The Significant Solar Proton Events in the 20th Solar Cycle for the Period October 1964 to March 1970

W. Atwell

Lockheed Electronics Company

Solar proton data are presented from observations by the IMP 2, 3, F and G satellites. The NASA Solar Particle Alert Network (SPAN) solar optical and radio frequency data for the period May 1967 to March 1970 are associated with the proton events observed by the IMP F and G satellites; however, missing data are supplemented with data recorded at other international observatories. From a radiation hazard standpoint, NASA is concerned with solar proton events of the order of 10^8 proton/cm^2. Radiation dose data are presented for some of the large proton events that have occurred thus far in the 20th solar cycle and are compared with some of the large proton events of the 19th solar cycle. Finally, the results of a simple parametric correlation study are presented for both the 19th and 20th solar cycles.

The author is indebted to Mrs. Louise Lui, who assisted in the reduction and computer analyses of the RF data, and Messrs. M. D. Lopez and J. W. Snyder for many stimulating discussions and helpful suggestions. The author is also appreciative for the IMP 2 and 3 solar proton data from Prof. J. A. Simpson and to Dr. J. H. King, who performed the IMP 2 and 3 time integrations. Additionally, the author is indebted to Messrs. R. Doeker, D. S. Lund and P. S. McIntosh for providing some of the optical data and whose helpful comments were invaluable.

This research was supported by NASA Contract NAS 9-10950.

For more than 25 years it has been known that the sun unpredictably emits copious amounts of high-energy particulate radiation. Since the goal of the Apollo program was to land a man on the moon and return him safely, it was thought that solar radiation might present a hazard. Consequently, in 1967 NASA developed the Solar Particle Alert Network, called SPAN. The SPAN is a worldwide network of solar optical and radio frequency telescopes used to monitor solar activity in real-time. The primary SPAN sites are located at NASA/MSC, Houston, Texas; the National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado; the Canary Islands; and Carnarvon, Australia. Supplemental sites are located at Hawaii, Teheran and Culgoora, Australia. During manned spaceflight missions SPAN observers can provide, via the Manned Space Flight Network (MSFN) communications system, the NASA Flight Safety Office with real-time information concerning impending solar radiation hazards. During non-mission periods the SPAN has provided an almost constant patrol of solar activity. Consequently, a prodigious amount of solar optical and radio frequency data has been collected during the past few years. A more detailed description of the NASA SPAN has been presented by Robbins and Reid (ref. 1).

It is the purpose of this paper to present the solar proton data as observed by the IMP 2 and 3 satellites; to present the solar proton data as observed by the IMP F and G satellites and the associated SPAN solar optical and radio frequency data supplemented with data from other observatories; to present radiation dose data from both the 19th and 20th solar cycles for various Apollo shielding configurations; to present the results of a parametric correlation study for the solar proton events in the 19th and 20th solar cycles; and to conclude with recommendations for enhancing and improving the meaningfulness of the solar data.

SOLAR PROTON EVENTS FOR THE PERIOD OCTOBER 1964 TO APRIL 1967

The IMP 2 and 3 satellites were in earth orbit during the period covered by October 1964 to April 1967. Prof. J. A. Simpson, University of Chicago, had a charged-particle, solid-state detector experiment onboard these two satellites to measure solar protons in the 0.9-190, 6.5-19, 19-90, and 90-190 MeV ranges. Dr. J. H. King, NASA/GSFC, National Space Science Data Center, plotted the 2.4 hr averaged count rates and generated event integrated fluxes at the given energies. He assumed negligible flux above 190 MeV and interpolated to obtain event integrated fluxes above 10, 30 and 60 MeV.

Table 1 shows the solar proton events obtained from this interpolation. During this period 23 major solar proton events were recorded. The start time, time of peak intensity, end time, and event flux are given. The times are given in UT, and the integrated flux units are in proton/cm^2. The events marked by an asterisk are those cases where no significant flux was measured in the 90-190 MeV channel. Consequently, the event integrated fluxes above 30 and 60 MeV were extrapolated and are likely to be less reliable than the interpolated values of the other events (ref. 2).

These data are presented to provide a complete picture of the solar proton emissions from the commencement of the 20th solar cycle (October 1964) through March 1970. It remains to associate the optical and radio frequency data with these events.

Table 1. - IMP 2 and 3 solar proton events.

DATE	5 Feb 65	4 Oct 65	24 Mar 66	29 Apr 66*
E>10 MeV				
Start time	1912	0936	0000	1912
Peak time	0000/06	1424	0448	1912
End time	0712/09	1912/07	0936/07	0448/01
Event flux	5.90E07**	1.50E07	1.25E07	3.02E05
E>30 MeV				
Start time	1912	0936	0000	0712
Peak time	0448/06	1424	0712	1648
End time	0712/09	0712/08	0224/27	0448/01
Event flux	5.25E06	1.60E06	3.20E06	1.02E05
E>60 MeV				
Start time	1912	0936	0000	--
Peak time	2136	1648	0448	--
End time	0000/07	0224/05	0224/25	--
Event flux	1.17E06	4.25E05	9.30E05	1.99E04

Table 1. - IMP 2 and 3 solar proton events (cont'd).

DATE	3 May 66*	25 June 66*	7 July 66	14 July 66*
E>10 MeV				
Start time	0712	1648	0000	0000
Peak time	0936	2136	0936	0936
End time	0448/09	0224/28	0936/12	1648/15
Event flux	3.97E06	6.05E05	9.50E07	4.17E05
E>30 MeV				
Start time	0712	1424	0000	0000
Peak time	0936	2136	1200	0712
End time	0936/09	0224/28	0224/13	0448/16
Event flux	1.35E06	2.05E05	2.15E07	2.14E05
E>60 MeV				
Start time	--	--	0000	--
Peak time	--	--	1200	--
End time	--	--	0000/10	--
Event flux	2.70E05	3.95E04	7.10E06	7.80E04

Table 1. - IMP 2 and 3 solar proton events (cont'd).

DATE	16 July 66*	30 July 66	28 Aug 66	2 Sept 66
E>10 MeV				
Start time	0000/17	0224	1424	0224
Peak time	0712/17	1912/31	2136/29	0936
End time	0936/19	1912/02	0712/02	2136/03
Event flux	1.00E06	1.08E06	6.62E07	3.75E07
E>30 MeV				
Start time	2136	1648	1424	0224
Peak time	0712/17	1912/31	1912	0712
End time	0936/19	1424/01	0712/02	2136/03
Event flux	2.43E05	5.30E05	2.54E07	6.70E06
E>60 MeV				
Start time	--	0712/31	1424	0224
Peak time	--	1912/31	1912	0712
End time	--	1200/01	0712/02	2136/03
Event flux	2.81E04	5.10E05	1.18E07	2.83E06

Table 1. - IMP 2 and 3 solar proton events (cont'd).

DATE	3 Sept 66	13 Sept 66	20 Sept 66*	25 Sept 66*
E>10 MeV				
Start time	2136	0936	1912	1648
Peak time	2136	0448/15	0224/21	1424/26
End time	2136/10	1912/19	0712/24	1648/27
Event flux	3.35E08	2.50E07	8.80E05	3.98E05
E>30 MeV				
Start time	2136	0936	1912	1648
Peak time	0448/05	1648/14	2136	1424/26
End time	2136/10	1912/19	1424/23	1648/27
Event flux	1.10E07	1.07E07	1.49E05	1.48E05
E>60 MeV				
Start time	2136	0936/14	--	--
Peak time	0000/04	0936/15	--	--
End time	1424/04	0936/17	--	--
Event flux	2.60E05	6.25E06	1.00E04	3.36E04

Table 1. - IMP 2 and 3 solar proton events (cont'd).

DATE	27 Sept 66*	11 Jan 67	28 Jan 67	2 Feb 67
E>10 MeV				
Start time	1424	0224	0448	1912
Peak time	1648	0224/12	2136	0712/03
End time	0224/30	1912/13	2136/02	2136/13
Event flux	9.45E05	4.10E06	3.59E08	5.08E08
E>30 MeV				
Start time	1424	0224	0448	1912
Peak time	1648	0448	0936/30	0000/04
End time	0224/30	1912/13	2136/02	2136/13
Event flux	2.01E05	2.90E06	7.10E07	1.02E08
E>60 MeV				
Start time	--	0224	0448	1912
Peak time	--	0224/12	1912/31	1200/03
End time	--	1912/13	2136/02	1912/08
Event flux	1.99E04	2.50E06	2.95E07	3.13E07

Table 1. - IMP 2 and 3 solar proton events (cont'd).

DATE	13 Feb 67*	27 Feb 67	11 Mar 67
E>10 MeV			
Start time	1912	1648	1912
Peak time	0000/14	0000/28	0448/12
End time	1424/18	0712/07	1912/17
Event flux	6.97E06	4.60E07	6.90E07
E>30 MeV			
Start time	1912	1648	1912
Peak time	0936/14	0224/28	0000/12
End time	1424/18	1424/10	1648/19
Event flux	1.39E06	2.87E07	3.21E07
E>60 MeV			
Start time	--	1648	1912
Peak time	--	2136	0712/12
End time	--	1424/02	2136/14
Event flux	1.21E05	1.25E07	9.50E06

*-Events for which the flux in the 90-190 MeV channel was insignificant.

**-Exponential power of 10; 5.90E07 = 5.90×10^7.

SOLAR PROTON EVENTS FOR THE PERIOD MAY 1967 TO MARCH 1970

The IMP F (Explorer 34) satellite was in earth orbit from May 24, 1967, to May 3, 1969. This satellite carried the Solar Proton Monitoring Experiment (SPME) of Bostrom and Williams (ref. 3) and recorded approximately 32 solar proton events. The IMP G (Explorer 41) satellite was placed into earth orbit on June 21, 1969, and is still functioning properly. The IMP G satellite also contains the SPME, and both experiments record protons at the >10, >30, and >60 MeV levels.

The event integrations performed by the author are given in table 2. The table also contains the start time (UT), end time (UT), event duration (hr), peak intensity (proton/cm^2-sec-ster), time of peak intensity (UT), total integrated flux (proton/cm^2), and event integrated flux (proton/cm^2). The peak intensity is the highest hourly counting rate and includes the background flux for that hour.

Table 2. - Explorer 34 and 41 solar proton events.

DATE	23 May 67	28 May 67	6 June 67	2 Nov 67	3 Dec 67
E>10 MeV					
Onset time	2000	0700	0800	1100	1000
End time	0600/28	2400/31	1700/12	1300/04	2200/07
Duration	107	90	137	51	109
Peak intensity	1036	115	20.8	9.42	31.9
Time (peak int.)	1300/25	1100/28	1500	1800	1300
Integrated flux	1.07E09	7.40E07	9.60E07	7.50E06	2.53E07
Background flux	1.69E06	1.42E06	2.48E06	8.08E05	1.97E06
Event flux	1.07E09	7.26E07	9.35E07	6.70E06	2.33E07
E>30 MeV					
Onset time	2000	0700	0800	1100	1000
End time	2400/26	2400/30	1200/09	2 J0/03	2400/06
Duration	77	66	65	38	87
Peak intensity	32.9	27.6	5.55	1.39	11.3
Time (peak int.)	0900/25	1100/28	1500	1700	1300
Integrated flux	2.27E07	2.00E07	2.60E07	1.80E06	9.12E06
Background flux	2.60E06	2.24E06	2.35E06	1.25E06	2.95E06
Event flux	2.01E07	1.78E07	2.36E07	7.50E05	6.17E06
E>60 MeV					
Onset time	2000	0700	0800	no significant flux above background	1000
End time	2300/25	1900/30	1100/08		2400/05
Duration	52	61	52		63
Peak intensity	3.09	10.2	2.13		4.56
Time (peak int.)	0900/25	0800/28	1500		1300
Integrated flux	3.60E06	7.50E06	1.20E07		4.17E06
Background flux	1.76E06	2.07E06	1.88E06		2.14E06
Event flux	1.84E06	5.43E06	1.02E07		2.03E06

Table 2. - Explorer 34 and 41 solar proton events (cont'd).

DATE	16 Dec 67	9 June 67	6 July 68	13 July 68	26 July 68
E>10 MeV					
Onset time	0600	1000	1800	2000/12	1400
End time	2400/22	0900/14	1900/12	1800/17	0800/30
Duration	163	120	146	118	68
Peak intensity	6.45	354	5.33	54.6	0.78
Time (peak int.)	0800/18	0600/10	0200/11	2200	1900
Integrated flux	1.55E07	2.91E08	1.44E07	3.16E07	1.60E06
Background flux	2.95E06	1.63E06	2.11E06	1.71E06	9.84E05
Event flux	1.25E07	2.89E08	1.23E07	2.99E07	6.20E05
E>30 MeV					
Onset time	0600	1000	1800	0200	1300
End time	2400/20	1800/11	2400/11	1100/14	0500/29
Duration	115	75	127	34	65
Peak intensity	2.39	13.1	1.37	1.72	1.07
Time (peak int.)	2100/17	1400	1200/13	2200	1900
Integrated flux	6.39E06	1.12E07	8.28E06	1.41E06	2.29E06
Background flux	3.90E06	2.38E06	4.02E06	1.08E06	2.06E06
Event flux	2.49E06	8.80E06	4.26E06	3.30E05	2.30E05
E>60 MeV					
Onset time	0600	1000	1800	no significant flux above background	1300
End time	0500/19	0500/11	0900/11		2400/27
Duration	72	44	112		36
Peak intensity	1.30	6.13	1.15		0.98
Time (peak int.)	2100/17	1300	1200/07		1700
Integrated flux	3.10E06	3.99E06	4.58E06		1.32E06
Background flux	2.44E06	1.39E06	3.55E06		1.14E06
Event flux	6.60E05	2.60E06	1.03E06		1.80E05

Table 2. - Explorer 34 and 41 solar proton events (cont'd).

DATE	26 Sept 68	29 Sept 68	4 Oct 68	31 Oct 68	1 Nov 68
E>10 MeV					
Onset time	0900	1800	0200	0300	1100
End time	1600/28	0800/03	1600/08	1200/02	1100/04
Duration	57	87	111	57	73
Peak intensity	9.15	31.0	36.5	133	152
Time (peak int.)	1500	2300	0800	1500	0600/02
Integrated flux	6.45E06	2.89E07	3.28E07	6.57E07	1.18E08
Background flux	8.25E05	1.26E06	1.61E06	8.25E05	1.06E06
Event flux	5.62E06	2.76E07	3.12E07	6.49E07	1.17E08
E>30 MeV					
Onset time	1100	1800	0200	0300	1100
End time	2400	0800/02	0800/06	1800/01	0300/03
Duration	14	63	55	41	39
Peak intensity	0.97	19.6	6.93	10.7	12.3
Time (peak int.)	1500	2100	0500	1500	2100
Integrated flux	5.17E05	1.10E07	4.44E06	5.05E06	8.94E06
Background flux	4.24E05	1.91E06	1.49E06	1.11E06	1.06E06
Event flux	9.3E04	9.10E06	2.95E06	3.94E06	7.88E06
E>60 MeV					
Onset time	no significant flux above background	1800	0200	1000	1100
End time		1800/01	0600/05	0600/01	1300/02
Duration		49	29	21	26
Peak intensity		11.0	1.77	2.08	1.66
Time (peak int.)		2000	0400	1500	2000
Integrated flux		5.28E06	1.17E06	9.62E05	1.19E06
Background flux		1.44E06	7.87E05	5.70E05	7.06E05
Event flux		3.84E06	3.80E05	3.92E05	4.80E05

Table 2. - Explorer 34 and 41 solar proton events (cont'd).

DATE	4 Nov 68	18 Nov 68	3 Dec 68	24 Jan 69	25 Feb 69
E>10 MeV					
Onset time	0600	$\sim$1200	1000	0900	1000
End time	2300/07	2400/25	0600/13	2400/25	0700/27
Duration	90	$\sim$180	237	40	44
Peak intensity	19.6	849	152	3.47	88.7
Time (peak int.)	0900	1400	0400/06	1400	1300
Integrated flux	1.15E07	2.04E09	4.85E08	2.38E06	3.74E07
Background flux	1.30E06	2.61E06	2.79E06	5.79E05	6.37E05
Event flux	1.02E07	2.04E09	4.82E08	1.80E06	3.68E07
E>30 MeV					
Onset time	0600	$\sim$1200	1000	0900	1000
End time	0600/06	2400/23	0400/10	0500/25	2000/26
Duration	49	$\sim$132	163	21	35
Peak intensity	5.42	404	31.6	0.85	42.1
Time (peak int.)	0800	1400	0100/06	1100	1200
Integrated flux	3.37E06	4.10E08	3.99E07	6.94E05	1.48E07
Background flux	1.30E06	3.58E06	4.13E06	6.18E05	1.03E06
Event flux	2.07E06	3.54E08	3.58E07	7.60E04	1.38E07
E>60 MeV					
Onset time	0600	$\sim$1200	1000	no significant flux above background	1000
End time	0600/05	1000/21	0700/08		1700/26
Duration	26	$\sim$70	118		31
Peak intensity	2.06	96.7	5.83		24.9
Time (peak int.)	0800	1400	0100/06		1200
Integrated flux	1.16E06	6.54E07	7.85E06		7.69E06
Background flux	7.06E05	1.90E06	2.99E06		9.10E05
Event flux	4.50E05	6.35E07	4.86E06		6.78E06

Table 2. - Explorer 34 and 41 solar proton events (cont'd).

DATE	26 Feb 69	27 Feb 69	12 Mar 69	21 Mar 69	30 Mar 69
E>10 MeV					
Onset time	0700	1600	2000	0700	0400
End time	0900/28	2400/03	1500/15	0400/24	1800/12
Duration	51	105	68	70	327
Peak intensity	11.62	27.67	2.51	4.93	26.3
Time (peak int.)	1200	2200	2100	1800	1800
Integrated flux	9.63E06	2.73E07	2.34E06	5.78E06	7.70E07
Background flux	7.38E05	1.52E06	9.84E05	1.01E06	4.73E06
Event flux	8.89E06	2.58E07	1.36E06	4.77E06	7.23E07
E>30 MeV					
Onset time	0600	1600	2000	0700	0400
End time	1900/27	1100/02	1600/14	0700/23	0200/12
Duration	38	68	45	49	311
Peak intensity	4.72	9.98	1.47	1.14	13.6
Time (peak int.)	1200	2100	2100	1700	1800
Integrated flux	3.68E06	8.39E06	1.69E06	1.80E06	3.77E07
Background flux	1.12E06	2.00E06	1.32E06	1.44E06	9.15E06
Event flux	2.56E06	6.39E06	3.70E05	3.60E05	2.85E07
E 60>MeV					
Onset time	0600	1500	2000	no significant flux above background	0300
Fnd time	1000/27	0700/01	1800/13		2400/08
Duration	29	41	23		238
Peak intensity	2.45	4.34	0.86		9.39
Time (peak int.)	0900	1900	2100		1800
Integrated flux	1.85E06	3.28E06	7.72E05		2.23E07
Background flux	8.53E05	1.21E06	6.56E05		7.00E06
Event flux	1.00E06	2.07E06	1.16E05		1.53E07

Table 2. - Explorer 34 and 41 solar proton events (cont'd).

DATE	10 Apr 69	25 Sept 69	27 Sept 69	2 Nov 69	24 Nov 69
E>10 MeV					
Onset time	1900	0900	1100	1100	1200
End time	1100/28	0700/27	0500/30	0700/09	1000/27
Duration	425	47	67	165	71
Peak intensity	1375	15.2	11.3	1317	3.75
Time (peak int.)	0300/13	1200	0300/28	1400	1700
Integrated flux	2.26E09	6.24E06	1.08E07	7.34E08	3.98E06
Background flux	6.15E06	6.80E05	9.09E05	2.04E06	1.28E06
Event flux	2.25E09	5.56E06	9.90E06	7.32E08	2.70E06
E>30 MeV					
Onset time	0300/11	0900	1100	1100	1200
End time	2400/21	1700/26	1600/28	1600/08	1400/26
Duration	262	33	30	150	51
Peak intensity	123	1.60	0.74	737	1.49
Time (peak int.)	0300/13	1100	0300/28	1300	1500
Integrated flux	2.10E08	1.19E06	8.81E05	2.23E08	2.14E06
Background flux	7.70E06	8.96E05	8.14E05	4.07E06	1.38E06
Event flux	2.02E08	2.90E05	6.70E04	2.19E08	7.6E05
E>60 MeV					
Onset time	0600/11	0900	no significant flux above background	1100	1200
End time	2400/16	2100		2400/05	1000/25
Duration	139	13		86	23
Peak intensity	16.7	0.68		201	0.86
Time (peak int.)	0300/13	1100		1300	1500
Integrated flux	2.64E07	3.57E05		4.10E07	7.28E05
Background flux	4.28E06	3.23E05		2.14E06	6.24E05
Event flux	2.21E07	3.40E04		3.89E07	1.04E05

Table 2. - Explorer 34 and 41 solar proton events (cont'd).

DATE	7 Mar 70	23 Mar 70	29 Mar 70
E>10 MeV			
Onset time	1900	1900	0200
End time	1700/10	1500/26	2400/06
Duration	71	69	215
Peak intensity	93.54	8.18	66.0
Time (peak int.)	0300/08	2200	1900
Integrated flux	5.72E07	6.52E06	8.38E07
Background flux	1.03E06	1.25E06	4.38E06
Event flux	5.62E07	5.27E06	7.94E07
E>30 MeV			
Onset time	1800	1900	0200
End time	1900/08	0500/25	0200/05
Duration	26	35	171
Peak intensity	1.52	2.09	20.8
Time (peak int.)	2400	2200	1900
Integrated flux	1.09E06	1.64E06	3.13E07
Background flux	6.82E05	1.03E06	5.03E06
Event flux	4.13E05	6.10E05	2.63E07
E>60 MeV			
Onset time	no significant flux above backgrnund	1900	0200
End time		1100/24	0200
Duration		17	97
Peak intensity		0.81	7.05
Time (peak int.)		2100	1900
Integrated flux		5.27E05	1.13E07
Background flux		4.61E05	2.63E06
Event flux		6.60E04	8.7E06

Table 2. - Explorer 34 and 41 solar proton events (cont'd).

DATE	18 Dec 69	20 Dec 69	29 Jan 70	31 Jan 70	6 Mar 70
E>10 MeV					
Onset time	1700	0400	1400	1700	1500
End time	1800/19	1200/22	1500/31	1200/04	0800/08
Duration	26	57	50	92	42
Peak intensity	1.84	8.86	4.66	24.5	7.76
Time (peak int.)	2000	0400	2400	2400	0200/07
Integrated flux	1.17E06	4.48E06	3.89E06	2.13E07	5.09E06
Background flux	3.53E05	7.74E05	6.79E05	1.25E06	6.08E05
Event flux	8.20E05	3.71E06	3.21E06	2.00E07	4.48E06
E>30 MeV					
Onset time	1700	0200	1400	1700	1500
End time	1300/19	1100/21	1500/31	2400/02	1800/07
Duration	21	34	50	56	28
Peak intensity	1.81	2.47	2.61	6.86	0.94
Time (peak int.)	2000	0300	2400	2100	1900
Integrated flux	1.03E06	1.64E06	2.69E06	5.06E06	9.60E05
Background flux	5.70E05	9.23E05	1.36E06	1.52E06	7.08E05
Event flux	4.60E05	7.20E05	1.33E06	3.54E06	2.52E05
E>60 MeV					
Onset time	1700	0200	1400	1700	no significan flux above background
End time	1200/19	1500	1400/30	2400/01	
Duration	20	14	25	32	
Peak intensity	1.12	1.17	1.26	2.35	
Time (peak int.)	2000	0200	2400	2000	
Integrated flux	6.95E05	4.86E05	1.07E06	1.63E06	
Background flux	4.98E05	3.48E05	6.22E05	7.96E05	
Event flux	1.97E05	1.38E05	4.50E05	8.30E05	

THE SOLAR OPTICAL PARAMETERS ASSOCIATED WITH THE IMP F AND G OBSERVATIONS

The solar optical parameters associated with the solar proton events observed by the IMP F and G satellites are shown in table 3. The optical parameters listed are the proton event date (the superscripts refer to the reporting station where the letter G is grouped data from several stations as reported in Solar-Geophysical Data (ref. 3), 1 is the NASA/MSC site, 2 is the Canary Islands site, and 3 is the Carnarvon, Australia site), the Mt. Wilson calcium plage area and intensity (10^{-6} of the solar disk), sunspot area (10^{-6} of the solar disk), flare start and end times (UT), flare duration (min), flare maximum (UT), flare importance, flare area either measured (m) or corrected (c) in sq deg, the heliographic location, and the McMath plage region number. The optical parameters and the IMP proton data were obtained from the Solar-Geophysical Data (ref. 3), although Mr. P. S. McIntosh provided some of the calcium plage and sunspot data.

Table 3. - Solar optical parameters

DATE	PLAGE AREA	PLAGE INT.	SUNSPOT AREA	FLARE START	FLARE END	FLARE DURATION	FLARE MAX.	FLARE IMP.	FLARE AREA	LOCATION	McMATH REGION
1967											
23 May[aG]	10000	4.0	1820*	1803	2300	297	1844	3B	18.0_c	N28 E26	8818
28 May[G]	10000	4.0	1050*	0527	0712	105	0546	3B	13.11_m	N28 W33	8818
6 June[G]	2200	3.5	70	1846	2030	104	1937	2N	4.84_m	S18 W58	8824
2 Nov[G]	6900	3.5	110*	0855	0916	21	0859	1B	4.66_m	S18 W02	9047
3 Dec	No logical flare association - probably occurred behind the west limb										
16 Dec[G]	9100	3.0	230	0247	0446	119	0256	2N	5.47_m	N23 E66	9118
1968											
9 June[3]	3200	3.0	70	0843	0920	37	0854	3B	21.8_c	S16 W06	9429
6 July[G]	8000	3.5	1000	0946	1029	43	0956	1N	1.47_m	N14 E89	9503
13 July[G]	3200	3.0	160	1341/12	1522/12	101	1415/12	2N	5.97_m	N11 W21	9499
26 July	No logical flare association										
26 Sept[G]	5300	3.0	300	0026	0105	39	0031	2B	4.76_m	N14 E35	9687
29 Sept[1]	4300	3.0	100*	1618	1657	39	1623	2B	10.1_c	N16 W52	9678
4 Oct[G]	3700	2.5	230	2348/03	0330	222	0008/04	2B	6.38_m	S16 W37	9692
31 Oct[G]	7000	4.0	1070*	2339/30	0133	114	0013	3B	19.48_m	S14 W37	9740
1 Nov[3]	5600	3.5	1000*	0835	0930	55	0842	1B	5.00_c	S17 W49	9740
4 Nov[3]	3000	3.5	710*	0524	0606	42	0529	1B	4.80_c	S14 W90	9740

a - This flare included three flares that occurred in a close time proximity (ref. 4)
* - Complex sunspot group (ref. 5)
G,1,3 - observing station code; see text

Table 3. - Solar optical parameters(cont'd)

DATE	PLAGE AREA	PLAGE INT.	SUNSPOT AREA	FLARE START	FLARE END	FLARE DURATION	FLARE MAX.	FLARE IMP.	FLARE AREA	LOCATION	McMATH REGION
1968											
18 Nov[G]	3200	3.5	650	1026	1235	129	1058	1B	1.66_m	N20 W90	9760
3 Dec[G]	3600	2.5	150	2116/02	2350/02	154	2202/02	3N	3.71_m	N18 E80	9802
1969											
24 Jan[G]	6300	3.0	60	0803	0926	83	0811	2B	9.23_m	N20 W09	9879
25 Feb[3]	8700	3.5	640*	0909	0949	40	0913	2N	9.40_c	N11 W38	9946
26 Feb[3]	10000	3.5	670*	0422	0441	19	0426	2B	8.80_c	N14 W46	9946
27 Feb[G]	10000	4.0	260*	1352	1511	79	1415	2B	4.25_m	N13 W65	9946
12 Mar[G]	3800	3.5	270*	1738	1807	29	1744	2B	4.06_m	N12 W80	9966
21 Mar[G]	28000	3.5	1730*	0141	0330	109	0154	2N	6.80_m	N19 E16	9994
30 Mar[b]	11000	4.0	1000*	~0332	0400	?	?	1N	2.60_c	N19 W90	9994
10 Apr[bb]	7000	3.0	120	0410	0445	35	0414	1N	0.52_c	N11 E90	10035
25 Sept[3]	3800	2.0	0	0709	0815	66	0730	2N	8.50_c	N13 W16	10326
27 Sept[G]	4800	3.5	60	0347	0545	118	0412	3B	10.45_m	N09 E02	10333
2 Nov[G]	4500	3.0	1070*	1102	1220	78	1138	1B	0.97_m	N16 W90	10385
24 Nov[3]	14000	3.0	530*	0913	1000	47	0918	2B	10.60_c	N16 W32	10432
18 Dec	No logical flare association										
20 Dec	No logical flare association										

b - An unconfirmed flare reported by Manila observatory
bb - An unconfirmed flare reported by Mitaka, Japan observatory

Table 3. - Solar optical parameters(cont'd)

DATE	PLAGE AREA	PLAGE INT.	SUNSPOT AREA	FLARE START	FLARE END	FLARE DURATION	FLARE MAX.	FLARE IMP.	FLARE AREA	LOCATION	McMATH REGION
1970											
29 Jan[7]	5100	3.5	820*	0932	0939	7	0932	1N	2.10_c	S12 W45	10542
31 Jan[1]	5100	3.5	770	1516	1630	74	1533	2B	11.1_c	S26 W62	10542
6 Mar	6200	4.0	160	0926	?	?	?	3B	?	N09 W90	10595
7 Mar[8]	8300	3.5	490	1601	1635	34	1610	2N	6.50_c	S13 E42	10618
23 Mar[1]	1800	4.0	100	1545	1600	15	1545	-F(?)	1.60_c	N18 W61	10638
29 Mar[3]	8700	5.0	150	0009	0225	136	0048	2N	10.72_c	N14 W36	10641

7 - Uccle Royal Observatory, Brussels, Belgium
8 - NOAA, Boulder, Colo.

THE SOLAR RADIO FREQUENCY PARAMETERS ASSOCIATED WITH THE IMP F AND G OBSERVATIONS

The solar radio frequency parameters associated with the solar proton events observed by the IMP F and G satellites are shown in table 4. The RF parameters listed are the proton event date (the superscripts refer to the reporting station, where 1, 2, and 3 are the same SPAN observatories as given in table 3, 4 and 5 are the ARCRL Sagamore Hill and Manila stations, respectively, and were obtained from refs. 3 and 6), the peak RF intensity and background flux (10^{-22} W/m^2-Hz), the time-integrated RF burst energy (10^{-18} J/m^2-Hz), and the energy-to-peak ratio (sec) at the three fixed frequencies of 1415, 2695 and 4995 MHz.

RADIATION DOSES FOR THE LARGE PROTON EVENTS

Webber (ref. 7) assumed that an exponential rigidity spectrum best described the solar proton event and generated flux equations based on particle rigidity P. For energies greater than 30 and 60 MeV, the characteristic rigidity, P_0, is given by

$$P_0 = \frac{242.89}{\ln\left(\frac{\Phi(E>30MeV)}{\Phi(E>60MeV)}\right)}, \text{ MV},$$

where $\Phi(E>30MeV)$ and $\Phi(E>60MeV)$ are the time-integrated proton fluxes having energies greater than 30 and 60 MeV, respectively. A similar equation is obtained for protons with energies greater than 10 and 30 MeV:

$$P_0 = \frac{195.78}{\ln\left(\frac{\Phi(E>10MeV)}{\Phi(E>30MeV)}\right)}, \text{ MV},$$

where $\Phi(E>10MeV)$ and $\Phi(E>30MeV)$ are the time-integrated proton fluxes having energies greater than 10 and 30 MeV, respectively.

Table 4. - Solar radio frequency parameters

	1415 MHz				2695 MHz				4995 MHz			
DATE	PEAK INT.	BKGD.	ENERGY	ENERGY/PEAK	PEAK INT.	BKGD.	ENERGY	ENERGY/PEAK	PEAK INT.	BKGD.	ENERGY	ENERGY/PEAK
1967												
23 May[4]	85100 (1954)	102	1104.03	0.0130	5400 (1952)	220	513.08	0.0916	9858 (1948)	302	828.82	0.0841
28 May[3]	1540 (0543)	139	50.82	0.0330	1772 (0542)	223	70.44	0.0398	4691 (0545)	339	164.53	0.0351
6 June[4]	69.1 (?)				115.6 (?)				164 (?)			
2 Nov[3]	587 (0857)	96	4.81	0.0082	685 (0856)	120	2.60	0.0038	1080 (0856)	210	2.57	0.0024
3 Dec	No RF burst reported											
16 Dec[3]	200 (0252)	110	7.08	0.0354	320 (0252)	154	9.96	0.0311	440 (0252)	258	10.96	0.0249
1968												
9 June[2]	1022 (0849)	152	19.42	0.0190	986 (0851)	148	30.79	0.0312	3024 (0851)	352	53.67	0.0177
6 July[2]	415 (0946)	91	10.67	0.0257	831 (0945)	104	22.59	0.0272	2516 (0949)	189	61.64	0.0245
13 July[2]	269 (1357/12)	108	1.26	0.0047	331 (1357/12)	149	1.25	0.0038	317 (1357/12)	230	0.66	0.0021
26 July	No RF burst reported											
26 Sept[5]	839 (0031)	0	14.38	0.0171	353 (0033)	0	6.57	0.0186	699 (0030)	0	14.46	0.0207
29 Sept[1]	358 (1620)	106	9.10	0.0254	796 (1622)	152	22.09	0.0278	2112 (1621)	91	39.74	0.0188
4 Oct[5]	229 (0043)				108 (0000)				57 (0005)			
31 Oct[3]	935 (0013)	119	78.91	0.0844	2187 (0011)	154	183.6	0.0840	3370 (0011)	268	172.41	0.0512
1 Nov[3]	1138 (0915)	116	98.69	0.0867	2603 (0913)	161	242.44	0.0914	3487 (0912)	272	285.79	0.0820
4 Nov[3]	463 (0517)	94	5.28	0.1140	1141 (0520)	151	31.33	0.0275	5652 (0523)	369	145.59	0.0258
18 Nov[2]	1097 (1031)	101	25.62	0.0234	1449 (1030)	129	65.52	0.0452	1655 (1030)	223	142.81	0.0863
3 Dec[5]					270 (2116/02)	0	7.52	0.0279				
1969												
24 Jan[5]	158 (0721)	0	10.11	0.0640	176 (0721)	0	11.83	0.0672	185 (0720)	0	7.83	0.0423
25 Feb[3]	5314 (0913)	129	35.66	0.0067	2557 (0912)	223	46.79	0.0183	4950 (0912)	300	105.63	0.0213
26 Feb[3]	779 (0425)	140	14.99	0.0192	1268 (0425)	205	25.42	0.0200	2828 (0425)	334	52.25	0.0185
27 Feb[1]	467 (1409)	92	9.94	0.0213	1369 (1409)	249	32.38	0.0237	1853 (1410)	399	53.64	0.0289
12 Mar[1]	No data				2387 (1740)	146	24.48	0.0103	2329 (1741)	376	40.99	0.0176
21 Mar[3]	528 (0153)	168	17.95	0.0340	963 (0154)	259	33.93	0.0352	2060 (0153)	411	49.02	0.0238
30 Mar[3]	5793 (0250)	68	75.88	0.0131	10845 (0250)	95	90.79	0.0084	24733 (0249)	194	140.49	0.0057
10 Apr[3]	216 (0358)	112	3.2	0.0148	408 (0357)	128	8.35	0.0205	840 (0400)	183	24.54	0.0292
25 Sept	No RF burst reported											
27 Sept[5]	98 (0401)	0	4.64	0.0473	106 (0357)	0	2.46	0.0232	86 (0426)	0	9.37	0.1090
2 Nov[2]	697 (1043)	101	52.55	0.0754	1543 (1041)	138	157.88	0.1023	1455 (1041)	229	146.45	0.1007
24 Nov[2]	1420 (0918)	108	30.18	0.0213	2031 (0918)	173	53.68	0.0264	3378 (0925)	244	84.89	0.0251
18 Dec[4]	335 (1514)	0	14.57	0.0435	70 (1515)	0	?	?	30.8 (1517)	0	?	?
20 Dec	No RF burst reported											
1970												
29 Jan[3]	619 (0932)	115	0.59	0.0010	278 (0932)	161	0.51	0.0018	524 (0932)	254	1.11	0.0021
31 Jan[4]	15.5 (1516)				23.2 (1554)				46.4 (1556)			
6 Mar[3]	169 (0934)	135	0.21	0.0012	1034 (0934)	174	1.03	0.0010	413 (0934)	253	1.20	0.0029
7 Mar[4]	105 (1607)				110 (1607)				145 (1607)			
23 Mar[4]	28.8 (1547)				30 (1547)				93 (1550)			
29 Mar[3]	1400 (0040)	129	56.48	0.0403	1592 (0041)	178	86.48	0.0543	4062 (0041)	294	165.85	0.0408

Table 5 shows the characteristic rigidities computed for the 20th solar cycle proton events.

Hardy (ref. 8) has generated curves for the normalized proton dose versus characteristic rigidity for various Apollo shielding configurations. Table 6 shows the radiation (skin) doses for some of the large solar proton events that occurred during the 19th and 20th solar cycles. It must be emphasized that the doses listed are accumulated over the entire event duration, which can vary from several hours to several days. However, the dose rates at the event peak may be quite high.

The proton events for which the integrated flux is in the 10^5 to 10^7 range should be considered significant and are of interest to some medical people. Radiobiological effects vary with the individuals exposed, and knowledge and understanding in this area are still somewhat limited. It is for this reason that the possible radiation threat must be considered by mission planning and hardware design personnel for space missions such as advanced lunar exploration, lunar bases, and interplanetary travel.

CORRELATION OF THE SOLAR OPTICAL AND RADIO FREQUENCY PARAMETERS

Several of the optical and radio frequency parameters given in tables 3 and 4 were correlated with the event fluxes for E>30MeV and were compared with similar correlations generated from solar data presented by Gonzalez and Divita (ref. 9) and Lopez (ref. 10). Table 7 shows the correlation coefficient for the various solar parameters for the proton events of the 19th and first half of the 20th solar cycles. The correlation coefficients for the optical data for both solar cycles are not very impressive. In fact, negative coefficients were obtained for three of the four 20th cycle optical parameters. The importance of optical solar observations cannot be over emphasized, but utilization of the optical parameters for solar proton prediction should be made only to monitor active regions and to locate the proton source from proton emitting flares.

The correlation coefficients generated from the 19th cycle RF data are reasonably good. Using a 95% confidence limit, Gonzalez and Divita (ref. 9) obtained a 0.962 correlation coefficient for the 19th cycle RF energy parameter (13 proton events). Thus far in the 20th cycle the coefficient for the RF energy is rather poor. One of the reasons for this seems to be the preponderance of limb-region events (see figure 1). There appears to be an attenuating process which limits the RF burst observed at the earth. As an example, the correlation coefficient computed for the 20th cycle RF peak intensity was 0.033. When the events that occurred near or behind the limb were deleted and the correlation coefficient was recomputed, a value of 0.757 was obtained, which is a significant improvement. Obviously, if proton prediction techniques that utilize only the RF parameters are to be used satisfactorily, then methods must be devised to incorporate the limb and behind-the-limb radio frequency data.

DISCUSSION

Solar proton data were presented thus far for the 20th solar cycle. It remains to associate the solar optical and radio frequency data with the solar proton events observed by the IMP 2 and 3 satellites. Also, it is realized that only approximately one-half of the 20th solar cycle has occurred, and an intelligible comparison of the two solar cycles cannot be fully made. However, the results obtained thus far seem to imply that methods must be devised to improve the value of the optical and RF data and to determine other parameters that can be utilized in solar proton prediction techniques. One means of improvement that has attracted attention recently is the solar x-ray parameter (see, for example, ref. 11 and 12). Kuck (ref. 12) has found that the integrated x-ray flux is more proportional to the solar proton flux than the integrated radio flux. It appears that plasma clouds in the solar corona can effectively shield the centimeter radio burst from detection near earth, but these plasma clouds do not absorb the x-ray bursts. Efforts are underway to incorporate the available x-ray peak and integrated flux data in the existing solar proton prediction programs.

It is concluded that further research in the areas of the interplanetary medium and sector boundaries, particle propagation and diffusion, and other radio, optical and magnetic observations may, and probably will, improve and enhance our understanding of solar proton emissions and other associated solar phenomena.

REFERENCES

1. Robbins, D.E.; and Reid, J.H.: Solar Physics, Vol. 10, 1969, p. 502.
2. King, J.H.: Private Communication.
3. U.S. Department of Commerce: Solar-Geophysical Data, monthly publication
4. World Data Center A, Upper Atmosphere Geophysics: Data on Solar Event of May 23, 1967 and Its Geophysical Effects, Report UAG-5, Feb. 1969.
5. Lund, D.S.; and McIntosh, P.S.: Private Communications.
6. Air Force Cambridge Research Laboratories: Geophysics and Space Data Bulletin, Quarterly Publication.
7. Webber, W.R.: An Evaluation of the Radiation Hazard Due to Solar-Particle Events, Boeing Report D2-90469, 1963.
8. Hardy, A.C.: Private Communication
9. Gonzalez, C.C.; and Divita, E.L.: Solar Proton Forecast System and Procedures Used During the Mariner V Mission, JPL Technical Report 32-1303, 1968.
10. Lopez, M.D.: Private Communication
11. Arnoldy, R.L.; Kane, S.R.; Windkler, J.R.: Astrophys. Jour., 151, 1968, 711.
12. Kuck, G.A.: Prediction of Polar Cap Absorption Events, Air Force Weapons Laboratory Technical Note WLRTH 69-8, 1969.

Table 5. - Characteristic rigidity, P_0, for the 20th solar cycle events

Event Date	P_0,MV	Event Date	P_0,MV
5 Feb 65	162	13 July 68*	43
4 Oct 65	183	26 July 68	> 400
24 Mar 66	197	26 Sept68*	48
29 Mar 66	149	29 Sept 68	102
3 May 66	151	4 Oct 68	119
25 June 66	148	31 Oct 68	105
7 July 66	219	1 Nov 68	87
14 July 66	241	4 Nov 68	159
16 July 66	113	18 Nov 68	141
30 July 66	>400	3 Dec 68	122
28 Aug 66	317	24 Jan 69*	62
2 Sept 66	282	25 Feb 69	342
3 Sept 66	65	26 Feb 69	258
13 Sept 66	>400	27 Feb 69	215
20 Sept 66	90	12 Mar 69	209
25 Sept 66	164	21 Mar 69*	76
27 Sept 66	105	30 Mar 69	390
11 Jan 67	>400	10 Apr 69	110
28 Jan 67	277	25 Sept 69	113
2 Feb 67	206	27 Sept 69*	39
13 Feb 67	100	2 Nov 69	43
27 Feb 67	292	24 Nov 69	122
11 Mar 67	199	18 Dec 69	286
23 May 67	102	20 Dec 69	147
28 May 67	205	29 Jan 70	224
6 June 67	290	31 Jan 70	167
2 Nov 67*	89	6 Mar 70*	68
3 Dec 67	218	7 Mar 70*	40
16 Dec 67	183	23 Mar 70	109
9 June 68	199	29 Mar 70	220
6 July 68	171		

* - Events where there was insignificant flux above 60 MeV, consequently P_0 was calculated using time-integrated fluxes for E > 10 MeV and > 30 MeV.

Table 6. Radiation skin (chest) doses for the large solar proton events of the 19th and 20th solar cycles for various Apollo shielding configurations.

EVENT DATE	INTEGRATED FLUX	CHAR. RIGIDITY P_0,MV	SKIN DOSE (REM) C/SM	LM	SPACESUIT
(19th Cycle)					
23 Feb 1956	1.0E09	195	55.00	130.00	255.00
29 Aug 1957	1.2E08	56	4.18	34.80	136.80
10 May 1959	9.6E08	84	43.20	202.56	604.80
12 Nov 1960	1.3E09	124	65.00	136.50	507.00
12 Jul 1961	4.0E07	56	1.34	11.60	45.60
(20th Cycle)					
23 May 1967	2.01E07	102	0.95	3.56	9.95
18 Nov 1968	3.54E08	141	18.41	53.45	139.83
10 Apr 1969	2.02E08	110	10.10	35.96	66.90
2 Nov 1969	2.19E08	43	5.91	79.50	281.42
29 Mar 1970	2.63E07	220	1.45	3.24	6.31

Table 7. - Correlation coefficients for several solar optical and radio frequency parameters for the 19th and 20th solar cycles.

	plage area	plage int.	sunspot area	flare imp.	rf energy	rf** energy	peak int.	peak** int.	energy peak
19th cycle	0.287	0.328	0.187	0.316	0.772	0.768	0.707	0.708	0.050
20th cycle*	-0.149	-0.077	0.068	-0.274	0.078	0.332	0.033	0.757	0.267

* - For the period May 1967 to April 1970
** - Less limb region events

Figure 1. - Heliographic locations of solar flares for the 20th solar cycle.