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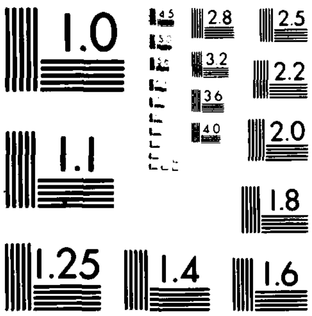

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ABSTRACT

The os calcis mineral is measured in the nine Skylab crew members and in eight control subjects utilizing a photon absoptiometric technique. These measurements are then compared with preflight measurements in an attempt to discover any long-term effects of space flight on the skeletal system. A statistically significant loss of bone mineral is found in the crew members who flew, but caution is urged in the interpretation of this difference. A recommendation to continue studies of this type is made.

LONG-TERM FOLLOW-UP OF SKYLAB BONE DEMINERALIZATION

by

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THESIS

Presented to the Faculty of the University of Texas
Health Science Center at Houston
School of Public Health
in Partial Fulfillment
of the Requirements
for the Degree of

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ABSTRACT

The os calcis mineral is measured in the nine Skylab crew members and in eight control subjects utilizing a photon absoptiometric technique. These measurements are then compared with preflight measurements in an attempt to discover any long-term effects of space flight on the skeletal system. A statistically significant loss of bone mineral is found in the crew members who flew, but caution is urged in the interpretation of this difference. A recommendation to continue studies of this type is made.

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INTRODUCTION

Osteoporosis has long been recognized to be a complication of a number of clinical situations. Acute and convalescent phases of paralytic anterior poliomyelitis (7), casting of fractures (3), and muscular dystrophy (15), are all examples of illness which result in confinement to bed for long periods of time with resulting disuse and bone demineralization. There also appears to be a direct correlation between the length of bed rest and the quantity of mineral lost (1).

These observations, however, are biased because the chronic illnesses which lead to extended periods of confinement could possibly lead directly to mineral loss. Several investigators have, therefore, conducted experiments to test the hypothesis that bed rest alone would cause demineralization and the hypothesis was confirmed (2,8).

It was logical to assume that the weightlessness of space flight should, therefore, produce similar effects on body mineral content, and this assumption was tested in several of the Gemini and Apollo missions. Definite mineral losses were observed; however, the missions were quite short, and these losses, while fairly substantial, were of no clinical significance (14).

The fact that bone mineral was lost in these relatively short missions raised fears that the much longer periods of weightlessness in Skylab missions would perhaps result in unacceptable levels of mineral loss (10). The three manned Skylab missions: Skylab 2, lasting 28 days; Skylab 3, lasting 59 days; and Skylab 4, lasting 84 days did produce some evidence of a dose response relationship between the length of the period of weightlessness and bone demineralization. There were no losses observed in Skylab 2; loss of mineral in one crew member, the scientist pilot, of Skylab 3; and loss of mineral in two crew members of Skylab 4, the scientist pilot and pilot, but none of the losses was clinically significant (9,13).

MATERIALS AND METHODS

This study is a reevaluation of the os calcis mineral content of the Skylab astronauts and seven of their control counterparts five years post flight, looking for possible long-term effects of space flight. Prior to each mission the calcaneous bone of each of the Skylab astronauts was scanned three times utilizing a photon absorptiometric technique, and the results of these scans were averaged to provide a mean baseline value for each astronaut (Table I). The back-up crew for Skylab 2 underwent the same measurements, and their baselines were computed in an identical fashion, but the same back-up crew was used for both Skylab 3 and Skylab 4 so their baselines are an average of six scans (Table II). The three additional control subjects, C.A., C.R. and J.V., were scanned many times, and their baselines are the average of all their scans accomplished prior to the launch of the last Skylab mission (Table III).

The original measurements were obtained by placing the subject's foot in a prefabricated mold containing water which served as a tissue equivalent, thereby compensating for the variation in individual soft tissue densities. The mold was situated on a wooden stand so as to position the foot (os calcis) between an ^{125}I source of monoenergetic photons which provided a 27.5 KeV γ-ray and a NaI scintillation detector (Figure

1) (12,14). In this follow-up study the same prefabricated mold is utilized to obtain gross positioning relative to previous scans.

A computerized five centimeter cross-section of the os calcis in the Y plane is then produced by back and forth movement of the yoke parallel to the X axis until sixteen rows, three millimeters apart are obtained (Figure 2).

In the original study the central two and one-half centimeter section of the cross-section was selected for analysis because it reflected the most reliable portion of the bone (11), and an average for this section was then computed so that a comparison could be made with subsequent measurements. This present study utilizes the same scheme for data computation.

The fact that the scanning rows are only three millimeters apart combined with the irregular geometry and non-homogeneity of the os calcis bone means that a slight change in foot position could easily effect the values obtained in a particular row of each scan. To compensate for possible positional variation, the computerized histogram obtained in the present study was compared with the histograms obtained in previous scans to insure that identical sections of the os calcis bone were selected for analysis.

Figure 3 summarizes the method of computing os calcis mineral content. I_0^* represents transmission through soft tissue, and I represents transmission through bone. The sum of ln (I_0^*/I) for each I through bone equals arbitrary computer units for that row and relates to mineral content in a particular cross-section of bone. These values are then compared to a Witt-Cameron standard for computation of mineral content in Mg./Sq. Cm. (16).

RESULTS

Table IV is a comparison of the preflight os calcis mineral content to the current value for the nine astronatus who flew. With only one exception, the pilot of the Skylab 3, the mineral content is reduced since flight, and the total difference is significant, $p < .01$.

Table V is the same comparison for the back-up crew members and the control subjects. In this group all but two of the subjects lost mineral; however, the difference is not significant, $p > .05$. The data for astronaut D.L. is included for interest only and is not included in the statistical analysis because he suffered a fracture of his left ankle in 1974 which required surgical repair and immobilization for approximately one year. The postflight data point for J.V. was obtained in 1976. While it is the only postflight data not obtained in 1979, it is included in the analysis because of the extremely small number of subjects available. The same statistical analysis was accomplished without J.V.'s data, and the results were unchanged.

Finally, Table VI summarizes the statistics and provides a comparison between the average loss of mineral in the two groups. At first glance it seems paradoxical that the total loss in the flight group is significant, the total loss in the control group is not significant, and yet the difference between the two groups is not significant. This, of course, is explained by the fact that the smaller the population in a study the greater the standard error and therefore the greater a change must be in order to be statistically significant.

DISCUSSION

The purpose of this study was to reexamine the Skylab astronauts in an attempt to determine whether or not there are any chronic effects of space flight on the skeletal system. In the original experiment, M-078, bone mineral measurements were obtained for the distal radius, the distal ulna, as well as the central left os calcis. There was such great variance in the data obtained from the arm that only os calcis measurements were considered in this paper.

Superficially, the data are consistent with a conclusion that space flight leads to a statistically significant long-term loss of bone mineral. However, this project is a retrospective observational study of a very small population of highly selected individuals. One must, therefore, consider additional factors in analyzing and interpreting the data obtained.

Studies performed on ballet dancers and weightlifters demonstrate that prepubertal exercise results in both increased bone mineral content and increased bone dimensions (6). Another study by B.E. Nilsson and N.E. Westlin reports that athletes have greater bone mineral content than do non-athlete controls, and that the controls who exercise have more mineral content than do the controls who don't exercise (5). R.B. Mazess reports that the population in Bilcabamba, Ecuador, has a much smaller intake of calcium than does the North American Population, but that due to their increased level of exercise they demonstrate no bone mineral deficiencies (4). Thus exercise and diet both directly effect bone mineral and both of these factors have varied <u>ad lib</u> over the last five years.

There are probably numerous other factors which could effect mineral content and which were not controlled for in this study; however, until such time as space flight becomes a common experience of the "average" person, or at least until enough missions have been flown to provide a reasonably large sample population, it will be impossible to perform an "ideal" study in which the investigator can have the luxury of randomization and controlling for variables, and studies such as this with their inherent shortcomings will be the only source of data available.

CONCLUSIONS

The results of this study are certainly very intriguing, especially when coupled with the results of previous studies of healthy males in the population which demonstrated no significant decrease in bone mineral content prior to age sixty (Unpublished data, V.S. Schneider, Chief, Endocrine-Metabolic Service, Director, Metabolic Unit, USPHS Hospital San Francisco, California).

While the mineral losses observed in this study and in the previous Gemini and Apollo missions have not been of clinical significance, they do lend support to the hypothesis that space flight has a direct effect on the human skeletal system, and if these preliminary findings are substantiated, future missions, which could possibly encompass months or even years, will have to be planned so as to minimize this effect as much as possible.

PREFLIGHT OS CALCIS MINERAL - CREW MEMBERS WHO FLEW Mg/Sq Cm

CREW MEMBER DATE	COMMANDER	SCIENTIST PILOT	PILOT
	2	2	2
4-16-73	387.67	628.45	654.21
5-2-73	393.42	623.99	651.39
5-11-73	388.87	641.41	649.93
BASELINE	389.99 ± 6.06	631.28 ± 18.10	651.84 ± 4.36
	3	3	3
6-27-73	473.88	532.48	644.81
7-12-73	470.27	534.80	634.91
7-23-73	473.85	512.79	632.49
BASELINE	472.67 ± 4.14	526.69 ± 24.18	637.40 ± 13.06
	4	4	4
10-12-73	516.46	720.73	562.51
10-26-73	520.70	698.67	562.92
11-6-73	517.58	705.04	573.94
BASELINE	518.25 ± 4.40	708.15 ± 22.70	566.46 ± 12.96

TABLE I

PREFLIGHT OS CALCIS MINERAL
BACK-UP CREW MEMBERS Mg/Sq Cm

DATE / CREW MEMBER	RS		BM
4-14-73	710.97		535.10
5-1-73	707.60		521.00
5-11-73	703.48		509.73
BASELINE	707.35 ± 7.50		521.94 ± 25.42
	WL	VB	DL
6-28-73	595.21	740.91	548.03
7-13-73	578.58	729.20	543.44
7-24-73	594.41	735.02	534.67
10-10-73	571.28	751.55	538.68
10-29-73	580.52	746.05	541.92
11-5-73	595.40	750.10	535.81
BASELINE	585.90 ± 20.90	742.14 ± 17.60	540.43 ± 10.06

TABLE II

PREFLIGHT OS CALCIS MINERAL CONTROLS Mg/Sq Cm

	SUBJECT		
DATE	CA	CR	JV
4-3-73			625.59
4-4-73	515.92		
4-5-73		456.74	620.93
4-15-73		453.85	
4-16-73			628.66
5-1-73		452.60	
5-2-73	510.11		
5-10-73	509.15		
5-11-73		449.15	631.61
6-20-73	524.66		
6-21-73		464.20	
6-22-73	522.27		
6-27-73		453.21	617.63
6-28-73	508.26		
7-12-73	523.17		627.01
7-24-73	500.08		
9-25-73	522.64		
9-26-73	531.76		620.94
10-2-73	518.07		613.82
10-10-73	527.74		603.71
10-12-73	528.27		
10-16-73			597.72
10-26-73	516.07		603.35
11-5-73			612.28
11-6-73	527.09		
BASELINE	519.01 · 17.98	454.96 · 10.28	616.94 · 21.92

TABLE III

PREFLIGHT VS POSTFLIGHT OS CALCIS MINERAL - CREW MEMBERS WHO FLEW Mg/Sq Cm

SUBJECT	PREFLIGHT	POSTFLIGHT	DIF
COMMANDER 2	389.99	351.52	38.47
SCIENTIST PILOT 2	631.28	612.24	19.04
PILOT 2	651.84	593.98	57.86
COMMANDER 3	472.67	456.38	16.29
SCIENTIST PILOT 3	526.69	491.03	35.66
PILOT 3	637.40	653.76	-16.36
COMMANDER 4	518.25	510.02	8.23
SCIENTIST PILOT 4	708.15	653.30	54.85
PILOT 4	566.46	525.98	40.48
TOTAL DIF			254.52

TABLE IV

PREFLIGHT VS POSTFLIGHT OS CALCIS MINERAL - CONTROL SUBJECTS*

SUBJECT	PREFLIGHT	POSTFLIGHT	DIF
RS	707.35	615.77	91.58
BM	521.94	497.69	24.25
WL	585.90	546.12	39.78
VB	742.14	713.40	28.74
DL	540.43	411.00	129.43*
CA	519.01	542.07	-23.06
CR	454.96	454.12	0.84
JV	616.94	621.37	-4.43
TOTAL DIF			157.70

TABLE V

*FOOTNOTE

D.L. fractured his left ankle in 1974. He subsequently underwent surgery and was immobilized for approximately one year. His data is included for interest only and is not included in the statistical analysis.

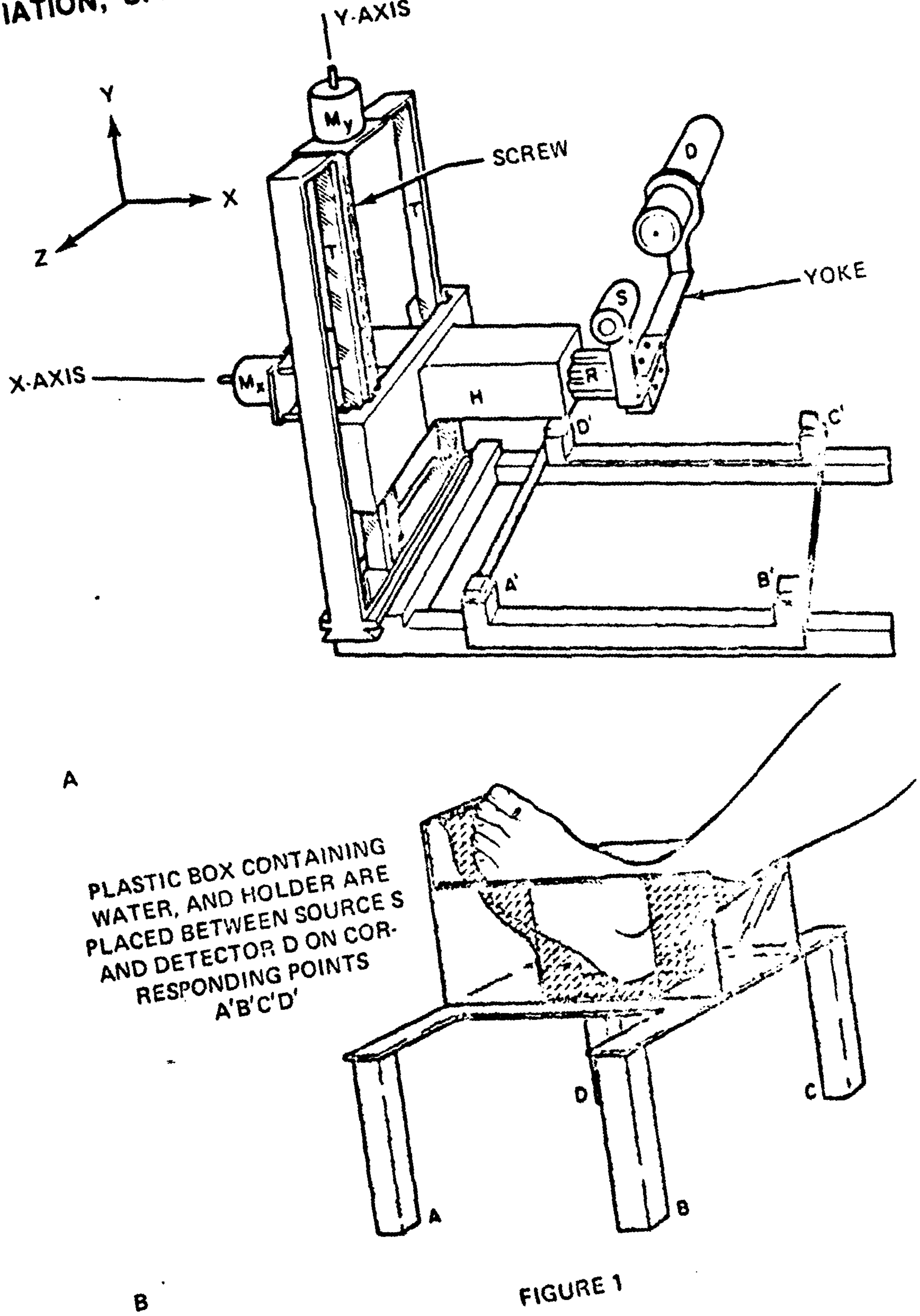
RESULTS

TEST CATEGORY	AVERAGE LOSS Mg/Sq Cm	STANDARD ERROR	P
FLIGHT CREWS	28.28	7.92	$<.01$
CONTROLS	22.53	14.13	$>.05$
COMBINED	——	30.35	$>.05$

TABLE VI

SCANNING APPARATUS

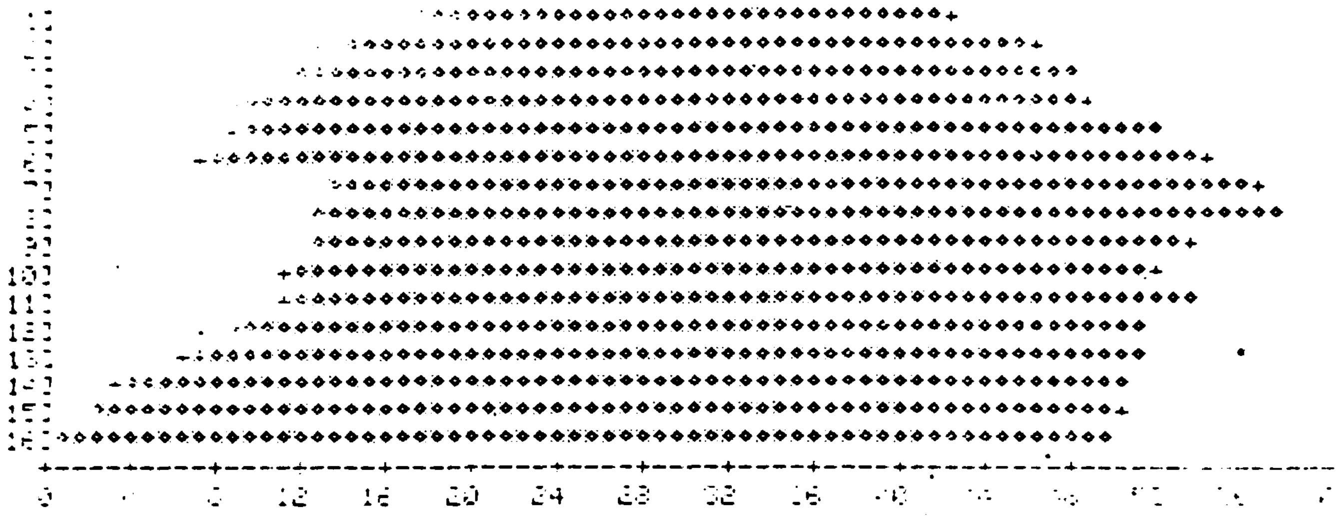
(ADAPTED FROM VOGEL, J. M., AND M. W. WHITTLE)
AVIATION, SPACE, AND ENVIRONMENTAL MEDICINE, 1976)



PLASTIC BOX CONTAINING WATER, AND HOLDER ARE PLACED BETWEEN SOURCE S AND DETECTOR D ON CORRESPONDING POINTS A'B'C'D'

FIGURE 1

SAMPLE OF COMPUTERIZED DATA



WIDTH IN MM
ROW INTERVAL=2MM

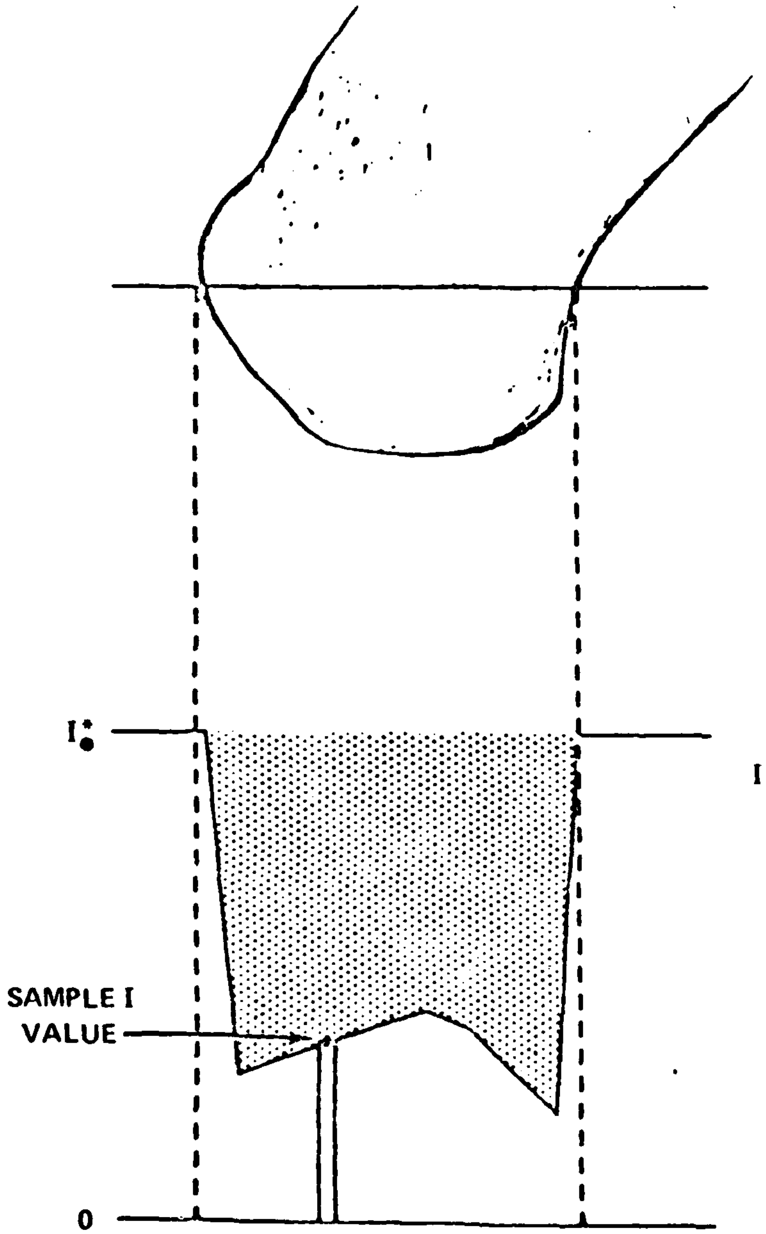
ROW	CU	AG SOCM	CU	AG SOCM	CU	AG SOCM
1	12.87	505.63	48.64	466.28	75.79	500.20
2	135.54	474.13	127.00	475.39	143.71	713.45
3	134.39	479.12	[illegible]	170.15	166.43	713.38
4	117.31	381.18	139.12	545.77	[illegible]	415.24
5	127.29	305.18	115.09	471.79	[illegible]	155.04
6	116.77	427.20	111.76	463.05	[illegible]	400.03
7	103.13	406.32	96.79	109.46	111.17	444.78
8	95.27	370.89	96.11	162.93	107.12	403.45
9	87.65	366.26	92.60	305.41	96.31	403.33
10	87.37	374.23	91.36	130.71	95.31	403.87
11	124.30	422.62	92.06	178.78	115.34	488.07
12	126.45	430.31	95.00	182.28	120.72	473.13
13	117.29	448.33	98.32	277.31	123.74	[illegible]
14	122.91	449.74	99.46	182.16	136.66	494.31
15	121.12	429.14	106.62	173.12	[illegible]	484.33
16	134.91	465.62	108.17	173.22	144.27	497.21
SUM	1841.46	7027.01	1674.39	[illegible]	[illegible]	2290.40
MEAN	115.09	[illegible]	104.65	414.14	125.71	[illegible]

ROW	CU	AG SOCM	CU	AG SOCM	CU	AG SOCM
1-7	[illegible]	711.12	427.81	[illegible]	[illegible]	[illegible]
2-10	1249.21	471.66	[illegible]	473.16	[illegible]	712.36
3-11	1211.15	[illegible]	976.29	442.44	[illegible]	303.15
4-12	[illegible]	11.72	[illegible]	412.45	[illegible]	[illegible]
5-13	[illegible]	13.35	916.57	[illegible]	[illegible]	460.27
6-14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7-15	[illegible]	411.20	46.11	[illegible]	[illegible]	[illegible]
8-16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	413.19

FIGURE 2

METHOD OF COMPUTATION

(ADAPTED FROM VOGEL, J. M.,
AND M. W. WHITTLE
AVIATION, SPACE, AND
ENVIRONMENTAL MEDICINE, 1976)



I_o^* = 100% TRANSMISSION THROUGH TISSUE EQUIVALENT MATERIAL DURING 1/64 INCH TRAVEL (SCAN SPEED CONSTANT)

I = TOTAL COUNTS ACCUMULATED DURING EACH 1/64 INCH TRAVEL OVER BONE

SHADED AREA REPRESENTS BEAM ATTENUATION DUE TO INTERPOSED BONE

SUM OF IN (I_o^*/I) FOR EACH I THROUGH BONE EQUALS COMPUTER UNITS FOR THAT ROW

SIXTEEN ROWS ARE MEASURED

FIGURE 3

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VITA

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