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SKYLAB

CYTOGENETIC STUDIES OF BLOOD (Experiment M111)

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INTRODUCTION

The Skylab M111 experiment is a continuation of the preflight and postflight chromosomal analyses of the air space flight crews that have been performed since the Gemini III mission. The experiment is designed with special attention to findings suggestive of exposure to ionizing radiation. It has been appreciated for some time that increased frequency of chromosomal aberration occurs in man following exposure to ionizing radiation. Information has been obtained by study of persons receiving an external body source, such as, therapeutic dosage or of those accidently exposed. Others receiving radiation exposure from an internal source, such as the decay of radioisotopes administered for diagnosis or treatment, have also been analyzed. It is obvious that interpretation of such data will be fraught with many problems, as the radiation exposure may be acute or chronic, partial or total body, repeated or a single event. The tissues studied and the time elapsed following exposure have also been quite variable. Structural chromosomal aberrations are also known to occur following exposure to other environmental factors such as viruses acquired either through immunization or infection, to various chemicals such as benzene, and to numerous drugs.

Concern over the possible harm of low levels of radiation exposure centers mostly around its association with hereditary damage or malignancy. Essentially no information is available concerning radiation effects on the chromosomes of gonadal or meiotic cells of man and estimates of hereditary damage are based in large part on theoretical views. It should be remembered that we cannot extrapolate findings in somatic cells (in the case under discussion circulating lymphocytes) to gametic chromosomal patterns. On the other hand concern regarding the cancer hazard in irradiated human populations has been suggested by well founded studies (1). A classic example is that of patients treated with x-rays for ankylosing spondylitis who have on the average a ten-fold increase in mortality from leukemia (2). These patients were reported by Buckton, et al. (3) in 1962 to have structural chromosomal damage of cultured peripheral leukocytes some years after the treatment. The fact that many agents which produce tumors in man and animals can also produce chromosomal aberrations in their cells is clearly established. This information coupled with the fact that in several rare human disorders (Bloom's syndrome, Fanconi's anemia and ataxia telangiectasia) there is a constitutional predilection for increased chromosomal aberration as well as an increased incidence of leukemia and lymphoma has suggested that an increase in structural chromosomes cannot be ignored.

These chromosomal aberrations are structural in nature, that is, they arise through breakage of the strands of chromatin. These breaks may occur

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either in one or in both chromatids of a single chromosome or multiple breaks may occur in several chromosomes within an individual cell. Following such accidents, the strands may recombine within themselves or the broken ends of several chromosomes may combine with each other. Two general types of aberrations occur depending on the stage of the cell cycle in which the break occurs. If the cell is in the pre-DNA synthesis period, chromosome strands are single (chromatids) and if the accident occurs after synthesis, the chromosome consists of two chromatids. Chromosomes are technically examined in the metaphase stage of division because that is when they can be separated as individuals. Replication may or may not have occurred when we examine the chromosomes of peripheral lymphocytes. In general, the pre and post replication aberrations may be morphologically separated, however, in several instances it is impossible to tell whether the break occurred in the pre-DNA synthesis and was replicated, or whether both strands were affected after replication. A break will produce a fragment that is generally lost in the next cell division.

Separation of the aberrations into chromatid or chromosome in nature is useful as the type of structural defect occurring in humans as a response to a specific exposure has varied with the agent to which the person is exposed.

It is with these considerations in mind that the NASA program has wisely considered cytogenetic studies important in past years and has especially concentrated on such aspects in the Skylab program with extended missions and possible increase in radiation exposure.

MATERIALS AND METHODS

Study of the chromosome patterns of the three Skylab missions follows a similar pattern. Blood lymphocyte studies were obtained on the crew members, the backup crew until it was apparent that they would not replace the crew, and from the control group consisting of three persons in the NASA program who would have an environment somewhat similar to the crew over the experimental period except for the flight. Venus heparinized blood was drawn either at the Johnson Space Center or the Kennedy Space Center in one to two milliliter aliquots and was obtained at the time of drawing for other medical procedures. The cultures were instituted at the University of Texas Medical Branch on all occasions except for two. Each sample was allowed to settle and five to seven drops of the buffy coat were placed in Chromosome Medium 1A. Four such cultures were initiated on each person from each blood drawing. The cultures were then incubated for a period of 60 to 70 hours at 37° C and processed by a modifier method of Moorehead (4). Colcemid was added to a concentration of 0.1 μg/ml for two hours. The cell suspension was then treated with a hypotonic solution followed by numerous washings with fixative (3 methanol: 1 acetic acid). Slides were prepared on the same day by flame drying and the cells stained with Wright's stain. The

slides were coded and a minimum of 200 cells were examined from the Skylab 2 specimens while a minimum of 100 cells were examined on each specimen from the Skylab 3 and Skylab 4 missions. All mitotic cells were found on low magnification and then examined under high magnification. Each cell was counted and a search was made for any type of structural defect. When an abnormality was found that could not be completely delineated visually or if a structural rearrangement was detected, the cell was photographed for further analysis by karyotyping. This was an attempt to determine whenever possible the chromosome and/or chromosomes involved in the aberration.

The cells were scored for the following structural arrangements: chromatid and chromosome constrictions and gaps (not to be considered in this paper); chromatid and chromosome breaks, fragments, and deletions (to be referred to as minor defects); and dicentrics, rings, inversions, translocations, and exchanges (to be referred to as structural rearrangements).

Blood lymphocyte studies were obtained on eleven occasions preflight and eight instances postflight from the Skylab 2 mission. Similar studies were obtained on five and six instances respectively during the Skylab 3 mission. A total of 80 specimens from Skylab 2 and 77 from Skylab 3 were processed. These have previously been reported (5). Tables I and II are the data derived from the studies in Skylab 2 and 3 respectively.

The results of the cytogenetic analysis of lymphocytes of the Skylab 4 astronauts, controls and the backup crew are shown in Table III. All but two specimens were sucessfully cultured and harvested. It was possible to obtain a repeat study on one occasion so data is lacking in only one instance. There were 42 preflight specimens and 36 postflight specimens analyzed.

RESULTS AND DISCUSSIONS

The results of the studies of the Skylab 2 mission are shown in Table I. There were four studies that were unsuccessful. These involved the recovery day specimens of the crew and of one control. These cultures were instituted aboard ship and transported by portable incubator with variable temperature range and this was considered to be the source of the problem. There were no individual studies from this mission that demonstrated greater than 8.0 percent minor structural defects except for one on subject L, a control. In only 16 specimens did such aberrations appear in from 5.0 to 7.9 percent of the cells examined. In our laboratory under similar technical conditions where 13,000 cells a year are counted and analyzed, it is expected that 3 to 4 percent of the cells analyzed will show one or more breaks, deletions or fragments. In other laboratories with varying preparation of cells for study, this aberration incidence may even be greater. These defects are known to increase in peripheral leukocyte cultures of persons following a viral illness, such as measles or adenovirus, after administration of viral vaccines, after certain diagnositc x-ray studies, and after exposure to certain chemicals.

This increase in response to such exposures is in general only temporary, and little can be suggested as to harmful effects.

Various radioisotope injections were administered to crews and controls alike in all the Skylab missions. In Skylab 2 only one blood culture on each person was instituted prior to such administration (Table IV) and no one in the crew, backup crew, or control group had greater than 3.86 percent aberrations on the first study. This may well be chance because at various other occasions throughout the experiment, each person demonstrated such low values. It is quite possible that control L had a viremia at the time in which the 11.51 percent aberrations were found, and throughout the remainder of the study his values returned to expected levels: It is noteworthy that in the first culture there was one crewmember and one control with evidence of breakage and recombination. This is not characteristic of the general population. It has been reported that such aberrations as dicentrics, rings, inversions and exchanges occur very rarely. Bloom, et al. (6) found only one dicentric and no rings in 7188 cells examined. Bender, et al. (7) reported 3 dicentrics and no ring chromosomes in 1642 cells from normal, unirradiated individuals. In our experience, it is less common. Figure I consists of abnormalities detected in Skylab 2.

It was realized in consideration of Skylab 2 data, that neither the crew nor the control group are members of the "general population". In the professional lifetime of such men there are many and varied experiences in comparison to those of the general population. No chromosomal analyses on these men were performed prior to their entrance into the NASA program. Gooch and Berry (8) reporting on the chromosome aberrations of the Gemina astronauts had also noted an occasional dicentric or ring chromosome. In reviewing the medical log of Skylab 2, such potential problems as exposure to various gases, high temperatures, to the atmospheric conditions in flight, and in fact to weightlessness have to be considered as possible factors associated with chromosomal breakage Prince, et al. (9) reported observations on man in an oxygen-helium environment and included chromosomal study. They noted up to 4 percent chromatid type lesions in the subjects. There are virtually no other good studies in regard to such a special environment. There was very good documentation regarding illness and drug ingestion in the astronauts of Skylab 2 and comparison of this data with the chromosomal pattern does not suggest a cause and effect relationship.

One or more structural rearrangements in 250 cultured cells is unusual, however, in the Skylab 2 study there appeared to be no remarkable difference in the crew and the control group in regard to such aberrations as they occurred sporadically throughout the studies. One factor common to both groups, however, appeared to be that of the administration of the radioisotopes for various metabolic studies. There did not appear to be an increase in such aberrations, however in the crew members following the mission. The culture failure that was noted on the initial studies after recovery was thought to have been the

result of difficult culture conditions. In personal communication, however, with Dr. S. E. Ritzman (experiment M112), it was realized that they may be related to defective lymphocyte transformation and/or DNA synthesis as his studies suggested on the day of recovery. In summary, the results of the Skylab 2 mission seemed to indicate that the flight itself was not a major contributing factor to chromosomal breakage or structural rearrangements. Repeated isotope injections were thought to be a likely etiological factor.

The results of the cytogenetic analysis of lymphocytes of the Skylab 3 astronauts, backup crew and controls are shown in Table II. All but one specimen was sucessfully cultured and harvested. Only one individual study had greater than 9.00 percent minor structural defects. This sample was that of control (ECB) on 7-19-73, 10 days preflight. By 7-27-73, 2 days preflight, the percentage had decreased 2.24 percent. In six instances throughout the study period, these aberrations were found in from 5.00 to 9.00 percent of the cells studied. Structural rearrangements were noted sporadically throughout the study on from one to three occasions in each of the subjects analyzed. Two crew members, in fact, exhibited one such abnormality in the first specimen obtained. One control subject (PB) failed to show such an aberration until the last study. Table V lists the radioisotopes administered to the crew and controls during the Skylab 3 study. These were injected on the day specified but only after blood was obtained for chromosomal study. Structural rearrangements appeared to occur randomly throughout Skylab 3 while in Skylab 2 it appeared that these aberrations occurred more consistently postflight in both crewmembers and controls than in the preflight period. Again, the flight does not seem to be a significant contributing factor to the appearance of structural rearrangements in Skylab 3 since one cannot distinguish pre and post flight studies in this regard.

Various other factors such as medication and weightlessness were again considered as well as the discrepancy in the length of the Skylab 2 mission (28 days) with that of the Skylab 3 (59 days). One might suspect that a more prolonged exposure to numerous variables including ionizing radiation would result in the increased frequency of significant chromosomal aberrations. This was not apparent and the longer time may have in fact allowed for disappearance of abnormalities from the lymphocytic chromosomes if these occurred early in the 59 day mission. It is reported by Bloom and Tijo (10) that partial-body x-irradiation, at diagnostic-level kilovoltage, is capable in some cases of producing chromosome damage in vivo in man. A majority of the patients studied were normal within two weeks. Again, in the Skylab 3 mission, it seemed that the more minor structural chromosomal defects were not significantly increased in the crews or the controls over that of the general population except in several individual studies. The incidence of structural rearrangements again appeared increased over that for the normal population but the etiology and significance of these aberrations is not apparent.

The results of the cytogenetic analysis of lymphocytes of the Skylab 4 astronauts, controls, and backup crew are shown in Table III. There were seven specimens with greater than 9.00 percent minor structural defects as compared to only one in the Skylab 3 studies. All of these occurred postflight. One control (DGW) on 2-9-74 had 10.28 percent. On all other occasions that his chromosomes were analyzed minor defects were detected in less than 5.00 percent of the cells. One could again speculate that this single episode might have been associated with a viremia. On 2-22-74, the crew commander and control WCA had 9.00+ percent breaks and fragments. On 3-1-74, the scientist pilot and controls ECB and WCA had from 9.52 to 11.01 percent minor structural defects. Of the 42 preflight studies, only two specimens demonstrated from 7.00 to 9.00 percent minor errors (control ECB on 10-26-73 and backup crew member Br on 11-3-73). Out of 36 postflight analyses, 12 studies showed from 7.00 to 9.00 percent minor defects. On recovery day, neither crew nor controls showed greater than 7.00 percent defects. (WCA culture showed no mitoses.)

Control WCA had the most erratic culture results throughout the mission. There were two occasions in which his culture showed no mitoses for analysis. His first study was attempted on 10-12-73 and was unsuccessful. It was repeated on 10-18-73 at which time he demonstrated three structural rearrangements along with 5.56 percent minor defects. He also had an unsuccessful study on 2-8-74 and this could not be repeated. His studies showed from 0.00 to 9.52 percent minor aberrations. It is interesting to note that WCA served as control in Skylab 2 as well as in Skylab 4. In Skylab 2 he had 14 structural rearrangements in 3296 cells examined. In Skylab 4 there were 5 in 1122 cells. There may be important data in the medical history of WCA unknown to the author since a medical log is not available on the controls. One might consider repeated intermittent multiple isotope injections as an etiologic factor. This seems unlikely after reviewing the studies of ECB, another control, who served in two missions, Skylab 3 and 4. He showed 3 structural rearrangements per 1354 cells and 3 per 1239 cells respectively.

Skylab 4, an 84 day mission, was three times as long as Skylab 2 of 28 days and 25 days longer than the Skylab 3 mission. On review of the medical log of Skylab 4, there were again numerous environmental variables. Members of this crew used more sleep medications than the other two crews, took more medications for decongestion and spent longer hours exercising than the other crew members. Dosimetry results showed that dose equivalents of ionizing radiation received by Skylab 4 crew men were the highest received in any NASA mission to date, although still within acceptable limits recommended by the Radiobiological Advisory Panel (11). These dose equivalents apply specifically to long term effects such as generalized life shortening, increased neoplasm incidence, and cataract production. Isotope injections were administered to this crew as shown in Table VI. Structural rearrangements occurred in one control and three crew member studies before the first injection on 10-26-73. There appears to be no remarkable increase

in percentage of minor structural defects following this injection and prior to flight.

When one compares the total preflight cells examined for minor structural defects on a specific individual to the postflight data it appears that each crewman had a significant increase. (C from 2.50 to 6.05 percent, G from 2.05 to 6.30 percent, and P from 3.99 to 6.55 percent.) This is not as suggestive for the controls. (WCA from 3.63 to 5.34 percent, ECB from 4.32 to 4.10 percent, and DGW from 2.83 to 4.53 percent.) This may be linked to the extended exposures of the crew.

SUMMARY

In summary, the crews of the Skylab missions and their control counterparts appear to have an increased incidence of structural rearrangements in lymphocyte chromosomes over that of the general population. There are numerous exposures that might be associated with these chromosomal findings and one or more specific etiologic factors could not be found. The scientific information regarding chromosomal structural rearrangements on a large number of healthy persons is meager but suggests that the population discussed in this report is somewhat different. There did appear to be an increase in postflight minor structural defects over that of preflight studies in Skylab 4 crewman.

There are several aspects of this experiment that could be improved upon in future programs. There should be another control group composed of healthy age and sex matched individuals in an environment disassociated with NASA. A larger number of preflight specimens should be studied. For various technical reasons, known to cytogeneticists, the time of specimens in culture should be decreased in future studies.

I strongly recommend that we receive specimens for study from the crewmen and controls of the Skylab missions on a yearly basis in order to learn what we can about the persistence of the chromosomal aberrations in this population. I would also request that we be informed of any significant delayed responses that might be considered related to these missions. It would seem important in the future to analyze the chromosome patterns at the initial entrance into the NASA mission programs much as is done in industry where environmental factors may be hazardous and different.

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Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
4-2-73 F-53	KSC		
C (26)	268	3.35	
K (43)	239	3.34	1 Exchange
W (34)	250	2.80	
A (80)	259	3.86	
H (55)	260	1.15	1 Inversion
L (14)	271	2.95	
Mc(84)	223	0.44	
M (65)	238	1.68	
S (72)	231	1.73	
4-24-73 F-31	KSC		
L (41)	277	1.44	
S (46)	244	2.45	
4-25-73 F-30	KSC		
A (28)	256	3.90	1 Exchange
H (85)	234	1.28	
L (38)	217	4.60	
4-26-73 F-29	KSC		
C (22)	273	1.83	1 Dicentric
K (12)	263	7.22	
W (59)	241	1.66	
A (7)	255	6.27	
H (89)	234	2.13	1 Dicentric
4-27-73 F-28	KSC		
C (31)	241	1.24	
K (10)	257	4.66	1 Translocation
W (69)	244	4.09	
5-1-73 F-24	JSC		
H (78)	242	0.83	
L (96)	247	4.05	2 Translocations
5-2-73 F-23	JSC		
C (64)	260	5.39	2 Rings, 1 Exchange
K (91)	257	3.89	
W (81)	250	5.20	
A (50)	244	6.56	

Crew: Conrad (C), Kerwin (K), Weitz (W)
Controls: Alexander (A), Hordinsky (H), La Pinta (L)
Back-up Crew: McCandless (Mc), Musgrave (M), Schweickert (S)

TABLE I
Skylab 2

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
5-7-73 F-18	JSC		
C (4)	247	3.64	
K (95)	230	3.48	1 Ring
W (13)	243	2.06	
A (29)	238	5.04	1 Dicentric 1 Exchange
5-8-73 F-17	JSC		
H (18)	257	0.78	
L (48)	267	3.74	
5-14-73 F-11	JSC		
C (66)	273	4.03	1 Exchange
K (35)	246	4.47	1 Dicentric 1 Exchange
W (51)	243	5.34	
A (25)	244	7.37	1 Exchange
H (5)	245	2.85	
L (17)	277	1.80	1 Dicentric
5-24-73 F-1	KSC		
C (47)	269	1.86	
K (77)	231	4.76	
W (99)	239	5.43	
A (53)	238	3.78	1 Exchange
H (83)	241	2.90	
L (98)	259	3.47	

Flight= 5-25-73

6-21-73 R-1	Ship		
A (92)	258	7.75	1 Dicentric
H (67)	Unsuccessful		
L (97)	139	11.51	
6-22-73 R+0	Ship		
C (15)	Unsuccessful		
K (90)	Unsuccessful		
W (56)	Unsuccessful		

TABLE I
Skylab 2

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
6-23-73 R+1	Ship		
C (23)	257	3.50	
K (32)	234	4.70	1 Chromatid Exchange
W (45)	255	1.57	
A (93)	274	5.11	
H (76)	266	2.25	
L (86)	249	4.01	
6-26-73 R+4	JSC		
C (19)	261	4.21	1 Tricentric 1 Exchange
K (63)	264	2.65	1 Ring
W (57)	290	3.10	1 Dicentric, 1 Ring
A (94)	256	2.73	
H (71)	234	2.99	2 Dicentrics
L (82)	250	2.00	
6-29-73 R+7	JSC		
C (27)	245	1.22	
K (44)	260	6.15	1 Dicentric
W (70)	248	2.02	1 Dicentric
A (87)	239	6.28	2 Exchanges 1 Dicentric
H (3)	232	0.43	
L (52)	248	2.82	1 Dicentric 1 Exchange
7-5-73 R+13	JSC		
C (88)	223	6.72	1 Exchange
K (60)	260	4.62	
W (54)	244	4.91	
A (37)	273	6.23	1 Dicentric 3 Exchanges
7-9-73 R+17	JSC		
K (30)	276	2.90	
7-10-73 R+18	JSC		
C (68)	256	7.03	1 Tricentric
W (73)	246	4.07	1 Dicentric
A (49)	262	3.81	1 Ring
H (33)	255	0.78	
L (42)	238	2.10	

TABLE II
Skylab 3

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
7-8-73 F-21			
B (192)	131	1.53	1 Dicentric
G (166)	133	2.26	1 Exchange
L (134)	121	0.83	
ECB (108)	120	0.00	
MWW (121)	108	3.70	
PB (150)	124	1.61	
7-9-73 F-20			
B (114)	120	0.83	
G (103)	123	0.81	
L (152)	146	1.37	
Li (171)	134	2.96	
Le (149)	140	4.29	
Br (125)	119	2.52	
ECB (143)	135	2.22	
MWW (186)	142	2.11	
PB (198)	145	2.79	
7-10-73 F-19			
Li (127)	133	2.26	
Le (173)	103	4.85	
Br (118)	106	1.89	
7-12-73 F-17			
B (102)	119	2.52	
G (111)	111	3.60	
L (128)	133	2.26	
ECB (131)	114	2.63	
MWW (146)	120	3.33	1 Dicentric
PB (160)	128	1.56	

Crew: Bean (B), Garriott (G), Lousma (L)
Controls: ECB, MWW, PB
Backup Crew: Lind (Li), Lenoir (Le), Brand (Br)

TABLE II
(Continued)

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
7-13-73 F-16			
Li (137)	126	3.97	1 Dicentric
Le (182)	121	0.83	1 Exchange
Br (161)	116	2.59	1 Inversion
7-19-73 F-10			
ECB (112)	122	13.11	1 Dicentric
MWW (148)	124	4.03	
PB (132)	117	8.55	
7-20-73 F-9			
B (155)	123	8.13	2 Translocations-1 Dicentric
G (141)	134	2.24	
L (110)	120	1.67	1 Dicentric
Li (197)	129	1.57	
Le (115)	134	4.48	1 Translocation 2 Dicentrics
Br (187)	120	3.33	
7-27-73 F-2			
B (169)	131	4.58	
G (123)	150	0.67	
L (105)	Unsuccessful		
ECB (194)	134	2.24	
MWW (158)	136	2.94	
PB (176)	126	6.43	
9-25-73 R+0			
B (135)	127	2.36	
G (184)	138	2.90	
L (178)	127	3.15	
ECB (145)	137	4.38	1 Exchange
MWW (116)	107	2.80	
PB (196)	118	3.39	

TABLE II
(Continued)

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
9-26-73 R+1			
B (165)	136	3.68	1 Dicentric
G (138)	154	0.65	
L (175)	167	1.20	
ECB (189)	161	1.24	1 Exchange
MWW (156)	137	0.00	
PB (120)	140	2.86	
9-28-73 R+3			
B (140)	125	8.80	1 Translocation
G (130)	173	1.16	1 Translocation
L (109)	105	0.95	
ECB (200)	134	3.73	
MWW (181)	125	4.00	
PB (167)	141	0.71	
10-2-73 R+7			
B (170)	134	2.99	
G (163)	139	0.72	
L (154)	133	1.50	1 Dicentric
ECB (190)	155	1.29	
MWW (191)	147	1.36	
PB (179)	136	2.94	
10-9-73 R+14			
B (126)	161	2.48	
G (188)	149	6.71	
L (122)	135	3.70	1 Exchange 1 Dicentric
ECB (101)	132	3.79	
MWW (193)	131	3.06	
PB (151)	116	3.45	

TABLE II
(Continued)

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
10-15-73 R+20			
B (106)	123	5.69	
G (136)	118	5.93	
L (117)	133	1.50	
ECB (No Specimen)			
MWW (153)	118	5.08	1 Dicentric
PB (142)	136	4.40	1 Exchange

TABLE III
SKYLAB 4

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
10-10-73 F-37			
Br (571)	107	1.87	
Le (545)	100	0.00	
Li (520)	105	1.90	
10-12-73 F-35			
C (552)	108	0.93	
G (535)	132	3.79	1 Exchange
P (522)	105	5.71	
ECB (590)	101	4.95	
DGW (501)	108	1.85	
10-18-73 F-29			
WCA (593)	124	5.65	1 Dicentric, 1 Ring, 1 Exchange
10-26-73 F-21			
C (537)	115	0.87	
G (525)	123	1.63	1 Exchange
P (503)	119	5.04	1 Dicentric
WCA (591)	118	2.54	
ECB (562)	110	7.27	
DGW (514)	121	4.96	
10-27-73 F-20			
C (526)	120	3.33	
G (567)	111	0.00	1 Translocation
P (550)	120	4.17	1 Ring
WCA (595)	114	4.39	
ECB (532)	117	2.56	
DGW (582)	109	3.67	1 Ring
10-29-73 F-18			
Br (585)	102	3.92	
Le (507)	129	0.00	1 Ring
Li (538)	111	1.80	

Crew: Carr (C), Gibson (G), Pogue (P)
Controls: WCA, ECB, DGW
Back up crew: Brand (Br), Lenior (Le), Lind (Li)

TABLE III
(Continued)

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearragements
10-30-73 F-17			
Br (561)	113	0.88	
Le (509)	102	1.96	
Li (521)	123	0.81	1 Ring
11-2-73 F-14			
C (530)	122	1.64	
G (541)	109	4.59	
P (519)	81	2.47	
WCA (586)	100	0.00	
ECB (575)	101	2.97	1 Ring
DGW (553)	113	0.88	
11-3-73 F-13			
Br (597)	109	8.26	
Le (540)	106	2.83	
Li (511)	107	4.67	
11-15-73 F-1			
C (506)	134	5.22	1 Translocation
G (549)	109	0.00	
P (527)	152	2.63	
WCA (554)	123	4.88	1 Exchange
ECB (576)	127	3.94	2 Rings
DGW (581)	114	2.63	
2-8-74 R+0			
C (546)	102	2.94	
G (510)	118	6.78	
P (598)	111	5.41	1 Dicentric
WCA (517)	Unsuccessful		
ECB (502)	107	1.87	
DGW (578)	131	3.82	1 Translocation
2-9-74 R+1			
C (565)	120	3.33	
G (531)	106	4.72	
P (558)	114	5.26	1 Ring
WCA (584)	107	9.35	
ECB (599)	111	7.21	
DGW (573)	107	10.28	

TABLE III
(Continued)

Date & Subject	No. Cells Examined	% Minor Defects	Structural Rearrangements
2-11-74 R+3			
C (508)	107	6.54	1 Translocation
G (523)	107	8.41	
P (542)	109	8.26	
WCA (551)	111	1.80	
ECB (518)	136	2.21	
DGW (587)	106	2.83	
2-15-74 R+7			
C (583)	117	5.98	
G (533)	129	4.60	1 Exchange
P (592)	120	5.83	
WCA (528)	112	4.46	
ECB (548)	106	0.94	
DGW (566)	107	3.74	
2-22-74 R+14			
C (529)	104	10.58	
G (512)	115	7.83	
P (596)	145	4.83	1 Dicentric
WCA (557)	108	9.26	1 Dicentric
ECB (539)	114	1.75	
DGW (544)	121	3.30	
3-1-74 R+21			
C (555)	111	7.20	
G (594)	107	4.67	1 Ring
P (563)	103	10.68	
WCA (524)	105	9.52	
ECB (536)	109	11.01	
DGW (515)	113	3.54	

TABLE IV
ISOTOPE INJECTIONS

Skylab 2

1973

4/2	4/24	5/2	5/7	5/14	5/23	6/21	6/22	7/5	8/2	8/28
	^{125}I					^{125}I		^{125}I	^{125}I	^{125}I
	^{51}Cr					^{51}Cr		^{51}Cr	^{51}Cr	^{51}Cr
	^{35}S					^{35}S		^{35}S		^{35}S
	^{3}H				^{3}H	^{3}H		^{3}H	^{3}H	^{3}H
^{14}C										
	^{42}K	^{42}K	^{42}K	^{42}K	^{42}K		^{42}K	^{42}K		
						^{59}Fe				

TABLE V
Skylab 3
1973
ISOTOPE INJECTIONS

7/8	9/25	10/9
^{125}I	^{125}I	^{125}I
^{51}Cr	^{51}Cr	^{51}Cr
^{35}S	^{35}S	^{35}S
^{3}H	^{3}H	^{3}H
^{43}K	^{43}K	^{43}K
^{14}C	^{14}C	^{14}C
	^{59}Fe	

TABLE VI

Skylab 4

ISOTOPE INJECTIONS

1973				1974			
10-26	11-2	11-9	11-15	2-8	2-9	2-11	2-22
^{125}I			^{125}I	^{125}I			^{125}I
^{51}Cr			^{51}Cr	^{51}Cr			^{51}Cr
^{35}S			^{35}S	^{35}S			^{35}S
^{3}H			^{3}H	^{3}H			^{3}H
	^{43}K	^{43}K		^{43}K	^{43}K	^{43}K	^{43}K
^{14}C							
				^{59}Fe			

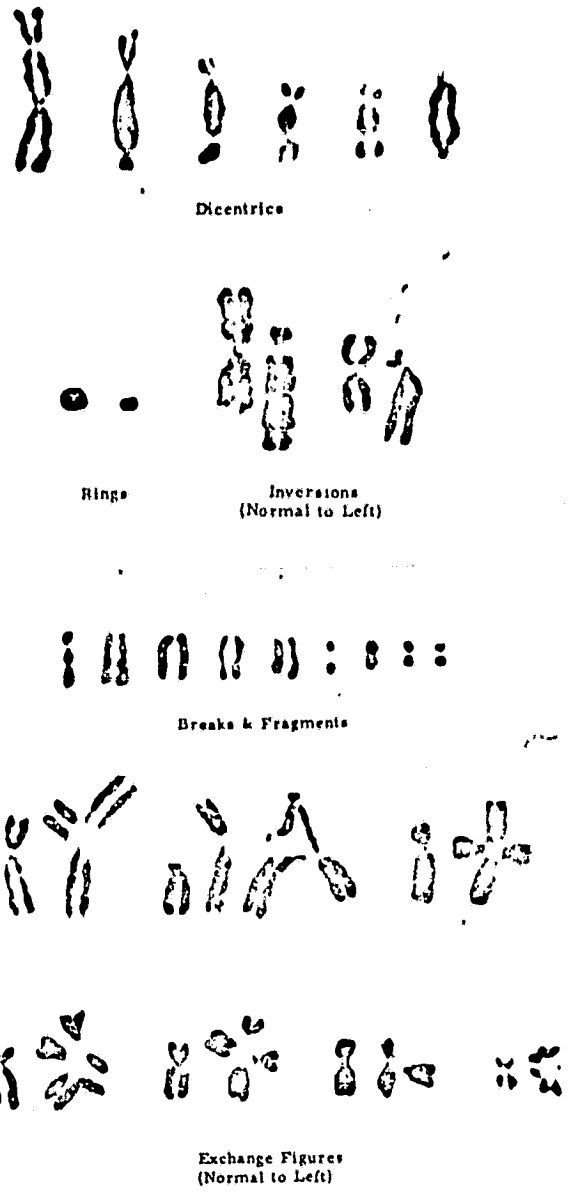

Figure 1. Skylab abnormalities.