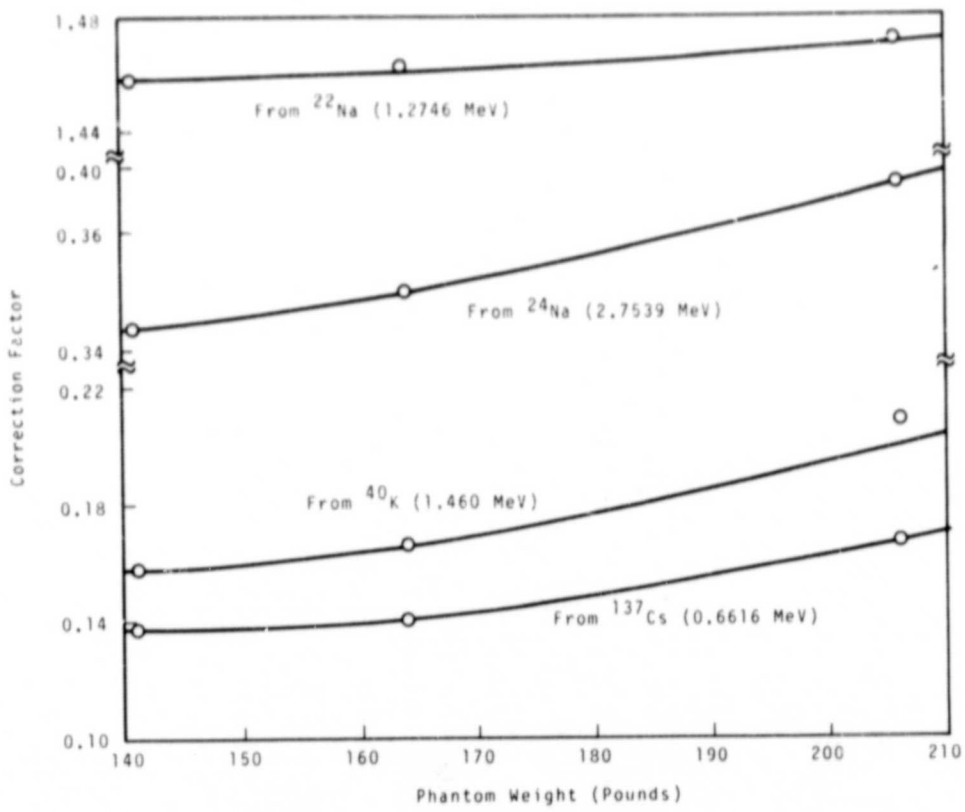

FIGURE 4
Compton Correction Factors for ^{7}Be

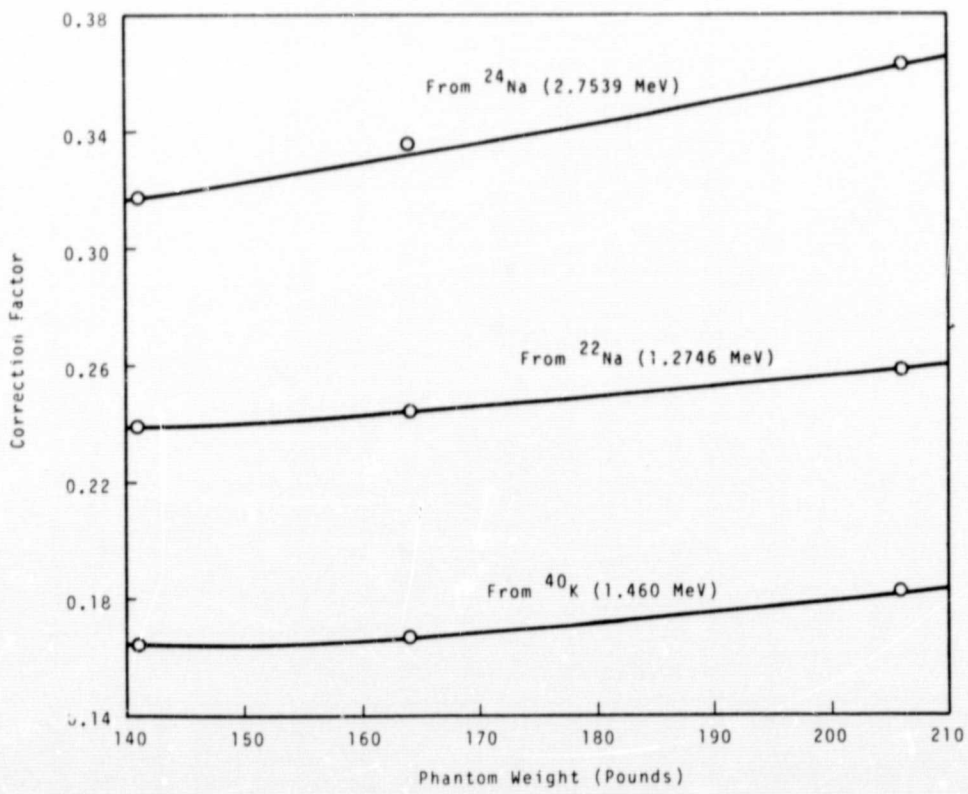

FIGURE 5
Compton Correction Factors for ^{137}Cs

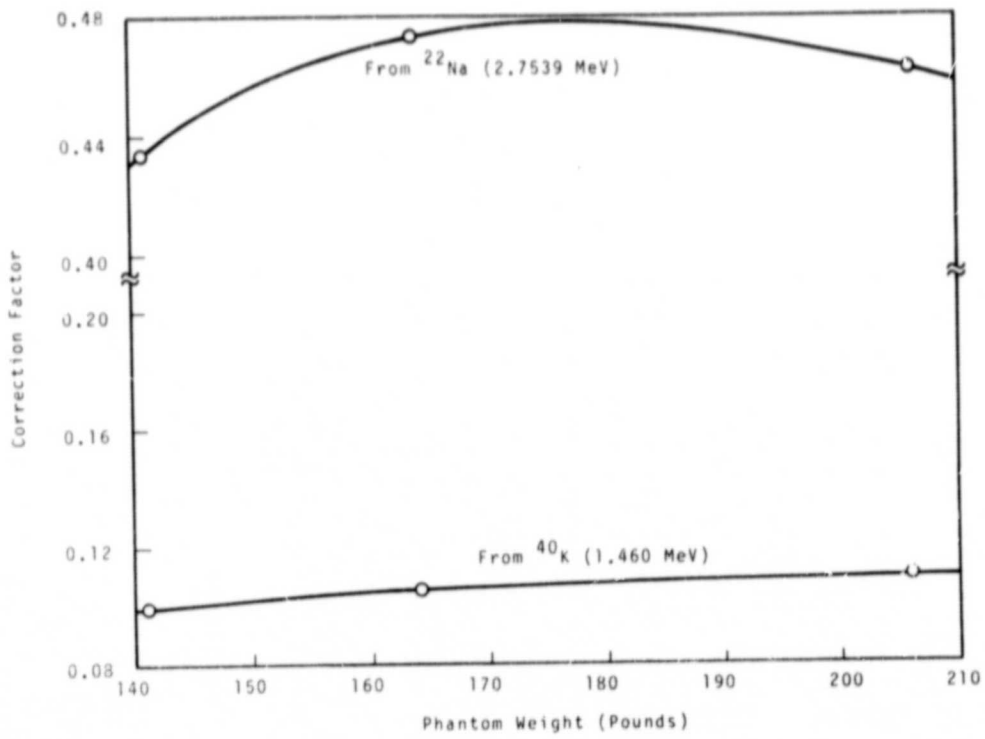

FIGURE 6
Compton Correction Factors for ^{22}Na

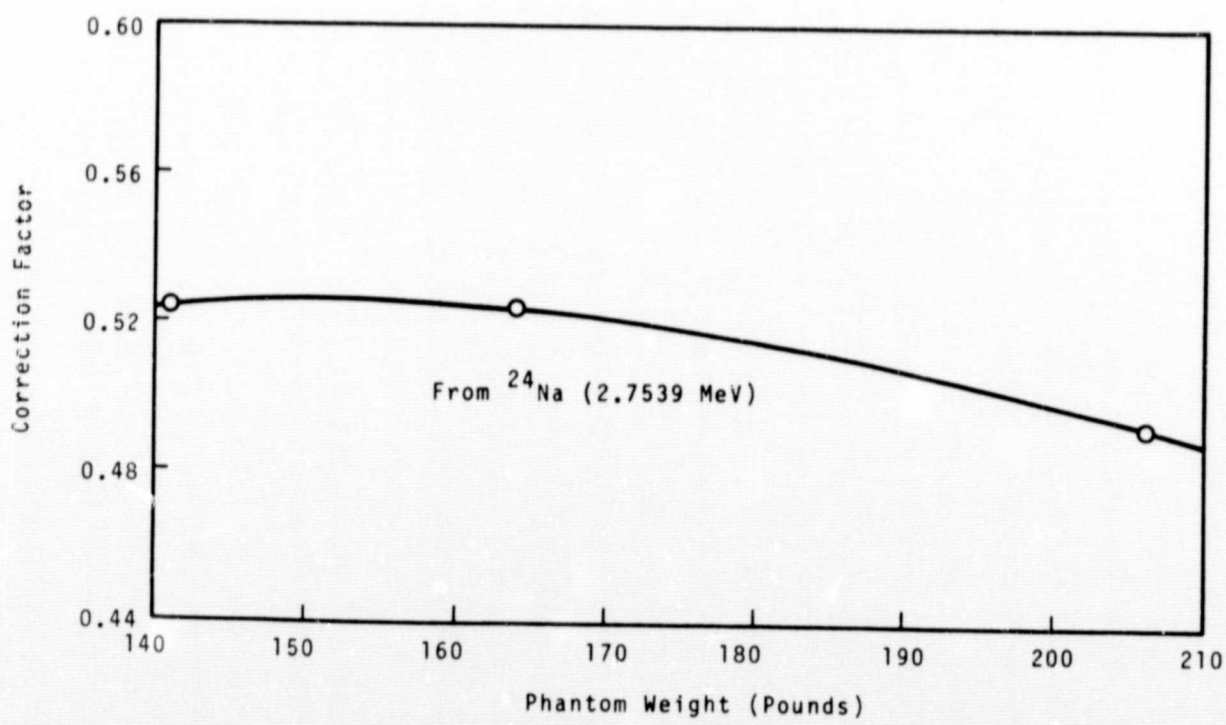

FIGURE 7
Compton Correction Factors for ^{40}K

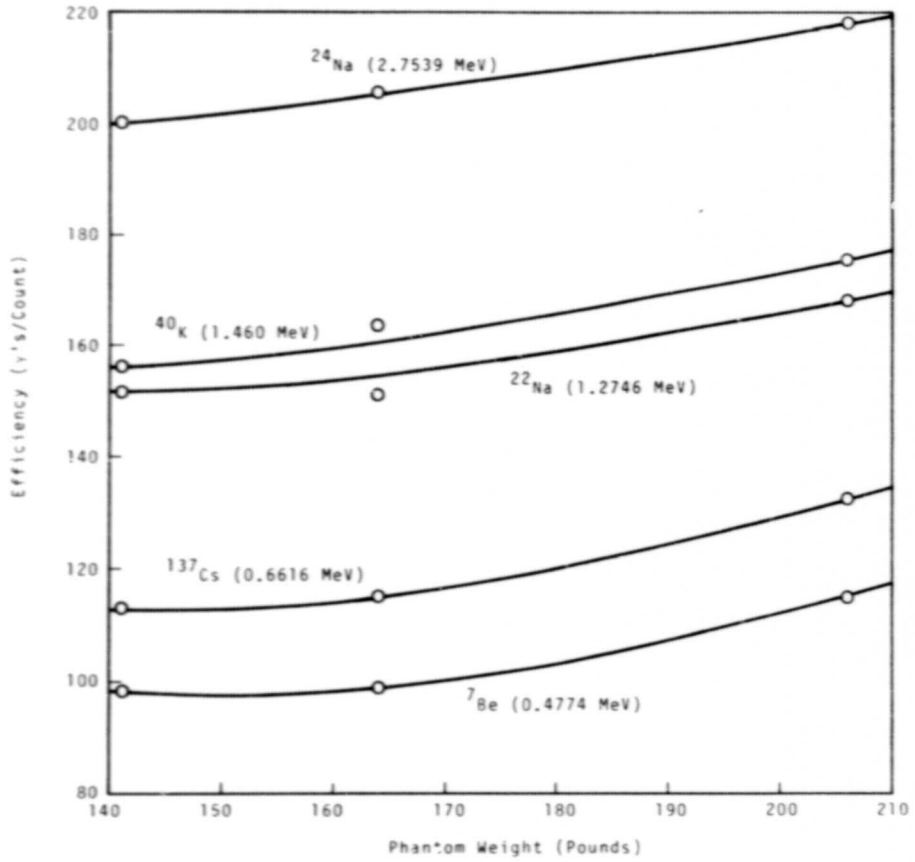

FIGURE 8
Whole Body Counter Efficiencies as Function of Weight

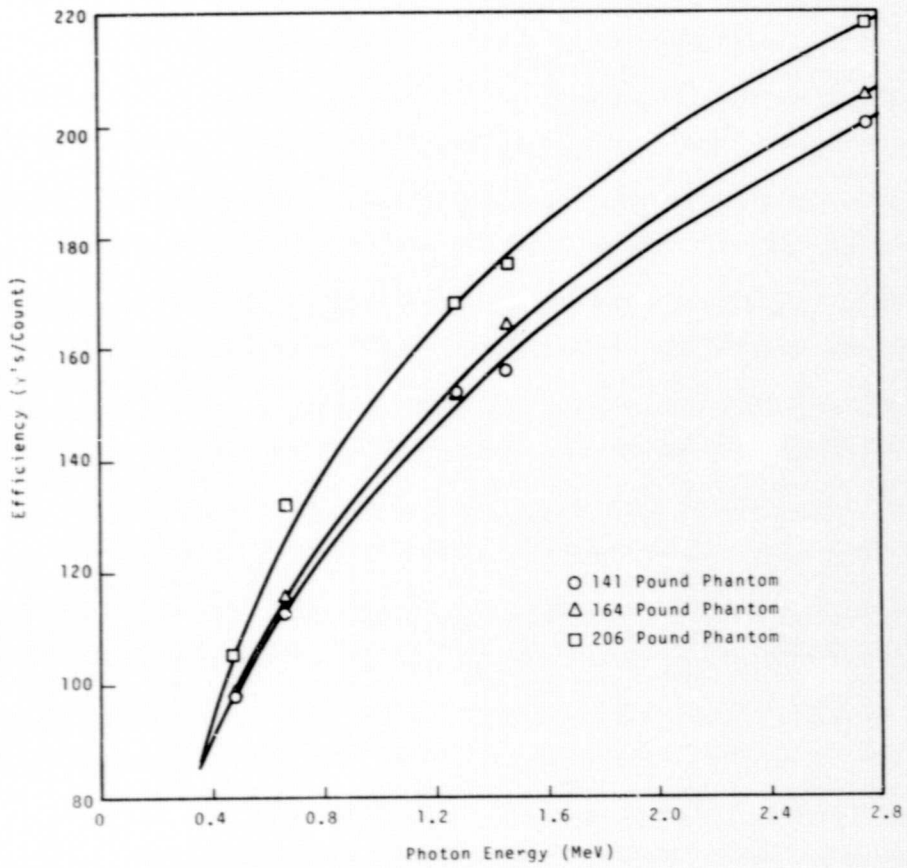

FIGURE 9
Whole Body Counter Efficiencies as Function of Energy