ENERGETIC PARTICLE OBSERVATIONS OF THE SOLAR-GAMMA RAY/NEUTRON FLARE EVENTS OF 3 JUNE 1982 AND 21 JUNE 1980 ISOTOPIC AND CHEMICAL COMPOSITION

M.A.I.Van Hollebeke, Musee National des Sciences, Technique et Industrie PARC de La Villette, Paris, France
Frank B. McDonald, NASA Headquarters/Code P, Washington, DC 20546
James H. Trainor, NASA/GSFC, Code 600, Greenbelt, MD 20770

ABSTRACT

Studies of the charge composition of two solar gamma-ray/neutron-flare events reveal a striking enrichment of Iron relative to Oxygen with a smaller enrichment of intermediate nuclei. He/O is also enhanced and moderate amounts of ^{3}He are detected but there is no evidence for ^{2}H or ^{3}H.

1. Introduction. The extensive studies of the charge composition of flare-associated energetic particles (McGuire et al., 1979, 1985; Cook et al., 1980, 1984; Mason et al., 1980) have shown there are large changes in the relative abundances of the various elements from event-to-event. J.P. Meyer (1985) has established that this data can be organized to first order by the assumption that there is a basic composition pattern (that differs from the photospheric composition by a simple bias related to an elements first ionization potential) with a superimposed additional bias which is a monotonic function of Z for Z = 6 - 26 and which varies from event-to-event.

It is of interest to compare these basic patterns with the charge and isotopic composition measured for the flare events of 3 June 1982 and 21 June 1980. Both of these events produced nuclear gamma-rays and solar neutrons that were detected by the Solar Max Mission gamma-ray experiment (Chupp 1984). These observations of nuclear gamma-rays and energetic neutrons require that a significant fraction of the solar energetic ions accelerated in conjunction with the flare event must have undergone nuclear interactions as they traversed the region of the lower corona and solar photosphere. It is especially useful to examine the isotopic composition of hydrogen and helium for the presence of the generally rare isotopes ^{2}H, ^{3}H and ^{3}He that could have been produced by spallation processes. Furthermore, the near simultaneity of the x-ray and γ-ray emission (Forrest & Chupp 1984) characterize these as very impulsive events that place stringent constraints on the particle acceleration time.

As reported previously (McDonald & Van Hollebeke, 1985a, b) the observed characteristic of the energetic protons and electrons accelerated in these events differ in several important aspects from typical solar particle increases. They had flat energy spectra (γ = 1.22 from 3-200 MeV for 3 June 1982 and γ = 2.7 for 21 June 1980), are electron rich (P/e = 1 at 4 MeV for 3 June 1980) and both have small but well-defined precursor events that begin some 3 hours before the impulse flare increase.

The principal detector used in these composition studies was the Low Energy Telescope (LET-1) of the Goddard Helios I cosmic-ray experiment. This 4 element multi-parameter system (two 150 micron Si dE/dx detectors, one 0.25 cm total energy solid-state detector and an anti-coincidence element) has a geometric factor of 0.13 cm^2-sr and is identical to that flown on Pioneer 10/11 except that the gain settings and priority selection system on Helios were modified to provide full scale coverage from Z = 1-26. Webber et al., 1975 has discussed in detail the excellent charge resolution of this telescope.

On 3 June 1981, Helios I was at a heliocentric distance of 0.57 AU and $\sim$3° in heliolongitude from the nominal interplanetary field-line connecting to the region above the flare site (S09, E72). On 21 June 1980 the spacecraft was $\sim$33° from the nominal field line joining the flare site (N20, W88) at a heliocentric distance of 0.54 AU.

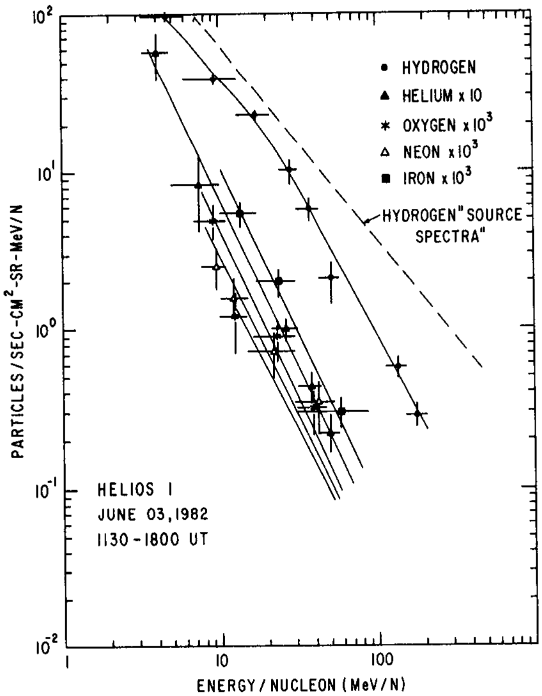
2. Isotopic Composition. The detection of nuclear gamma-rays and neutrons from these two flare events indicate that nuclear interactions are occurring in the solar atmosphere and photosphere. At higher particle energies, nuclear spallation processes should result in the production of ^{2}H, ^{3}H and ^{3}He. The presence of these otherwise rare isotopes would provide additional information on the acceleration and transport of these energetic particles. From Table 1, it is seen that no ^{2}H or ^{3}H was detected except for one candidate ^{2}H on 3 June 1982. The upper limits in Table 1 are comparable to those of Mewaldt and Stone 1983 and McGuire et al., 1985 for single solar events but are substantially larger than their upper limits obtained by averaging over many events.

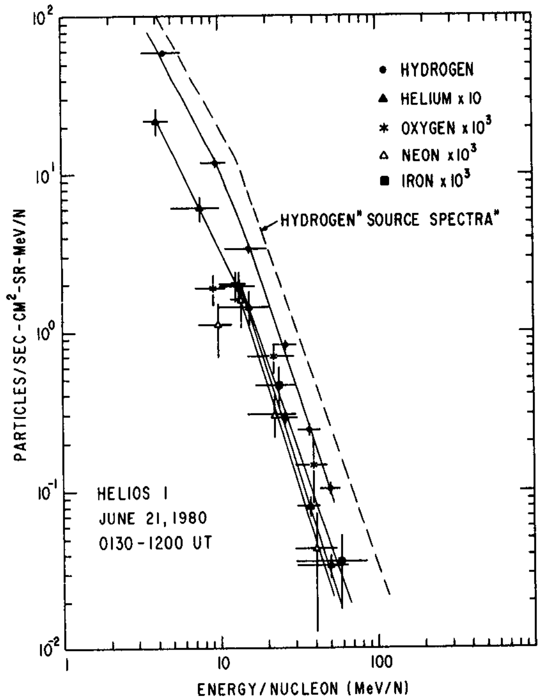
TABLE 1

	^{2}H/H 3.3-39 MeV/nuc	^{3}H/H	^{3}He/^{4}He 30-50 MeV/nuc
3 June 1982	$<4\times10^{-4}$	$<4\times10^{-4}$	.02±.014
21 June 1980	$<5\times10^{-4}$	$<4.5\times10^{-4}$	.03±.013

From the thin-target calculation of Ramaty and Kozlovsky, 1974, with γ = 1.3, an upper limit of $\sim$0.25 g/cm^2 is obtained for the solar material traversed by 30 MeV ions. There is a small but finite amount of ^{3}He detected for both of these events suggesting preferential injection and/or acceleration of this component rather than production by nuclear spallation processes.

3. Charge Composition. As in other studies of the elemental abundances, it is necessary to extend the analysis period beyond the time of peak intensity. However, because of the impulsive nature of the events, unusually short integration periods have been used (6.5 hrs for 6/3/82 and 10.5 hrs for 6/21/81). The resulting energy spectra for the more abundant species are shown in Fig 1. The H, He, C, O and Mg have a spectral index, $\gamma \simeq$ 1.4 for 3 June 1982 event and γ = 2.0 ± .1 for Fe. For 21 June 1980 the corresponding γ values are 2.2 and 2.75. This steepening may result from the fact that the Iron spectra extends to higher energies (the H data is in agreement with this interpretation).





The details of the charge composition (Table 1) reveal a striking over abundance of Fe. The Fe/O of 2.5 ± .5 for the 3 June 1982 event is a factor of 34 above the baseline SEP value of McGuire et al., while the value of 0.91 for the 21 June 1982 increase is 14x the SEP baseline. The final line in Table 2 is an enhancement factor using the GSFC solar energetic particle baseline which is an average of events with little or no Fe enrichment. J. P. Meyer has derived a "mass-unbiased" baseline using a different criteria for selecting events. By either measure these events display a remarkable Fe/O enrichment. The Ne/O, Mg/O are enhanced by more modest amounts. The Si/O ratio is substantially less than would be expected but the poor statistics for this element do not permit any definite conclusions.

TABLE 2

SOLAR ENERGETIC PARTICLE ABUNDANCES 10-47 MeV/nuc

	H/He	He/O	C/O	N/O	O/O	Ne/O	Mg/O	Si/O	Fe/O
3 June 1982 1130-1800	132	102±14	0 38±1	-------	1	0 87± 2	0 62± 18	0 2± 08	2 5± 5
21 June 1980 0130-1200	29	79±10	0 53±1	16± 06	1	0 46± 13	0 19± 06	0 4± 1	0 91± 02
McGuire et al SEP Baseline	66	53±5	0 45± 02	13± 01	1	0 13± 01	0 18± 01	0 15± 01	0.066± 006
Enrichment Factor 3 June 1980	2	1 9± 27	0 84± 2	-------	1	6 7 ±1 5	3 4 ±1	1 3± 5	38±7 6

4. Discussion. The general pattern of Z enrichment for $6 \leq Z \leq 26$ appears to be consistent with that proposed by Meyer (1985). The high value of Fe/O correlate remarkably with the data of McGuire et al., 1985, showing a strong inverse relation between the spectral index γ and the Fe/O ratio (Fig. 2). This effect may be a key factor in understanding Z enrichment. It is also interesting that the He/O ratio of 102 ± 14 for 2 June 1982 is very high and is consistent with the previously reported positive correlations between the He/O and Fe/O (Meyer et al., 1985). This correlation does present difficulties with interpreting the Z-enrichment as a rigidity effect.

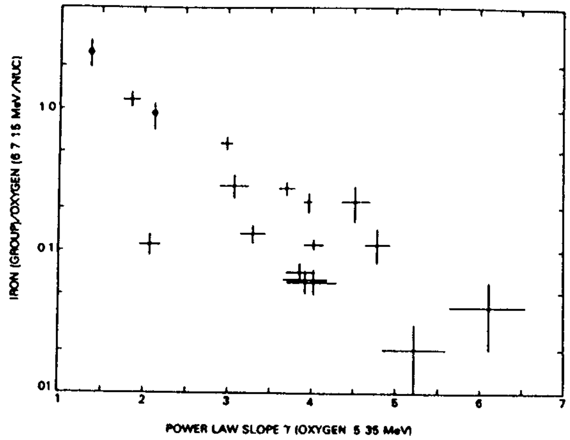


Fig. 2 Compilation by McGuire et al., 1985, of Fe/O vs Power Law Slope γ with the two added values (black dots) from this paper.

Solar neutrons are probably produced mainly by the spallation of He nuclei, but the large overabundance of Iron means Fe nuclei will make a substantial contribution to these events. Further studies are now underway to determine this relative role of He and Fe.

References

1. Chupp, E.L., (1984), Ann. Rev. Astron. Astrophysics, 22, 359
2. Cook, W.R., Stone, E.C., and Vogt, R.E., (1980), Ap.J., 238, L97; (1984), Ap. J. 279, 827
3. Forrest, D.J., and Chupp, E.L., (1984), Nature, 305, 291
4. Mason, G.M., Fisk, L.A., Hovestadt, D., and Gloeckler, G., (1980), Ap.J. 239, 1970
5. McDonald, F.B., and Van Hollebeke, M.A.I., (1985a), Ap.J., 290, L67; (1985b), Proc. 19th ICRC, Paper # SH1.3-8
6. McGuire, R.E., von Rosenvinge, T.T., and McDonald, F.B., (1979), Proc. 16th ICRC, Kyoto, 5, 61; (1985) submitted for publication to Ap.J.
7. Mewaldt, R.A. and Stone, E.C., (1983), Proc. 18th ICRC, Bangalore, 4, 52
8. Meyer, J.P., (1985), Ap.J. Supplement, 57, 151S.
9. Ramaty, R, and Kozlovsky, B., (1974), Ap.J., 193, 1974
10. Ramaty, R., Lingenfelter, R.E., and Kozlovsky, B., (1982), Gamma Ray Transients and Related Phenomena, Ed. R.E. Lingenfelter, et al., (N.Y. AIP) P211
11. Webber, W.R., Roelof, E.C., McDonald, F.B., Teegarden, B.J., and Trainor, J.H., (1975), Ap.J., 199, 482.