NRL Report 6917

Solar X-Ray Emission During the Flight of Apollo 8

December 21, 1968 - December 27, 1968

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ABSTRACT

Records of solar x-ray emission during the Apollo 8 manned lunar-orbiting mission show only one significant x-ray event. Comparison of this event with other large flares shows that it is completely overshadowed by two huge flares which occurred in July 1968. Events as large as those of July 1968 must be considered possible during the next year or two.

PROBLEM STATUS

This report is on one phase of a continuing problem.

AUTHORIZATION

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SOLAR X-RAY EMISSION DURING THE FLIGHT OF APOLLO 8

December 21, 1968 - December 27, 1968

INTRODUCTION

During the Apollo 8 manned lunar-orbiting mission in late December 1968, x-ray emission from the sun was measured by the NRL Solrad 9 satellite (1968-17A). Solrad 9 is able to store up to 14.25 hours of energy flux data for the 0.5 to 3 Å, 1 to 8 Å, and 8 to 20 Å x-ray bands with a time resolution of 1 minute. A complete description of the spacecraft and its detectors can be found in NRL Report 6800.*

DESCRIPTION OF X-RAY DATA PLOTS

Figures 1 through 7 show plots of the solar x-ray emission vs time during the flight of Apollo 8. The regularly spaced data gaps of about 30 minutes duration indicate periods of satellite night. The larger gaps in the data between 2023 UT on December 23 and 0208 UT on December 24 and between 1645 UT and 1856 UT on December 27 are due to an irretrievable loss of data during transmission from the satellite to the ground station. In each of these plots the top curve represents the solar x-ray emission in the 8 to 20 Å band and the next lower curve represents solar x-ray emission in the 1 to 8 Å band. In both cases a 2×10^6 °K color temperature was assumed in converting from detector current output to energy flux units. The third curve from the top represents emission in the 0.5 to 3 Å band assuming a 10×10^6 °K color temperature for the emitting region on the sun. Since the 0.5 to 3 Å band solar emission is generally below the threshold level of the detector, the curve representing these data will be quite intermittent.

The x-ray emission is plotted in units of ergs/cm^2-sec on a logarithmic scale. The abscissa is linear with the integers denoting hours in Universal Time (UT). Charged-particle interference with x-ray detectors, which can cause the plotted flux levels to be higher or lower than the actual flux, is indicated by the lowest data line. The ion chamber current caused by the charged-particle background is digitized and recorded as a "count." The number of "counts" is linearly related to the current generated in the 0.5 to 3 Å ionization chamber by penetrating charged particles when the detector is facing away from the sun. Counts of 10 to 15 indicate no particle interference with the detectors. Counts of 20 to the maximum value of 127 indicate increasing amounts of particle interference. However, the data processing computer program does not plot data obviously contaminated by particle interference, and this feature causes randomly spaced data gaps of 30 minutes duration or less.

HISTORY OF SOLAR X-RAY EMISSION DURING FLIGHT

The flight of Apollo 8 began at 1251 UT on December 21, 1968. The x-ray energy flux for that day is shown in Fig. 1. There was a small flare at 1230 UT, shortly before launch. Two more small events occurred at 1415 and 1820. The background x-ray emission, i.e., the x-ray emission from the nonflaring sun, was generally around 1.0×10^{-3} erg/cm^2-sec for the 1 to 8 Å band and around 1.2×10^{-2} erg/cm^2-sec for the 8 to

*R.W. Kreplin and D.M. Horan, "The NRL SOLRAD 9 Satellite, Solar Explorer B, 1968-17A," NRL Report 6800, Mar. 24, 1969.

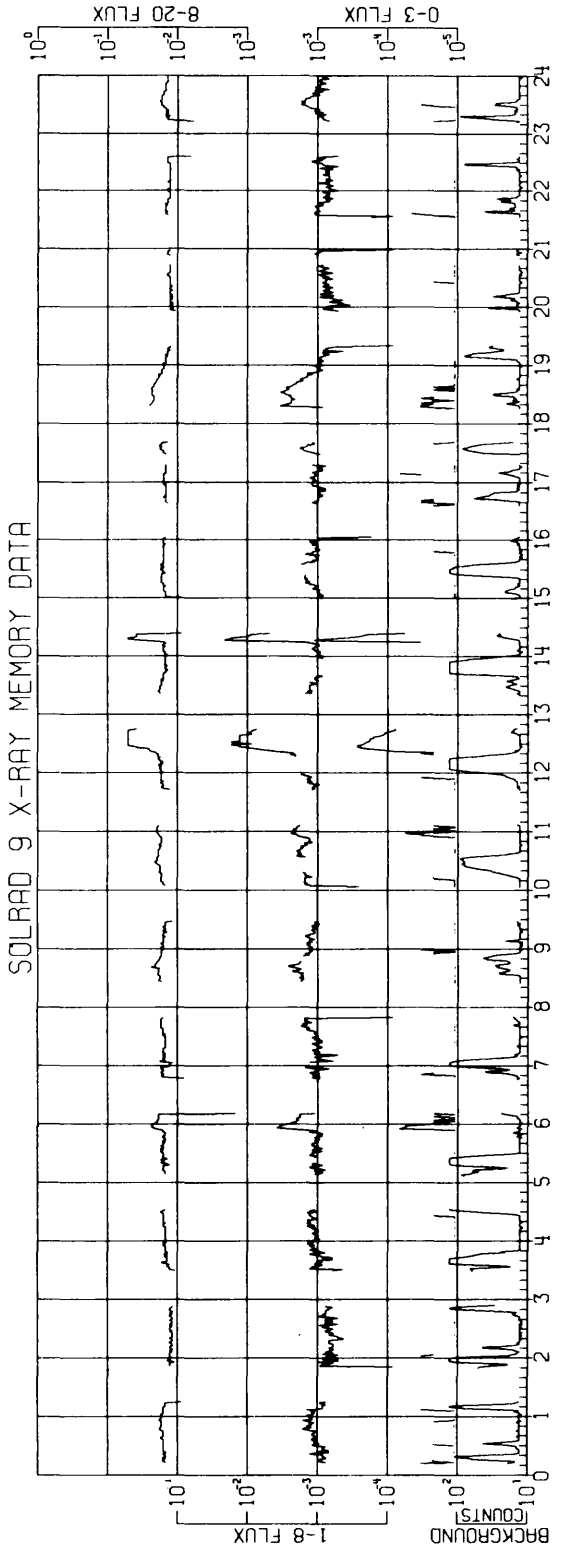

Fig. 1 - Solar x-ray plot for December 21, 1968

20 Å band. These values are considered high and indicative of the presence of active regions on the sun. In this case the active regions were probably McMath Plage Regions 9841 and 9842, both of which were on the east limb, and Region 9817, which was approaching the west limb.

The x-ray energy flux for December 22, shown in Fig. 2, shows generally high background levels throughout the day on the 1 to 8 Å and 8 to 20 Å bands. The increased emission between 0905 and 0955 was probably associated with a small flare in Region 9833. The sharp spikes in the data at 0958 and 1950 correspond to a flare (possibly 1N) observed in Region 9817 and a Class 1 flare observed in Region 9829.

Figure 3 shows an increase in the x-ray energy flux between 0030 and 0230 on December 23, which corresponds to a subflare which occurred at 0032 and a Class 1 flare which was observed in Region 9841. After an x-ray event at 0630, the 8 to 20 Å background drops to a moderate level and the 1 to 8 Å background fluctuates between low and moderate levels until 2000 when a rise in levels corresponding to a reported subflare occurs. Data for the remainder of the day were lost in transmission.

When the data begin again on Fig. 4 at 0208 of December 24, the background levels are moderate, and there is no indication of x-ray activity from a Class 2 flare reported to be in progress at that time in Region 9842. By 0400 the background had returned to high levels. X-ray emission from a series of reported subflares is evident at 0414, 0726, 1038, 1404, 1704, and 1839. Two Class 1 flares in Region 9826 were observed at 0755 and 1940, and a Class 1 flare was observed in Region 9842 at 2230. The x-ray emission associated with these events is clearly shown on the plot.

Figure 5 shows high and relatively constant background levels on December 25 until 0630 when the x-ray emission corresponding to a large subflare followed by a Class 1 flare in Region 9826 at 0710 is observed. By 0900 the x-ray emission from the flares has decayed, and moderate to high background levels prevail until the emission from Class 1 flares in Region 9826 at 1841 and 1902 is observed.

The data for December 26, Fig. 6, show the x-ray emission corresponding to a subflare observed at 0050 and then high, relatively constant background levels until 1000, when a succession of small x-ray events is observed until 1830. The x-ray emission from reported subflares at 1834, 2022, and 2050 is clearly shown.

Data for December 27, Fig. 7, show the x-ray emission corresponding to a Class 1 flare in Region 9826 at 0300, followed by a subflare at 0318. After this flare the background levels remained high until 1047 when the x-ray emission associated with a Class 2 flare in Region 9842 appears. This flare was, by far, the largest occurring during the flight of Apollo 8, which ended at 1551 without encountering further flare activity. Although this flare showed signs that energetic particles had been emitted from the sun, no particle flux from it or from any other flare during the flight was detected.

This analysis of the plots shows that the background x-ray emission was generally quite high, and only one flare having significant x-ray emission occurred during the flight. Since a large x-ray flare produces a peak x-ray energy flux several thousand times larger than the background levels, the background x-ray emission, whether high or low, is not important when compared to flare x-ray emission. The hardening of the x-ray emission spectrum which accompanies a flare means that more x-rays of shorter wavelength, and therefore higher quantum energy, are present. Therefore, the increased x-ray energy flux during a solar flare is due to both a larger number of x-ray photons and a relative increase in the number of the higher-energy x-ray photons. Both of these factors should be considered in evaluating the effects of flare x-ray emission on a spacecraft and its occupants.

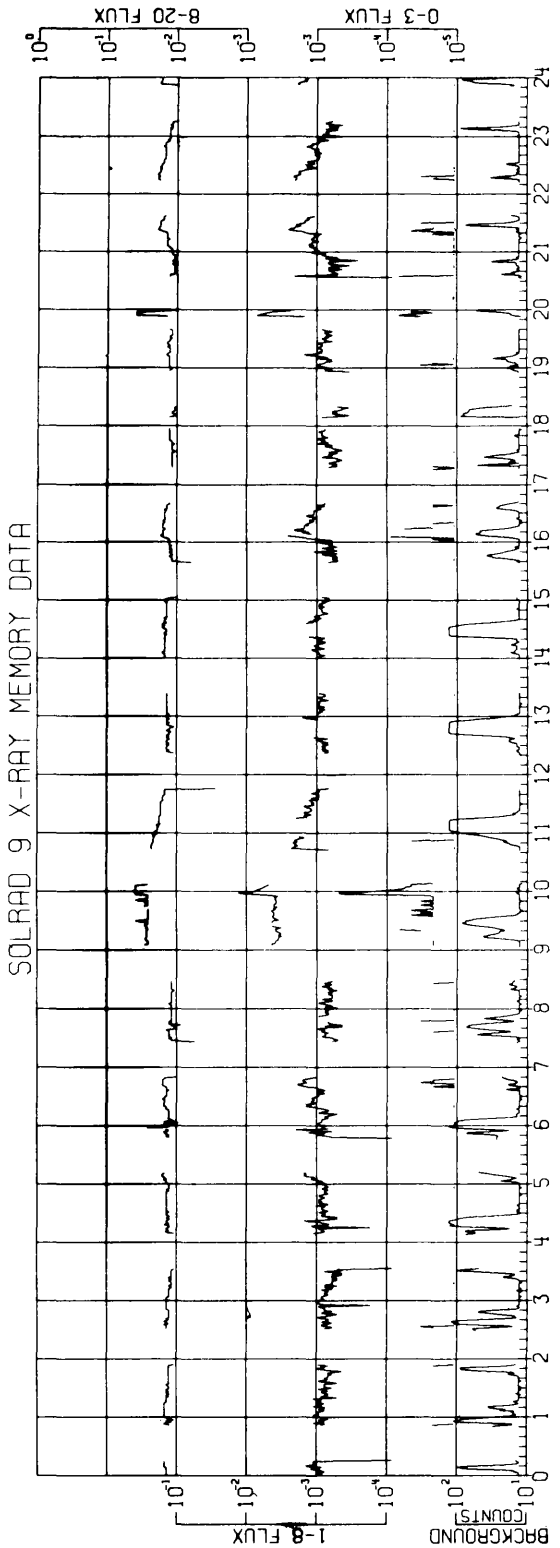

Fig. 2 - Solar x-ray plot for December 22, 1968

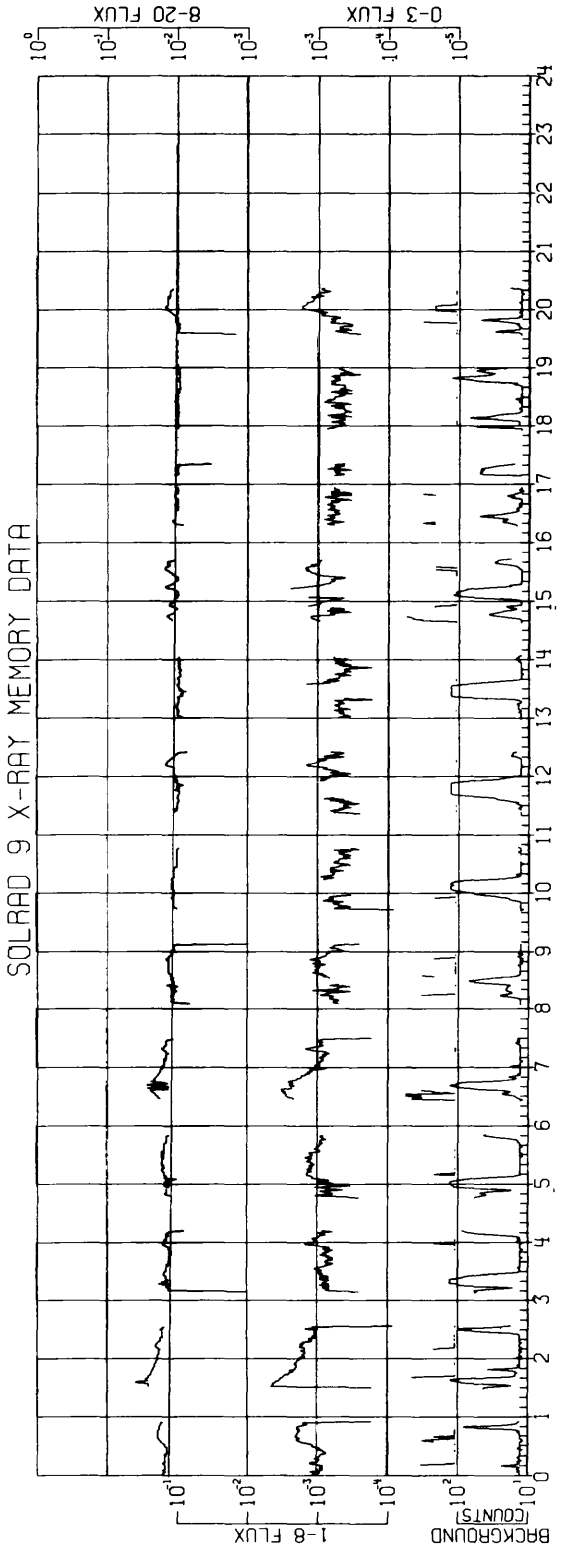

Fig. 3 - Solar x-ray plot for December 23, 1968

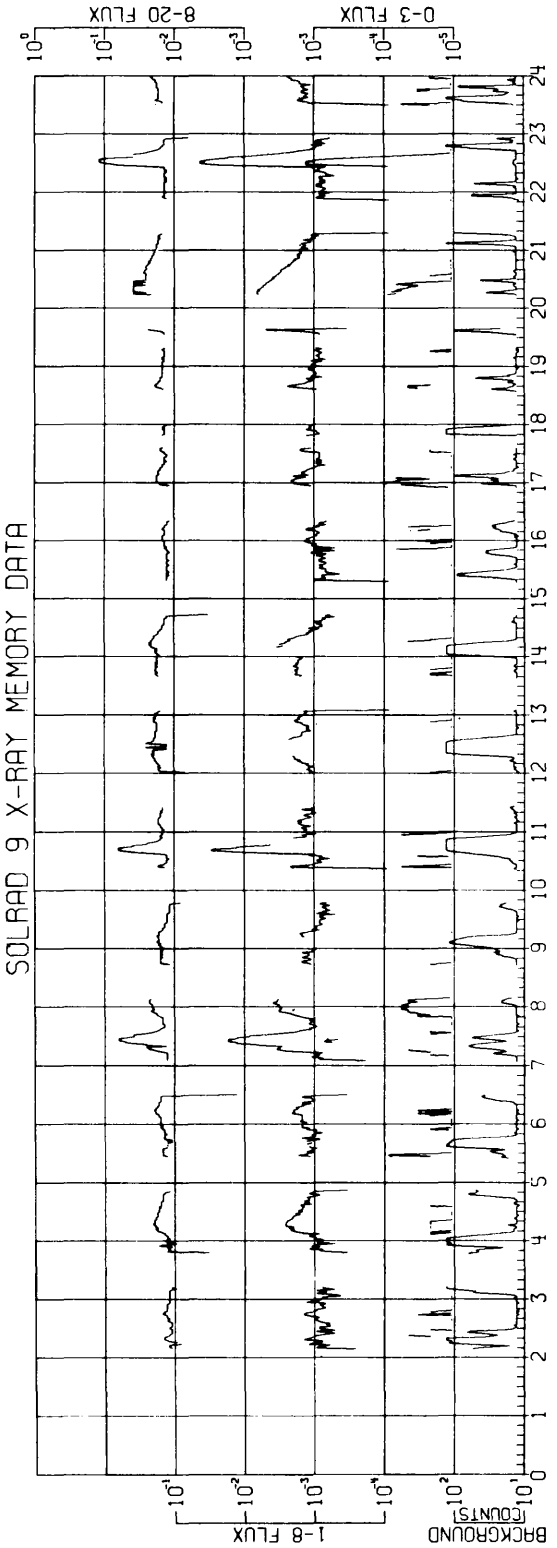

Fig. 4 - Solar x-ray plot for December 24, 1968

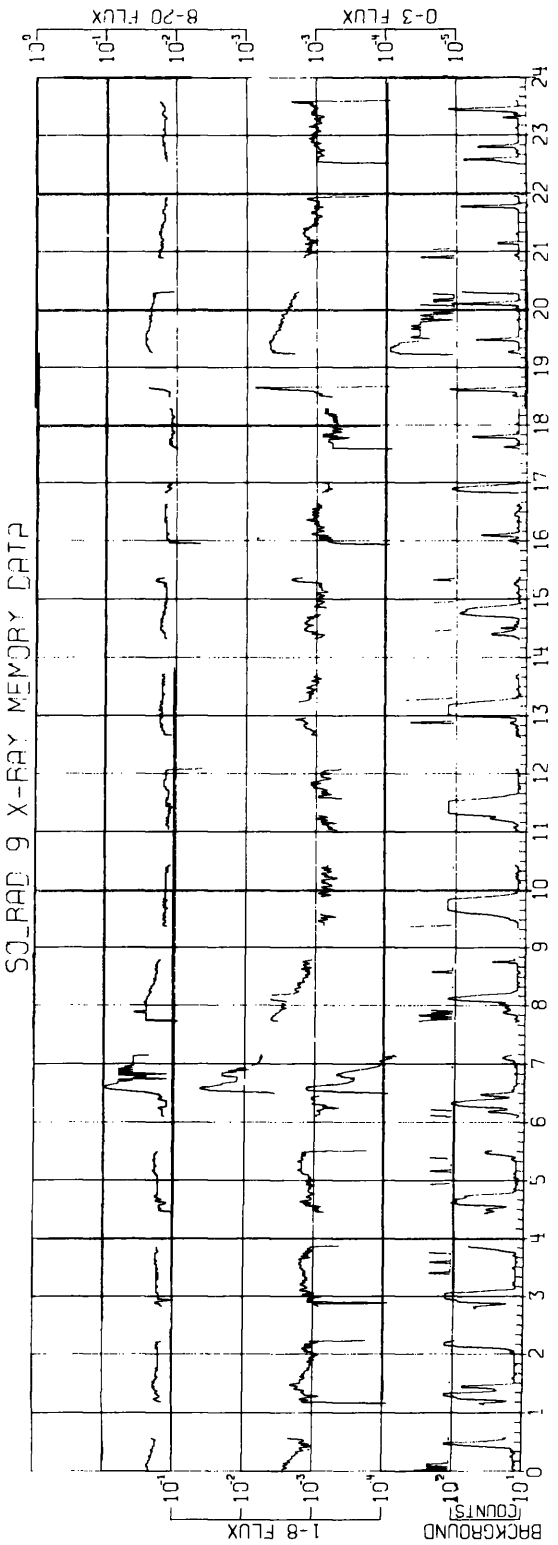

Fig. 5 - Solar x-ray plot for December 25, 1968

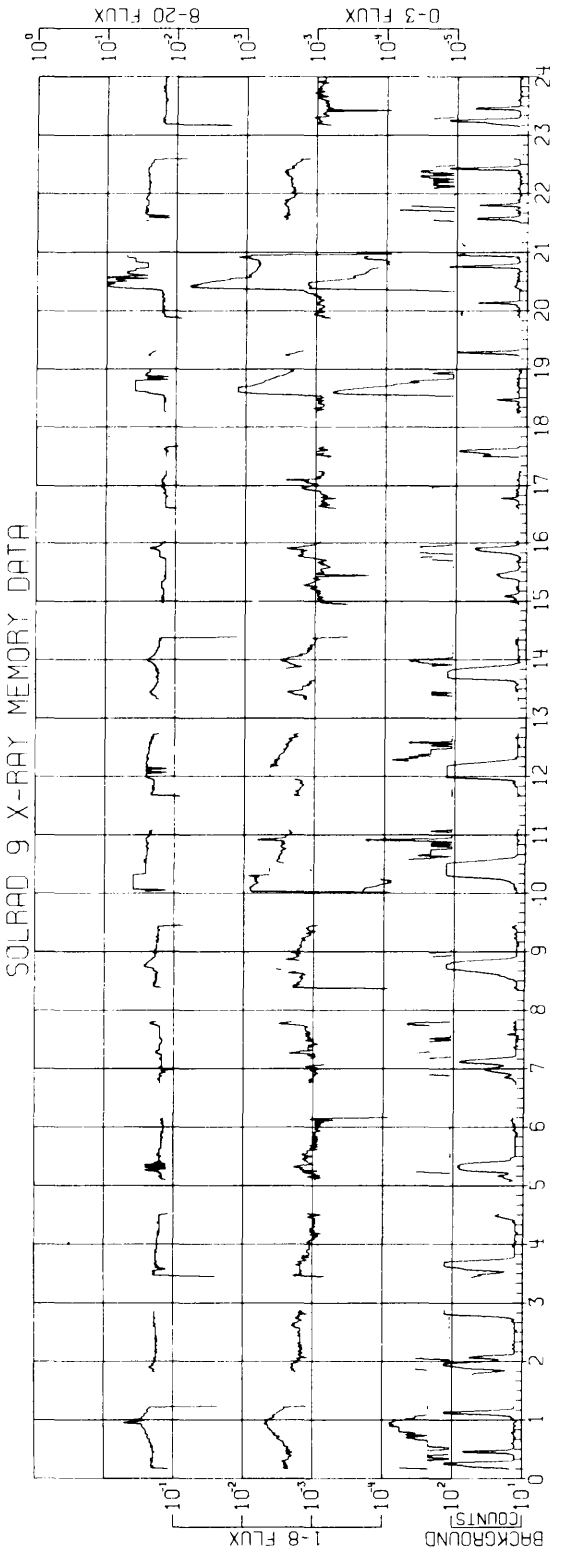

Fig. 6 - Solar x-ray plot for December 26, 1968

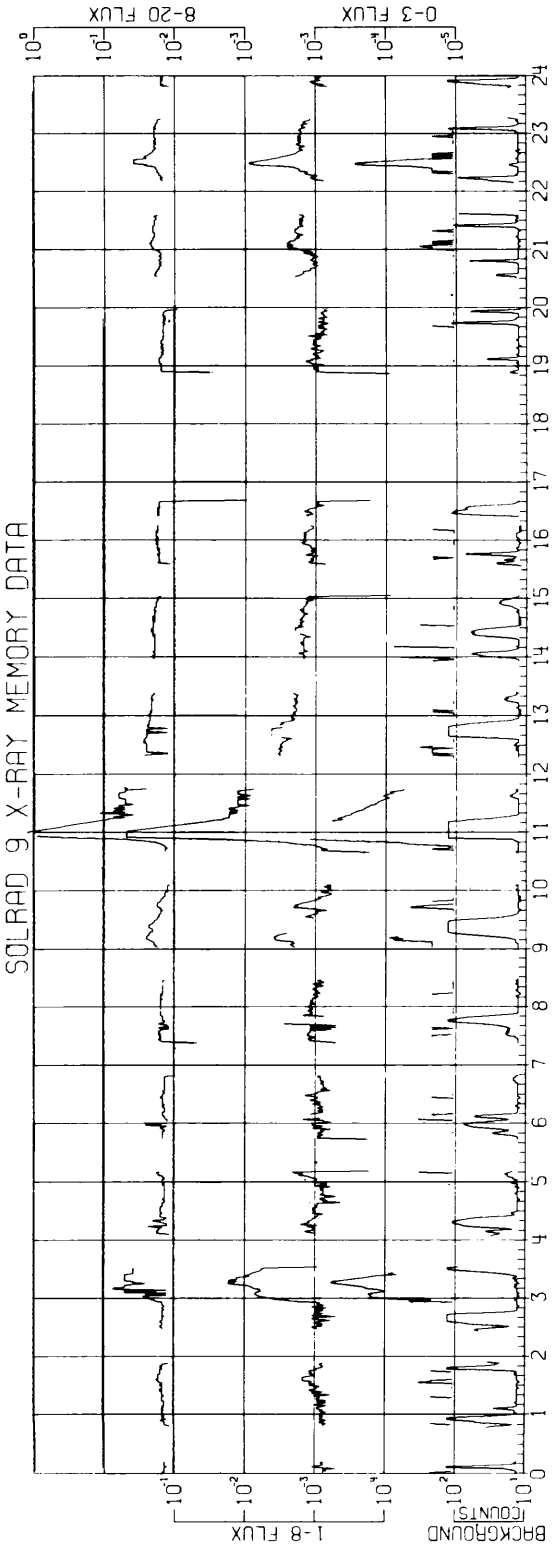

Fig. 7 - Solar x-ray plot for December 27, 1968

Information on flare Class, Region of origin, and particle emission was obtained from Space Disturbance Forecasts of the Space Disturbance Forecast Center, ESSA, Boulder, Colorado; Solar Forecasts of the Solar Forecast Center, NORAD Cheyenne Mountain Complex, Colorado; and "Solar-Geophysical Data," IER-FB-293, January 1969, published by the ESSA Research Laboratories.

CLASSIFYING SOLAR X-RAY EVENTS

At the present time there is no adequate way to classify solar flares according to their x-ray emission. Although a general correlation exists between the x-ray emission and the optical classification of a flare, e.g. 1N, 2F, 3B, the exceptions are of sufficient number to make unreliable any assumptions as to the amount of x-ray emission based on the optical classifications of the flares. The peak flux reached in one or more bands is also inadequate to describe flare x-ray emission, because the use of this parameter alone fails to take into consideration the length of time that high x-ray flux levels are maintained. Therefore, to scale flare x-ray emission in a numerical way for this report, we will use rough calculations of the energy per unit area received in the vicinity of the earth during the course of a solar flare. In making such calculations one assumes a diluted black-body (gray-body) emission spectrum of a certain temperature for the emitting region on the sun. Although the temperature of the emitting region varies from flare to flare, a single temperature will be assumed for all calculations. Therefore, the values obtained must be used as relative indicators of the size of the x-ray event and not as valid measurements of the absolute energy per unit area received in the vicinity of the earth.

Since the x-ray emission in the 0.5 to 3 Å band was generally below the threshold level of our detector (1.1×10^{-5} erg/cm^2-sec) during the initial and final phases of flares, only the 1 to 8 Å and 8 to 20 Å bands were used to compare flare sizes. The color temperature of the emitting solar region was assumed to be 2×10^6 °K. Figure 8, which shows the x-ray emission produced by the 3B flare of October 30, 1968, can be used to demonstrate that it is not important to precisely define the end time of a large flare for energy calculations. Using 2340 UT on October 30 as the starting time and 0612 UT on October 31 as the ending time, we find that in the vicinity of the earth 795 ergs/cm^2 were received for the 1 to 8 Å band and 2860 ergs/cm^2 were received for the 8 to 20 Å band. However, if we use the same starting time but 0500 UT as the ending time, we find 775 ergs/cm^2 for the 1 to 8 Å band and 2670 ergs/cm^2 for the 8 to 20 Å band. Since less than 10% of the total energy was emitted during the final hour, this indicates that a reasonable amount of inconsistency and inaccuracy in defining the end time of a large flare can be tolerated.

Figures 8 through 11 are examples of large x-ray flares which occurred at times when no manned spacecraft were aloft. Included in these examples is the Class 3B flare of July 8, 1968, Fig. 9, which is the largest x-ray event we have noted so far. This event, the Class 2B flare of July 6, 1968, in Fig. 10, and the Class 2B flare of December 27, 1968, in Fig. 7 saturated the 1 to 8 Å detector, and we had to extrapolate the rise and decay curves to estimate the time and flux level of the peaks. Figures 12 and 13 show the largest x-ray flares observed during the flights of Apollo 7 (October 11 through 22, 1968) and the USSR's Soyuz 3 (October 26 through 30, 1968). The event shown in Fig. 13 was actually two distinct Class 2B flares whose peaks were separated by only 52 minutes. Table 1 shows the calculated energy per unit area received in the vicinity of the earth for each of the flares shown in Figs. 8 through 13 plus the three largest x-ray flares observed during the flight of Apollo 8.

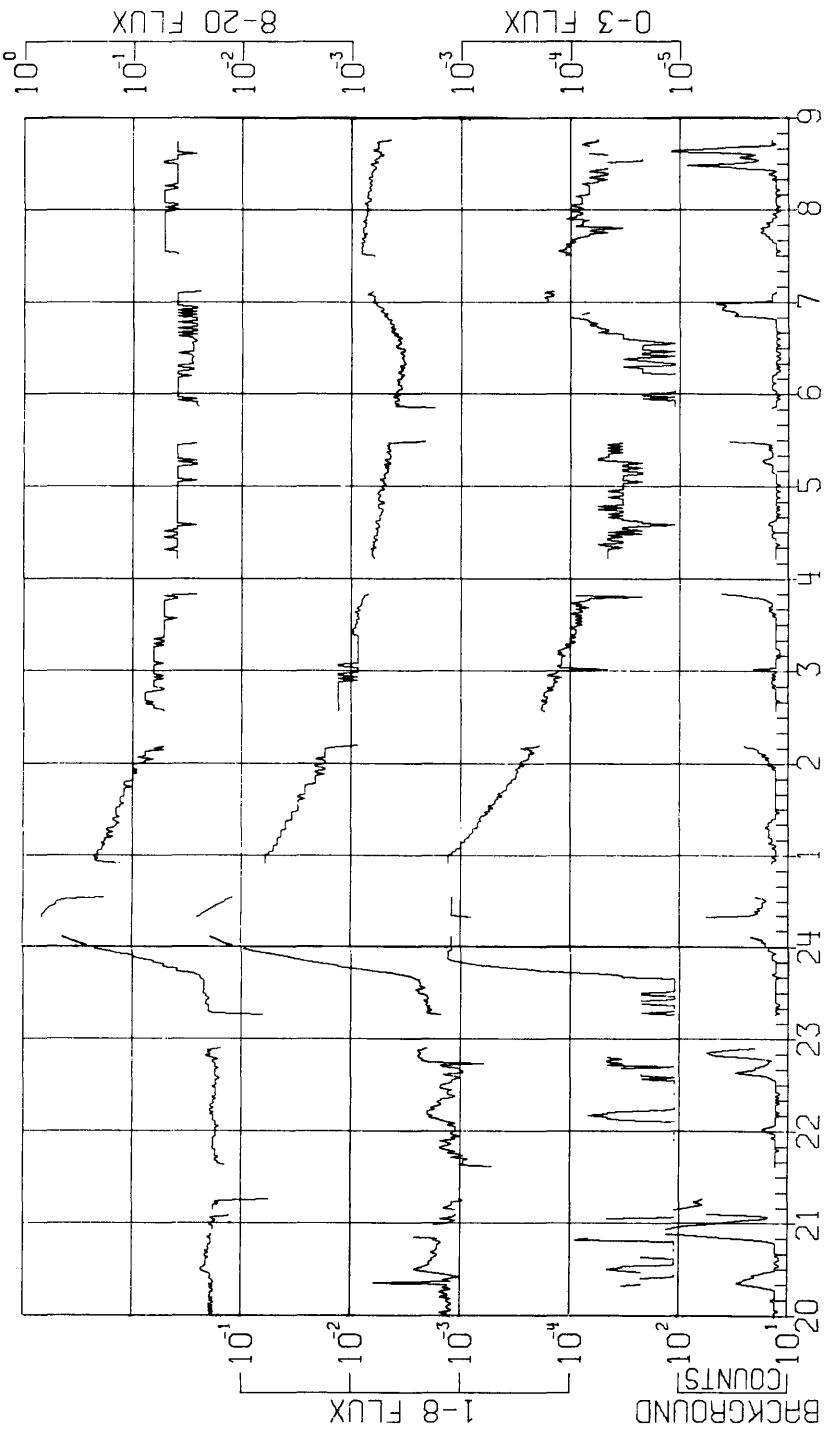

Fig. 8 - X-ray plot of Class 3B flare of October 30, 1968

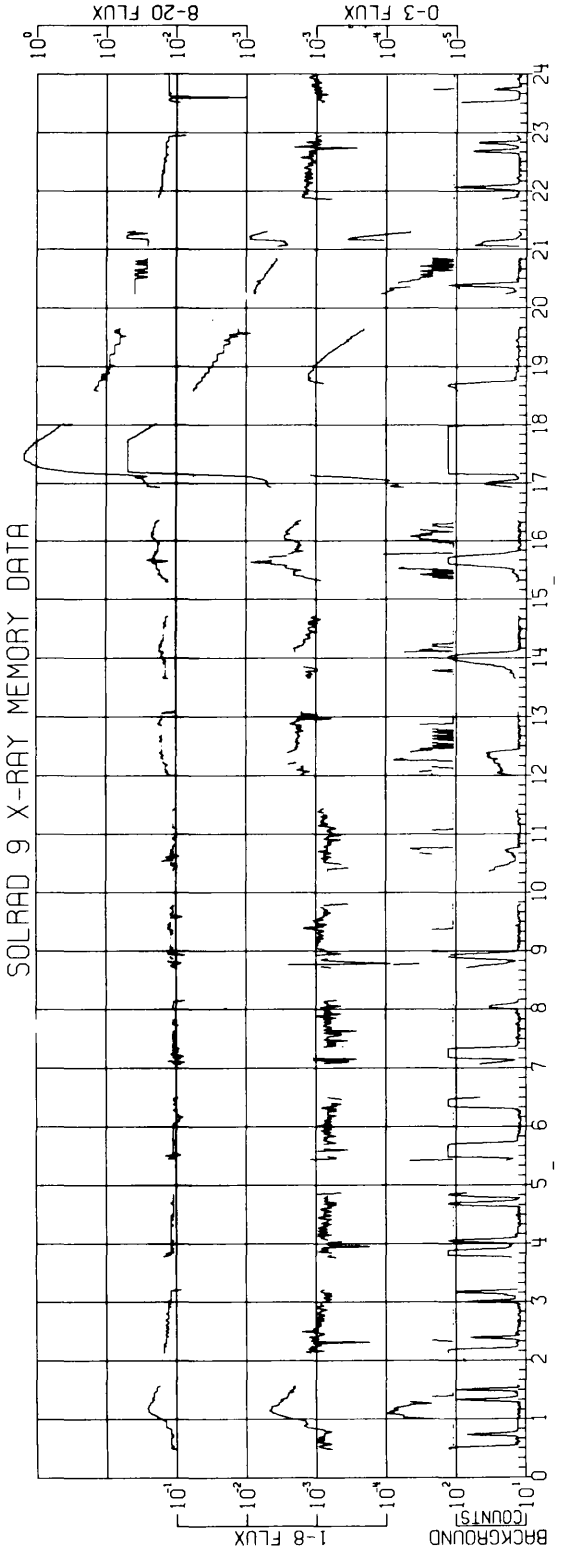

Fig. 9 - X-ray plot of Class 3B flare of July 8, 1968

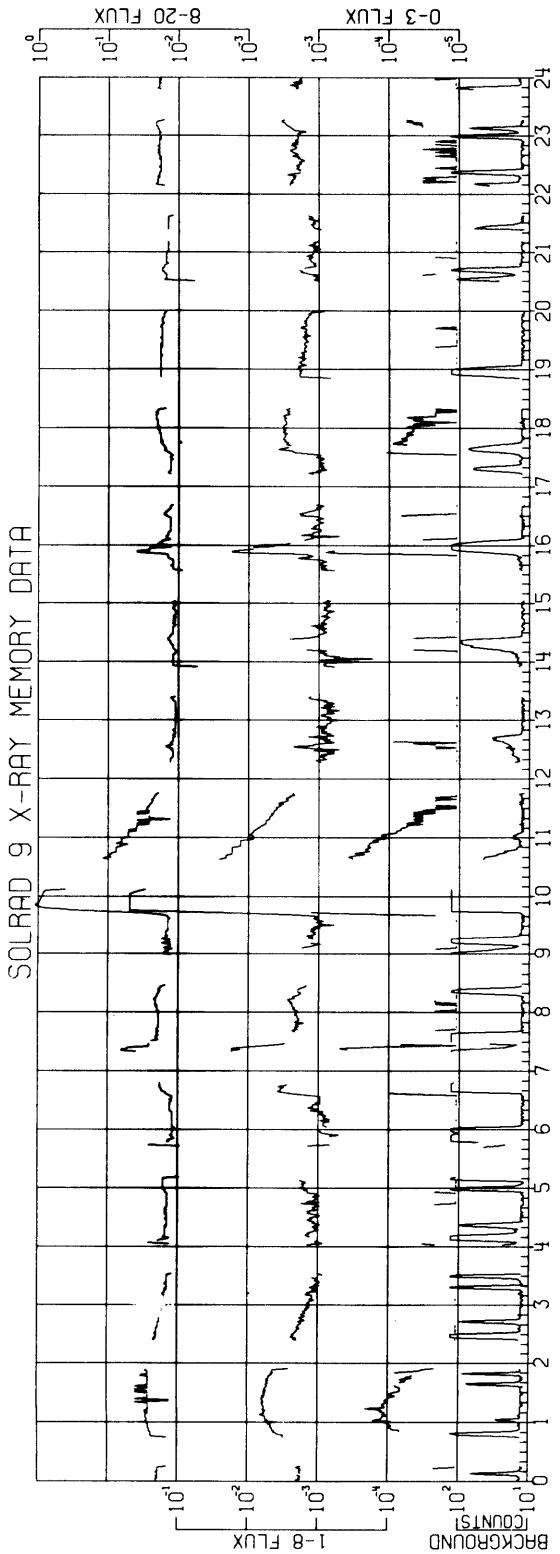

Fig. 10 - X-ray plot of Class 2B flare of July 6, 1968

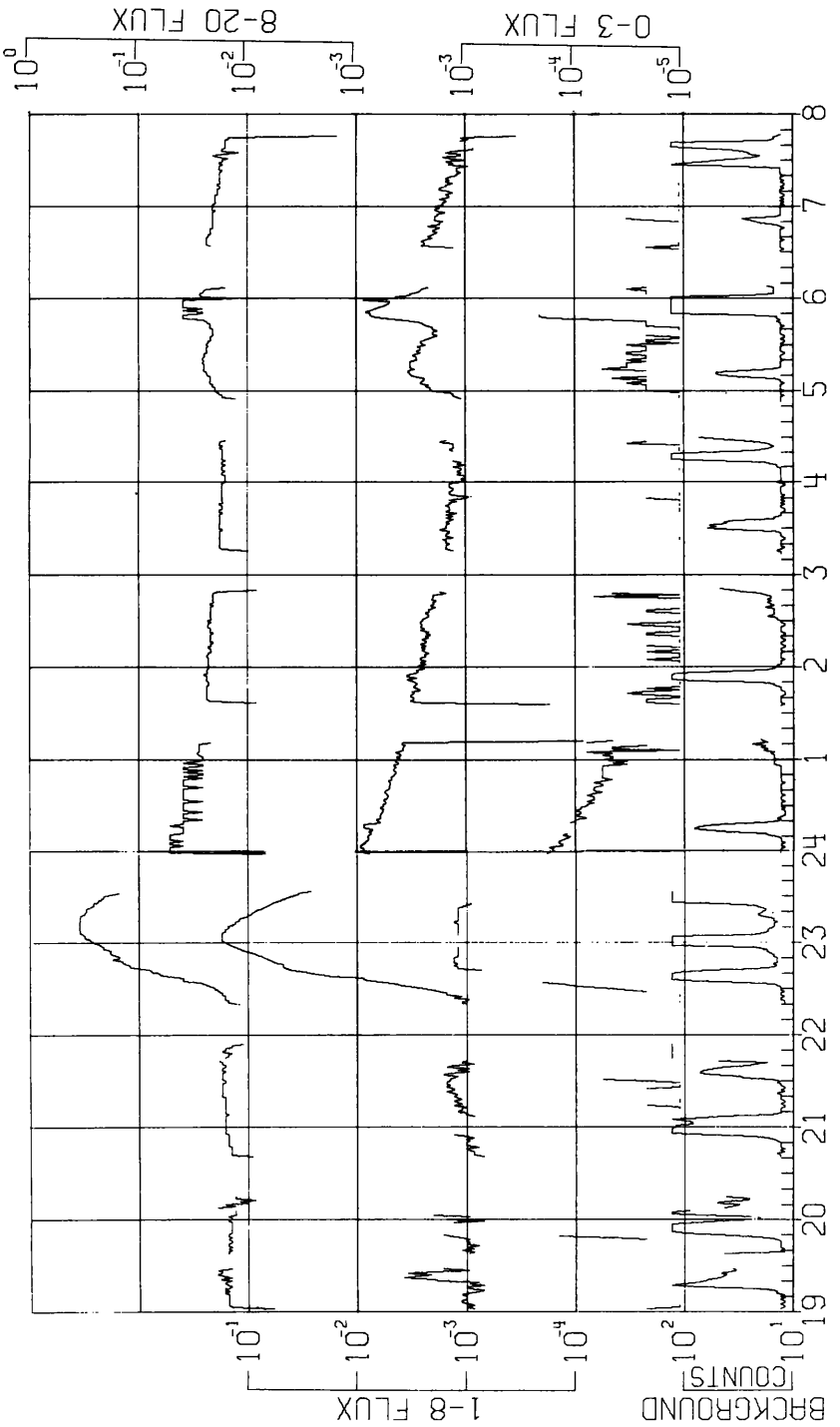

Fig. 11 - X-ray plot of Class 2B flare of October 31, 1968

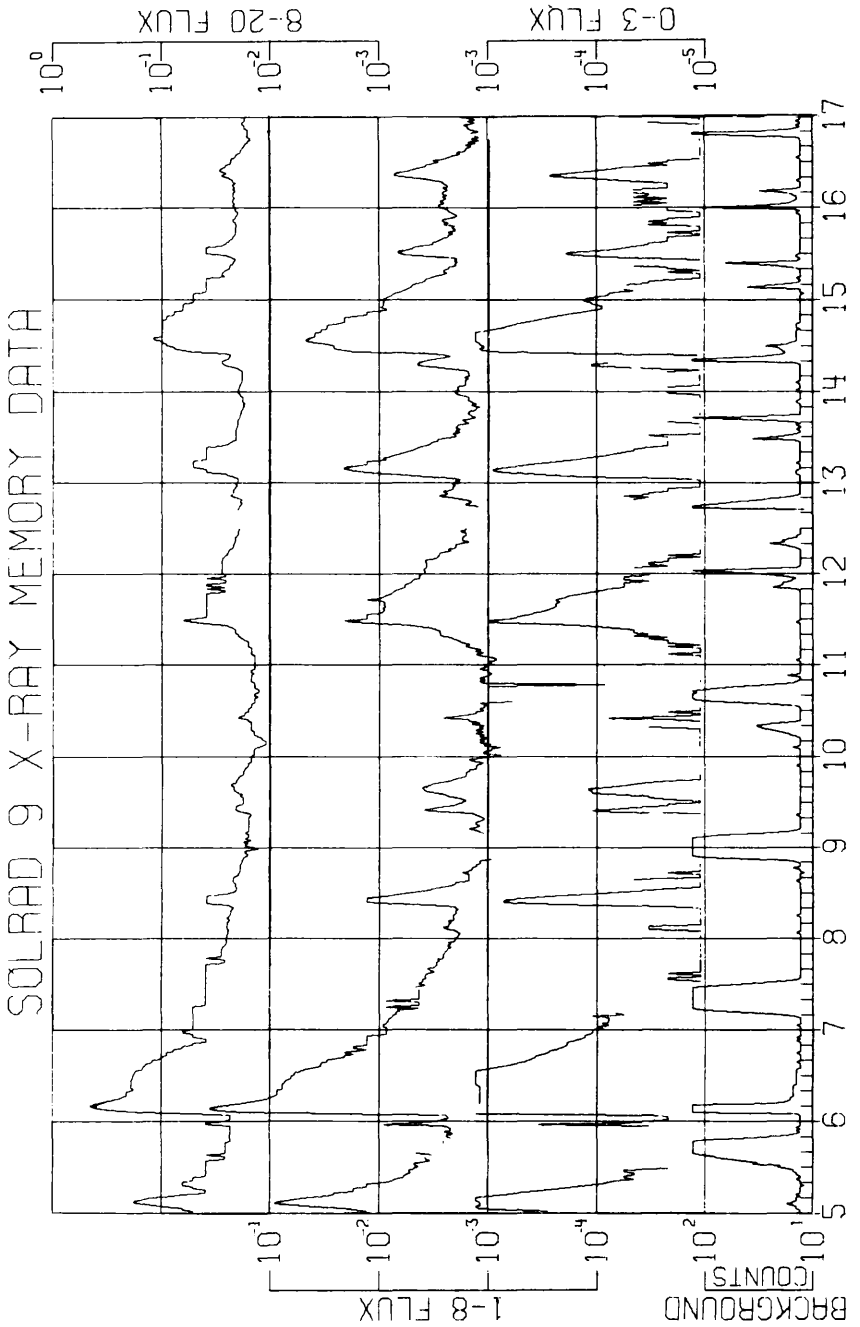

Fig. 12 - X-ray plot of Class 1B flare of October 21, 1968

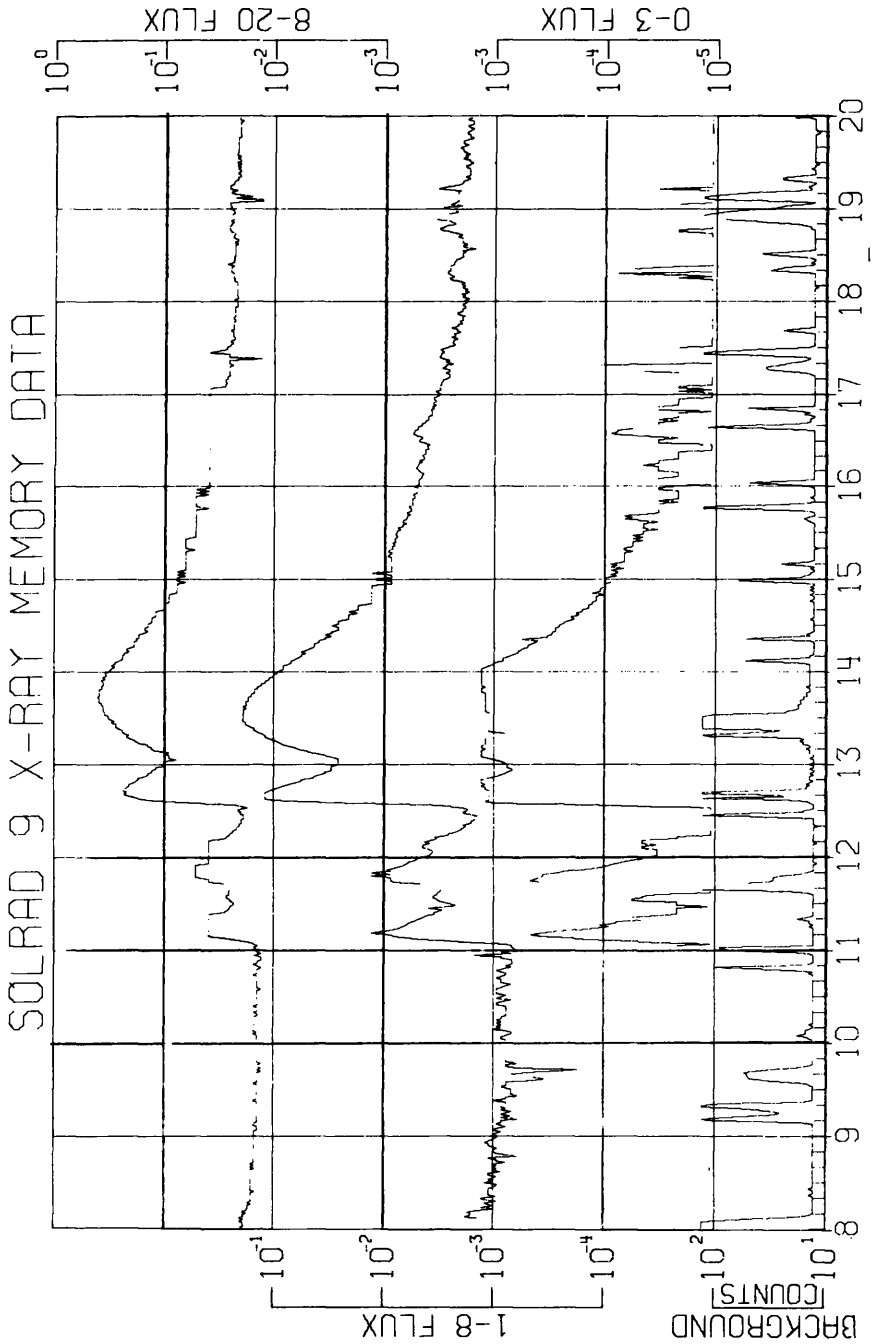

Fig. 13 - X-ray plot of two Class 2B flares of October 27, 1968

Table 1
Energy Received from Large Flares

Start Date	Start Time	End Time	Optical Class	1 to 8 Å (erg/cm^2)	8 to 20 Å (erg/cm^2)	Manned Flight
July 8, 1968	1700	2045	3B	3130*	3660	–
July 6, 1968	0942	1220	2B	2050*	1750†	–
Oct. 30, 1968	2340	0612	3B	795	2860	–
Oct. 27, 1968	1232	1808	2B‡	640	2180	Soyuz 3
Dec. 27, 1968	1047	1315	2B	540*	1070	Apollo 8
Oct. 31, 1968	2227	0400	2B	380	1140	–
Oct. 21, 1968	0605	0802	1B	220	625	Apollo 7
Dec. 25, 1968	0630	0815	1B	60	240	Apollo 8
Dec. 26, 1968	2020	2240	1B	50	285	Apollo 8

*Based on estimated time and flux level for peak due to detector saturation.
†This value is too low, because darkness hides the shape of the initial decay from the peak, and the straight-line approximation is clearly wrong.
‡Two Class 2B flares in succession.

CONCLUSIONS

It is important to note that the large flares presented in Figs. 8 through 11 are just examples and do not exhaust the list of large flares. Therefore, one must not conclude that the flares of October 27 and December 27 rank among the five largest x-ray events ever recorded. But whatever their rank among x-ray events, they are obviously dwarfed by the two events of July 1968. The Class 3B flare of July 8 produced twice as much 1 to 8 Å band energy per unit area in the vicinity of the earth during its 4-hour lifetime than was received by the Apollo 8 spacecraft during its entire 147-hour flight. In addition, the hardening of the emission spectrum during a flare means that there was a disproportionate increase in the number of the higher-energy, more penetrating, photons. When compared to the background x-ray levels, the peak 8 to 20 Å photon flux during the July 8 flare increased by a factor of 10^2, but the peak 1 to 8 Å and 0.5 to 3 Å band photon fluxes both increased by a factor of 10^3. One cannot dismiss the possibility of other flares as large as, or even larger than, those of July 1968 occurring during the most active phase of the solar cycle, which extends over the next year or two.

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13. ABSTRACT

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