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SOLAR COSMIC RAY COMPOSITION ABOVE 10 MeV/NUCLEON AND ITS ENERGY DEPENDENCE IN THE 4 AUGUST 1972 EVENT

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Abstract

Observations of the proton, helium, (C,N,O) and Fe-group nuclei fluxes made during the large 4 August 1972 solar particle event are presented. The results show a small, but significant variation of the composition of multiply-charged nuclei as a function of energy in the energy region above 10 MeV/nucleon. In particular, the He/(C,N,O) abundance ratio varies by a factor ~ 2 between 10 and 50 MeV/nucleon and the Fe-group/(C,N,O) ratio suggests a similar variation. Abundance ratios from the 4 August 1972 event are compared as a function of energy with ratios measured in other solar events to show that several of the earlier results are consistent with an energy variation like that observed in August 1972, while certain other events must have had a substantially different dependence of composition on energy. At energies $\geqslant 50$ MeV/nucleon, the He/(C,N,O) abundance ratio for August 1972 is consistent with all earlier measurements made above that energy which suggests that variations may vanish at high energies.

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I. INTRODUCTION

The original observation of multiply-charged nuclei in a solar particle event (Fichtel and Guss, 1961) and subsequent observations in several large events during 1960 indicated that the elements with atomic number $Z \geq 2$ exhibited relative abundances at energies above approximately 40 MeV/nucleon that were constant within uncertainties throughout an event and from event to event in marked contrast with the large variations seen in the H/He abundance ratio (see Biswas and Fichtel, 1965). In addition, these abundances of elements with $2 \leq Z \leq 14$ were in good agreement with the corresponding solar-photospheric abundances where comparisons were possible. The He/(C,N,O) ratio was taken as statistically the best indication of the constancy of the solar-particle composition and was found to have a value of 60 within the 20-30% uncertainty of the individual events involved.

While several measurements during the present solar cycle confirm that the composition in the high energy per nucleon region is nearly constant (see Bertsch et al., 1972), an increasing number of observations, especially those at lower energies, showed that the composition in solar particle events did indeed vary in such a way that relative abundances of heavier nuclei are significantly enhanced (Armstrong and Krimigis, 1971; Mogro-Campero and Simpson, 1972; Armstrong et al., 1972; Teegarden et al., 1973; Shirk and Price, 1973; Braddy et al., 1973 Bertsch et al., 1973b). This enhancement of heavy nuclei, which appears as a suppression of the He/(C,N,O) ratio, can be quite large and variable. Armstrong and Krimigis (1971), for example, found

He/C,N,O) to vary between approximately 10 and 60 in the 0.5 to 2.5 MeV/nucleon interval.

The existence of heavy-element enhancements in solar events is now firmly established, but the conditions under which enhanced or normal abundances occur remain unclear. Can the presence or absence of enhancements or their magnitude be correlated with characteristics of an event, such as size, or with the energy of observation? The measurements made during the last solar cycle involved large events in terms of particle fluxes and particles of fairly high energies ($\geq$ 40 MeV/nucleon for C,N,O). When one notes that the characteristic energy of an abundance-ratio measurement always lies near the lowest energy observed owing to the steep solar spectra, one finds that all of the measurements during the present solar cycle lie below 40 MeV/nucleon. It, therefore, seems appropriate to examine the solar-particle composition at energies that overlap those of the original measurements, especially since those few experiments that have studied the energy dependence of ratios when enhancement is present, appear to indicate a strong decrease of the observed enhancement with increasing energy (Crawford et al., 1972; Price et al., 1973; and Braddy et al., 1973).

The present experiment examines the solar composition in the large solar particle event of 4 August 1972 with the particular view of studying the energy dependence of abundance ratios, especially the He/(C,N,O) ratio over a wide region of energy overlapping that of the original measurements. This information, together with other abundance ratio measurements, enables one to examine to what extent the variability of the composition is related to the particle event or to the energy of observation.

II. EXPERIMENTAL PROCEDURE

Measurements of the charge and energy of solar cosmic ray nuclei in the August 1972 event were made by analyzing particle tracks in nuclear emulsion stacks exposed during a sounding rocket flight that was conducted as part of the SPICE (Solar Particle Intensity and Composition Experiment) program series. The payload was launched from the Churchill Research Range, Fort Churchill, Manitoba, Canada at 1916 UT on 4 August 1972 approximately 13 hours after a 3B flare beginning at 0621 UT. The exposure took place during a time of very high particle intensity at about 1 hr. 40 min. before the maximum intensity of > 10 MeV protons observed at 2100 UT on the IMP-5 and IMP-6 satellites by Bostrom et al. (1972).

During the flight, which reached an altitude of 160 km, solar particles were sampled for a period of 240 s, essentially outside the earth's atmosphere, by opening the nosecone when the payload reached 50 km and closing the nosecone prior to reentry at 125 km altitude. The rocket axis was kept in a near vertical direction by imposing an axial spin of 6 rev/s. Aspect data indicate that the payload slowly precessed (period $\approx$ 47 s.) at an angle 8° from an axis that was 10° from the magnetic field and was within $\sim$ 12° from the zenith. Thus all particles entering the emulsions from within 70° of the payload axis were from directions above the earth's horizon and were free of atmospheric interactions.

The payload included four nuclear emulsion stacks; in three of these (called vertical stacks) the plane of the emulsion was parallel to the rocket axis and in the fourth (called the horizontal stack) it was perpendicular. One vertical stack was composed of Ilford K.2 emulsions of area 50 cm^2; the other two vertical stacks were composed of K.5 emulsions with a total area of 150 cm^2. In these stacks, the top pellicle was 200μ thick and it was followed by three 300μ and the sixteen 600μ pellicles. A cover of 1/2 mil titanium foil and 1 mil polyethylene, together having a stopping power equivalent to 34μ of emulsion, was used to protect the vertical stacks from heat and light. This was about a factor of two smaller than covers used in previous SPICE series flights. The horizontal stack was composed of both Ilford K.2 and K.5 600μ thick pellicles, covered by 5 mil polyethylene tape. Because of thinner shielding and larger area of emulsion detectors and the very high intensity of solar particles, this rocket flight provided the largest sample of multiply-charged solar nuclei recorded so far.

The top several sheets of emulsion were scanned to locate tracks of particles in a given charge region in overlapping intervals of residual range. Data recording and track selection were made with the aid of a digitized microscope system, operating on-line to a computer. Selection criteria included a dip interval (measured with respect to the emulsion surface) of 10° to 40° for H and He nuclei and 10° to 60° for (C,N,O) and heavier nuclei. In addition, a minimum track length projected in the emulsion plane was required to ensure sufficient information for analysis. For H and He scans this length was 200μ

and for (C,N,O) and heavier nuclei it was 75μ. All accepted particle tracks were followed in successive pellicles until they came to rest (or in a few cases interacted).

Helium nuclei were resolved from protons by the measurements of grain density vs. residual range of each track in the underdeveloped K.5 emulsions. All grain density measurements were made on each track near the point of entry of the particle in the emulsion plate at a given depth from the air surface. A plot of grain density vs. residual range for a sample of tracks measured in a particular scan is shown in Fig. 1 to show the resolution between H and He nuclei. Similar results were obtained in six other scans. It is noted in Fig. 1 that the separation between H and He counts decreases at residual ranges less than about 300μ due to saturation of grains along the track. Therefore, an additional selection criterion was imposed in which each track had to have a grain measurement at a residual range in excess of 300μ. Hence, all accepted He nuclei are identified in an unambiguous manner.

Differential energy per nucleon spectra for H and He components were calculated using the results of these scans. As a result of the geometric criteria used, the scans at different depths provided spectral information in overlapping regions of energy which in each case was found to be statistically consistent. An independent determination of the proton integral energy per nucleon spectrum was made by making measurements of track density at different depths in the horizontal emulsion stacks.

The scanning criteria for (C,N,O) nuclei were such that tracks of these and heavier nuclei were efficiently located. Scanning and measurements were made in several emulsion sheets including the top one. Appropriate corrections are made to subtract out the intensity of particles heavier than oxygen based on abundances observed in earlier events (Bertsch et al., 1972). This correction is $\leqslant 10\%$ so that uncertainties in heavier nuclear abundance are not important here. Measurements of energy spectra made different depths of the emulsion stack are in good agreement with one another and these are combined in the final analysis.

Additional scans involving large areas were made to select preferentially nuclei heavier than (C,N,O). Measurements of track opacity per unit length were made with a digitized television-microscope system, operating to an on-line computer. The track opacity per unit length, corrected for dip angle of the track and depth in the emulsion plate, is a measure of the ionization of the particle. Charges of individual nuclei have not been identified in these preliminary measurements, although Fe-group nuclei (defined as charges 22 through 28, but expected to be predominantly Fe) can be distinguished from lower-charged particles. On the basis of these preliminary measurements, an Fe-group flux is presented and compared with (C,N,O) and He nuclei. More detailed results on composition during the August 1972 event will be reported separately.

III. RESULTS AND DISCUSSION

Although the primary objective of this experiment is to study the multiply-charged nuclei in solar cosmic ray events, proton data are included, both for completeness and to emphasize the magnitude of the August 1972 event. The differential and integral energy spectra of protons are shown in Figs. 2a and 2b. For comparison, corresponding proton spectra are indicated for the 12 November 1960 event (Biswas et al., 1962) which prior to August 1972 was the largest event in which detailed composition studies were made. Both the differential and integral spectra in August 1972, exceeded the 1960 event by factors ranging from approximately 3 to 6 in the energy interval from 20 to 60 MeV. Integral proton intensities for the other events studied during the SPICE program series all lie within the shaded region of Fig. 2b (Biswas and Fichtel, 1965; Durgaprasad et al., 1968; and Bertsch et al., 1972), a factor of 10 or more below the August 1972 event. Proton data from Explorer 41 (Bostrom et al., 1972, and Van Hollebeke and McDonald, 1973) are given in Fig. 2b for comparison. These results show approximately the same energy dependence but are larger by a factor ~ 1.6. Since the satellite was at six earth radii at the time, it is possible that spatial variations might account for the difference in observed intensities. Figs. 2a and 2b show the data obtained from the H-He grain density measurements such as shown in Fig. 1 and from the total flux measurements at different depths in the emulsion stack. The two procedures lead to consistent results providing a check on the scanning and identification technique.

Spectra for multiply-charged nuclei are presented in Figs. 3 and 4. The He data include 228 tracks in the energy interval from 7 to 60 MeV/nucleon. The spectra for (C,N,O) were determined over a wider interval of 9 to 95 MeV/nucleon using 1350 tracks with charge ≥ 6 as described in the previous section. The energy dependence of the He and (C,N,O) intensity can be compared in Fig. 2 where the (C,N,O) spectrum, multiplied by an arbitrary factor of 40, is shown by the dashed curve. It is immediately evident that spectra of these two species have a different functional dependence on energy.

Fig. 5 shows in more detail how the relative abundance of He and (C,N,O) nuclei varies with energy in the August 1972 event. In the interval from 10 to 55 MeV/nucleon, the proportion of He appears to increase smoothly with respect to (C,N,O) in a manner that can be represented by an exponential form, exp (E/E_o) where E_o is 50 $\pm$15 MeV/nucleon. For comparison, the H/He abundance ratio between 10 and 50 MeV/nucleon is given in Fig. 6 where again the energy variation appears to be exponential, exp (E/E_o) with $E_o = 75 \pm 47$ MeV/nucleon. All previous observations in the SPICE program series have found that He, (C,N,O), and other multiply-charged nuclei, whenever they were found in sufficient quantity to determine a spectrum, had similar spectral shapes (Biswas et al., 1962, 1963; Biswas and Fichtel, 1965; Durgaprasad et al., 1968; Bertsch et al., 1973a) although small, systematic differences in relative abundances between different events have been noted (Bertsch et al., 1973b). On the other hand, protons and He, which have different charge-to-mass ratios, often had large relative abundance variations with energy. For example, Durgaprasad et al. (1968) find that the H/He ratio changes by a factor of 15 between 10 and 35 MeV/nucleon while in the August 1972 event the factor is only 1.4.

The only previous measurement of the energy dependence of He/O ratio* was made at lower energies (≤ 10 MeV/nucleon) in the 17 April 1972 event by Braddy et al. (1973). By examining the He/O and O/Fe ratios, they conclude that heavy nuclei are enhanced relative to lighter species and this enhancement, when compared with assumed solar photospheric values as a basis, begins at about 10 MeV/nucleon and increases as energy decreases. Price et al. (1973) arrive at the same conclusions based on several solar events prior to 1972. The variation of He/(C,N,O) shown in Fig. 5 similarly can be interpreted as an enhancement of (C,N,O) extending to a significantly higher energy of ~ 50 MeV/nucleon where the ratio approaches the early SPICE experiment value of 58 ±5 (Bertsch et al., 1972), often used as a basis for inferring the He abundance in the sun.

The fact that He/(C,N,O) continues to vary at energies well above 10 MeV/nucleon where the nuclei are almost certainly stripped of electrons and consequently have equal charge-to-mass ratios suggests that these abundance variations are not a feature of the propagation process since the electromagnetic effects (except for Coulomb energy losses) are proportional to the charge-to-mass ratio. Energy loss, while possibly

*The abundance of the (C,N,O) group relative to oxygen is not expected to vary appreciably from the value of 1.75 observed in solar cosmic rays above 10 MeV/nucleon (e.g., Bertsch et al., 1972) and in the photosphere (Withbroe, 1971).

present, cannot account for the variation observed in Fig. 5 since it would suppress heavy nuclei relative to lighter species rather than enhance them. Consequently, some phase of the acceleration process must lead to the energy dependent bias in solar cosmic rays.

It may be noted that the spectra of multiply-charged nuclei in the August 1972 event can be represented by exponential energy functions of the form exp $(-E/E_0)$ for the energy region shown in Fig. 7. The proton spectrum, on the other hand, is not a simple exponential. A weighted least squares fit gives $E_0 = 15.3 \pm 1.3$ MeV/nucleon for He and 12.0 $\pm$0.2 MeV/nucleon for (C,N,O) with a ratio He/(C,N,O) = 16.3 $\pm$2.5, extrapolated to E = 0. If the ratio He/(C,N,O) approaches an energy independent value at high energies as suggested by Price et al. (1973), then the slope of either (or perhaps both) the He or (C,N,O) spectrum must change at some high energy. In this connection, a fit to the (C,N,O) data above 60 MeV/nucleon yields an $E_0 = 15.4 \pm 1.7$ MeV/nucleon, similar to that of He, and a ratio He/(C,N,O) = 60.

The Fe-group results shown in Fig. 7 are based on 27 events identified in a small fraction of the total area scanned. These preliminary results are compared in Fig. 7 with the (C,N,O) spectrum which may be scaled to give the ratio (Fe-group)/(C,N,O) = 0.044 $\pm$0.009. Assuming a (C,N,O)/O value of 1.75 as discussed above, gives Fe-group/ O = 0.078 $\pm$0.015. This value is consistent with observations in the January and September 1971 solar events, but is significantly higher than the 0.031 $\pm$0.01 observed in September 1966 (See Bertsch et al., 1973a.). The Fe data of Price et al. (1973) above 10 MeV/nucleon measured in plastic detectors exposed during the same rocket flight are shown in Fig. 7. Clearly the two measurements are in good agreement.

Charge identification of other heavy nuclei in the region $10 \leq Z \leq 20$ has not been made as yet. However, the flux of nuclei with $Z \geq 10$ in an energy interval from 10 to ~ 32 MeV/nucleon is 3.3 ± 0.3 particles/cm^2-sr-s which is (15 ± 2) % of (C,N,O) in the same energy/nucleon interval. A summary of SPICE results in earlier events (Bertsch et al., 1972) finds $(Z > 8)/(C,N,O) \simeq 15.6\%$ and Withbroe's (1971) summary of photospheric abundances based on spectroscopic measurements gives 13.3% for the same ratio. Hence the overall abundance of $Z > 8$ nuclei in the August 1972 event appears to be normal in that it is similar to earlier observations.

Finally, it is of interest to compare the ratios He/(C,N,O) and Fe/(C,N,O) observed in the August 1972 event with corresponding values in other solar events. This is done as a function of kinetic energy/nucleon in Figs. 8 and 9. He/(C,N,O) values observed at high energies during the previous solar cycle are shown only as an average in Fig. 8 since each measurement involved the same energy interval and all were statistically consistent with a constant value of 60 ± 7 (Biswas et al., 1963). The data in the August 1972 event , fitted by the straight line in Fig. 8, is consistent with the early He/(C,N,O) average and with four other observations during the current solar cycle made at lower energies. On the other hand, four observations in the energy interval 12 to 30 MeV/nucleon occur well above the August 1972 curve. Notice that the points in both categories include both SPICE program measurements and IMP-5 satellite values of Teegarden et al. (1973). The shaded region in Fig. 8 denotes the range of values reported by Armstrong and Krimigis

(1971) for 27 solar events at very low energies. More recently they report significant time variations in composition at low energies associated with interplanetary magnetic field shock waves (Armstrong and Krimigis, 1973). Results of Braddy et al. (1973) at energies from 0.2 to 10 MeV/nucleon indicate a strong increase in He/O as energy increases for the 17 April 1972 solar event. Their results, however, are not included in Fig. 8 due to the uncertainty in the absolute flux level of He (Price, 1973). The energy dependence of He to (C,N,O) ratios shown in Fig. 8 seem to suggest the possibility that solar events have different characteristic energy below which the acceleration process enhances heavy nuclei relative to source composition.

For the (Fe-group)/(C,N,O) ratios shown in Fig. 9 as a function of energy per nucleon, the data are not as complete as for He and (C,N,O). The (Fe-group)/(C,N,O) ratios from this experiment suggest an enhancement of Fe below about 15 MeV/nucleon compared to the earlier measurements at higher energies in the same SPICE program using the same experimental techniques. For these nuclei, solar spectroscopic measurements exist and the photospheric value of the ratio is shown by the dotted line (Withbroe, 1971). Solar system abundances (Cameron, 1974) are essentially the same. The Fe/O points of Braddy et al. (1973) have been adjusted by the (C,N,O)/O ratio of 1.75 as discussed earlier. The energy variation that they find is consistent with the results reported here and with low energy IMP-7 measurements by Hovestadt et al. (1973) (shown in Fig. 8 as an average value scaled by 1.75).
The results of Teegarden et al. (1973) are also statistically consistent with an overall abundance variation with energy. Data from Mogro-Campero

and Simpson (1972) obtained by integrating over seven small solar events indicate a very different abundance for such events even at energies above 35 MeV/nucleon. Other data suggesting Fe-group enhancement (Price et al., 1971 and Crawford et al., 1972) have not been included in Fig. 8 since (C,N,O) or O was not available in these measurements. As additional solar particle events are studied, Fe/(C,N,O) might be expected to display event-related differences similar to those observed for He/(C,N,O).

IV. SUMMARY AND CONCLUSIONS

The large solar particle event of 4 August 1972 has provided an opportunity to reinvestigate and and extend the conclusions derived from large events of the last solar cycle concerning the relative abundances of multiply-charged elements. It is found that at sufficiently high energies the composition as measured by He/(C,N,O) and Fe/(C,N,O) is in agreement with that found previously and with that of the solar photosphere.

Toward lower energies, however, the abundance of heavier nuclei are found to be increasingly enhanced, the magnitude of this enhancement in the above ratios reaching approximately a factor of two near 10 MeV/nucleon. Comparing with measurements made in other events one finds that both the magnitude of the enhancements and the energy at which they appear varies from event to event; no clear correlation with the size or other character of an event has been found.

The simplest explanation of the composition measurements would seem to involve the presence of two particle populations arising from solar events, namely, a component with relatively flat spectra in which the relative abundances are "normal" and a component with steeper spectra in which the abundances of heavier nuclei are enhanced. The enhancements might arise from the presence of partially-ionized nuclei during acceleration or might simply be a characteristic of the location (e.g., altitude above the sun) from which the sample was drawn. In such a picture the composition in a given spectral region would vary with changes in the spectral indices or the relative intensities of the two components from one event to the next.

Further investigation into the origin of abundance enhancements would seem to require more complete measurement of the energy dependence of the composition in the region where enhancements occur.

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Figure Captions

Figure 1 Observed grain density as a function of residual range for a sample of 200 events in one of several H - He scans made in underdeveloped Ilford K.5 emulsion plates. Each point represents one event. The separation between the H and He profiles decreases at low ranges due to saturation effects on particle tracks.

Figure 2 (a) Differential and (b) integral proton energy spectra at 1916 UT on 4 August 1972 compared with other large solar events. Open circles refer to hydrogen identified in the H - He scan measurements and triangles refer to results from total particle flux measurements. The dashed line represents the spectra in the 12 November 1960 (Biswas et al., 1962), the largest event studied previously. The shaded region in (b) represents the proton intensities of all remaining events studied by the SPICE program series. (See references in text). The symbols X (Van Hollebeke and McDonald, 1973) and *(Bostrom et al., 1972) are proton intensities from the Explorer 41 satellite at 1916 UT on 4 August 1972.

Figure 3 Helium differential energy/nucleon spectra at 1916 UT on 4 August 1972. The dashed line represents the (C,N,O) data presented in Figure 4, normalized by an arbitrary factor of 40. The spectral shapes are clearly different at low energies.

Figure 4 (a) Differential and (b) integral (C,N,O) nuclei energy/nucleon spectra. Error-limits not shown in (b) are comparable with the size of the symbol.

Figure 5 The ratio, He/(C,N,O), as a function of energy/nucleon during the 4 August 1972. The solid line represents a weighted least-squares fit to the data and has an e-folding value of 50 $\pm$ 15 MeV/nucleon.

Figure 6 Hydrogen-to-helium abundance ratio as a function of energy/nucleon. The line is a weighted least-squares fit and has an e-folding value of 75 $\pm$ 47 MeV/nucleon.

Figure 7 Comparison of the differential energy/nucleon spectra for protons, helium, (C,N,O) and Fe-group nuclei at 1916 UT on 4 August 1972. Linear fits in this figure signify an exponential form of the dependence on energy/nucleon. At low energies, protons and helium have similar slopes, but the proton spectrum significantly hardens relative to He at higher energies. Both He and (C,N,O) can be fit to an exponential form, exp $(-E/E_o)$ over the entire range of the data. For He, E_o is 16.3 $\pm$ 2.5 MeV/nucleon and for (C,N,O), E_o is 12.0 $\pm$ 0.2 MeV/nucleon. Iron-group nuclei data, shown by the inverted triangles, are fitted to a spectrum required to have the same E_o as (C,N,O) resulting in a normalization factor of 0.0443 $\pm$ 0.0086 times the (C,N,O) spectrum as indicated. Iron data of Price et al. (1973) are shown as asterisks, and are in general agreement with the

Fe curve in this figure. These data were obtained from plastic detectors aboard the same rocket flight as in the current analysis.

Figure 8 Comparison of He/(C,N,O) ratios observed for the 4 August 1972 event with measurements made in earlier solar events as a function of energy/nucleon. Solid points and the line are data from the current experiment taken from Figure 5. Open circles are data from previous solar events measured in the SPICE program and an earlier series of sounding rocket flights. Point 1 is a weighted average of measurements made during the preceding solar cycle (Biswas et al., 1963); points 2 and 3 are for the 2 September 1966 event; point 4 is for 12 April 1969; points 5 and 6 are for 25 January 1971; and point 7 is for 2 September 1971 (Bertsch et al., 1973b). IMP-5 satellite data of Teegarden et al., (1973) are shown by triangles. The inverted triangle represents the 6 April 1971 event and normal triangle is a measurement on 1 September 1971, in the same event as the point labeled 7. The shaded region represents data from 27 small events at low energies, which show a highly variable ratio (Armstrong and Krimigis, 1971). Note that the energy variation in the August 1972 event is consistent with some of the earlier observations but distinct from others indicating that not all solar events have the same energy dependence for the He/(C,N,O) ratio.

Figure 9 Comparison of the Fe-group/(C,N,O) abundance ratios for the 4 August 1972 event with measurements made in previous events. Solid points represent data from this experiment while the open circles and the upper limit are SPICE program measurements in other events (Bertsch et al., 1973b). An average Fe/(C,N,O) ratio, determined by integrating over seven small flare events during 1969, is shown as a cross (Mogro-Campero and Simpson,1972). As in Fig. 8, the triangles refer to measurements by Teegarden et al., (1973) (inverted triangle for the 6 April 1971 event and the normal triangle for the 1 September 1971 event). Asterisks are Fe/O data from an Apollo experiment during the 17 April 1972 event (Braddy et al., 1972) multiplied by 1.75 to account for the (C,N,O)/O abundance (see text). The open square is a measurement of Fe/O on IMP-7 by Hovestadt et al., (1973) also scaled by 1.75. Except for the latter two measurements, and the present work, ratios were determined over large energy intervals and have been plotted at the mean energy assuming an E^{-3} spectrum. Above 20 MeV/nucleon most of the data agree with solar photospheric measurements summarized by Cameron (1973) and shown by the dotted line. Below 20 MeV/nucleon iron is apparently enhanced relative to (C,N,O).

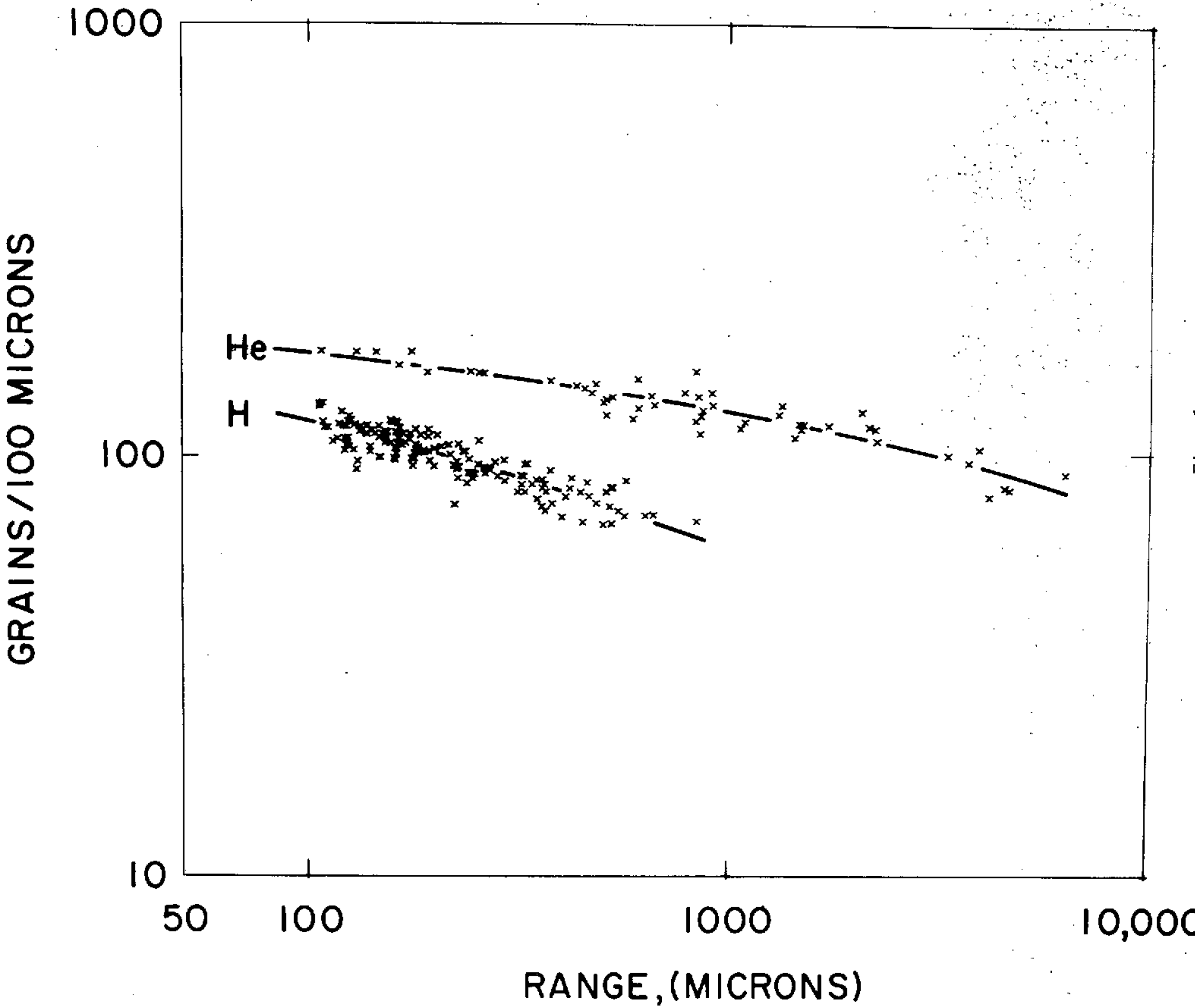
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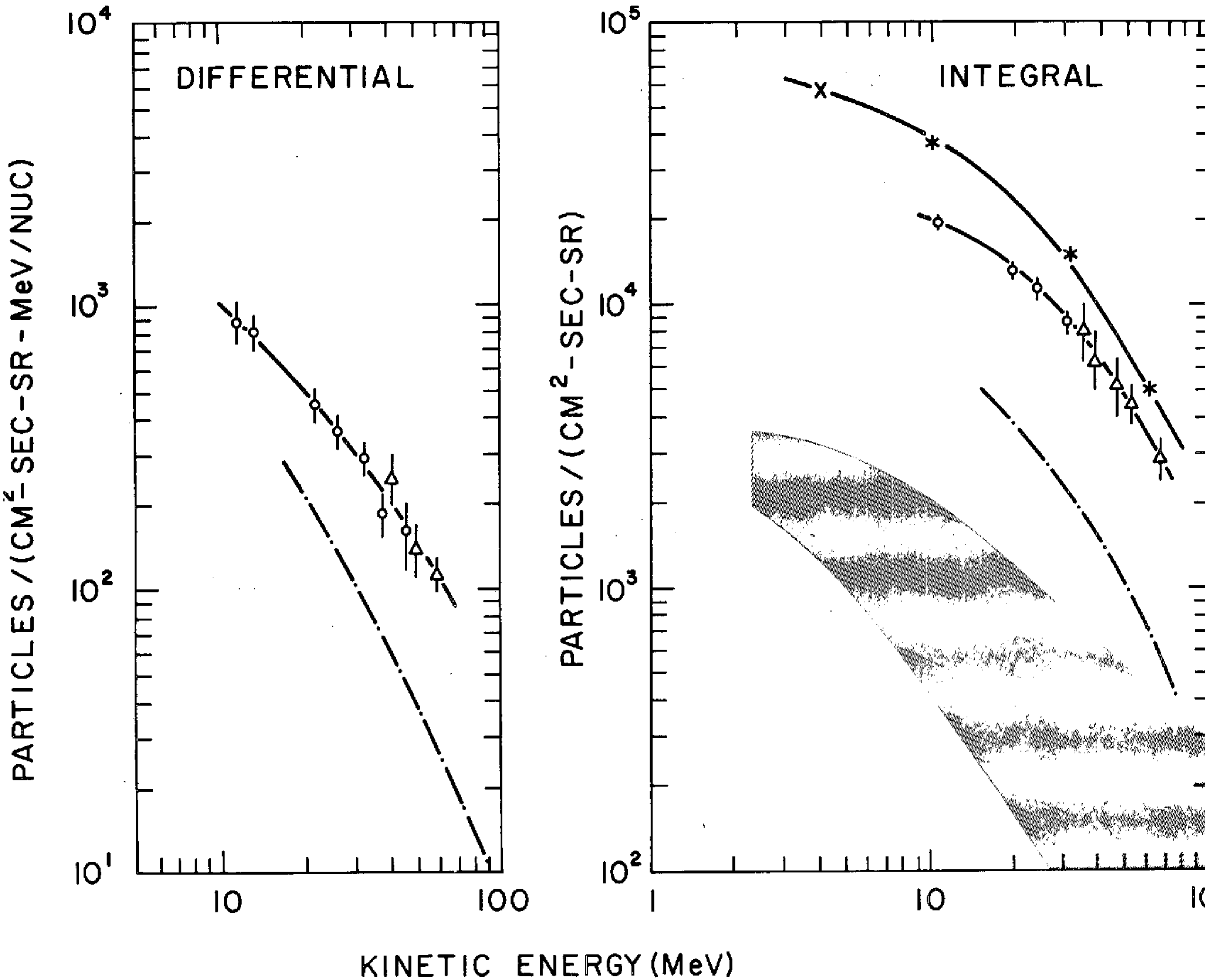
Fig. 1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10^3
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PARTICLES / $(CM^2$-SEC-SR-MeV/NUC)
INTEGRAL
10^5
10^4
10^3
10^2
1
10
100
PARTICLES / $(CM^2$-SEC-SR)
KINETIC ENERGY (MeV)

Fig. 2

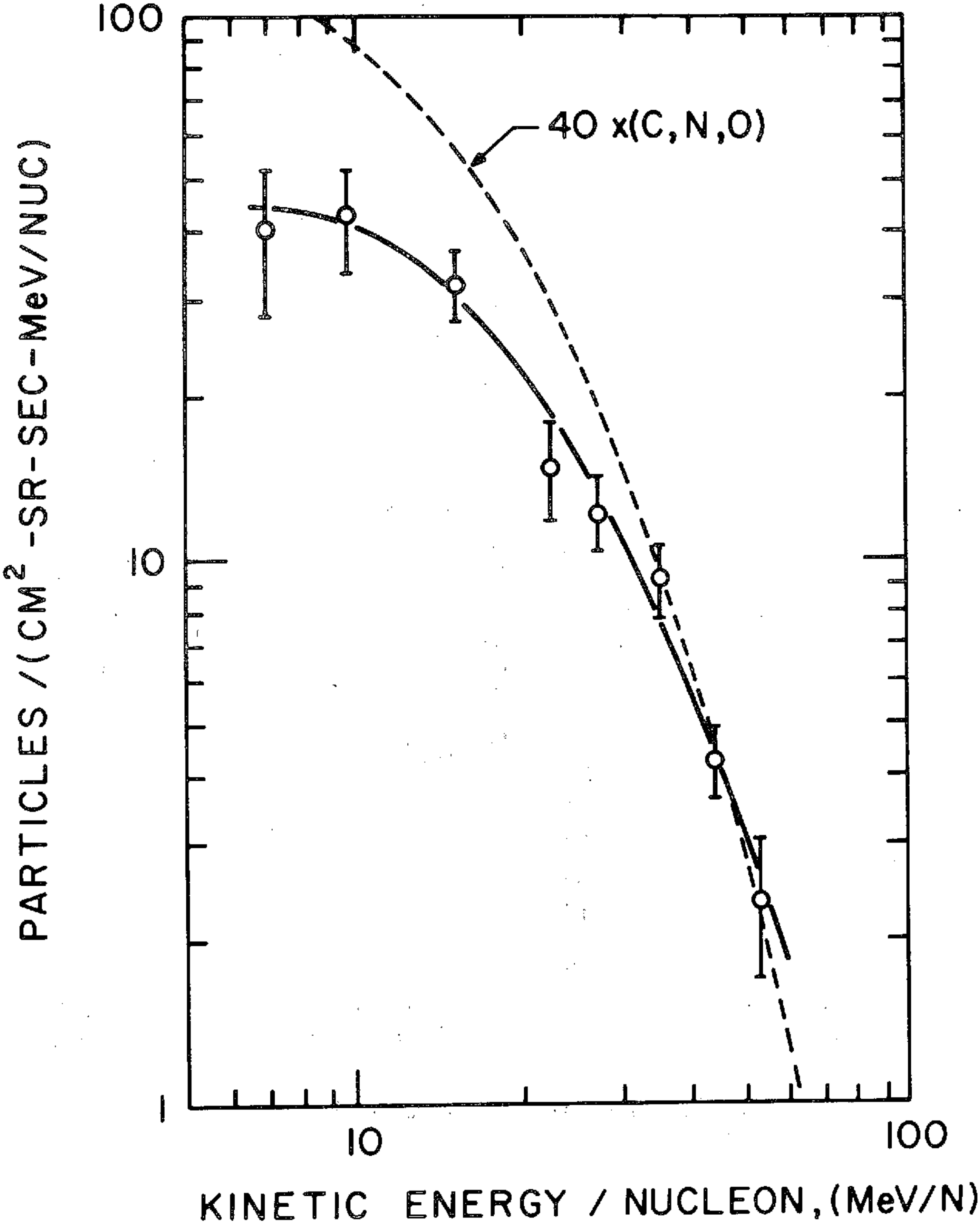

100
10
1
10
100
40 x(C,N,O)
PARTICLES /(CM² -SR-SEC-MeV/NUC)
KINETIC ENERGY / NUCLEON,(MeV/N)

Fig. 3

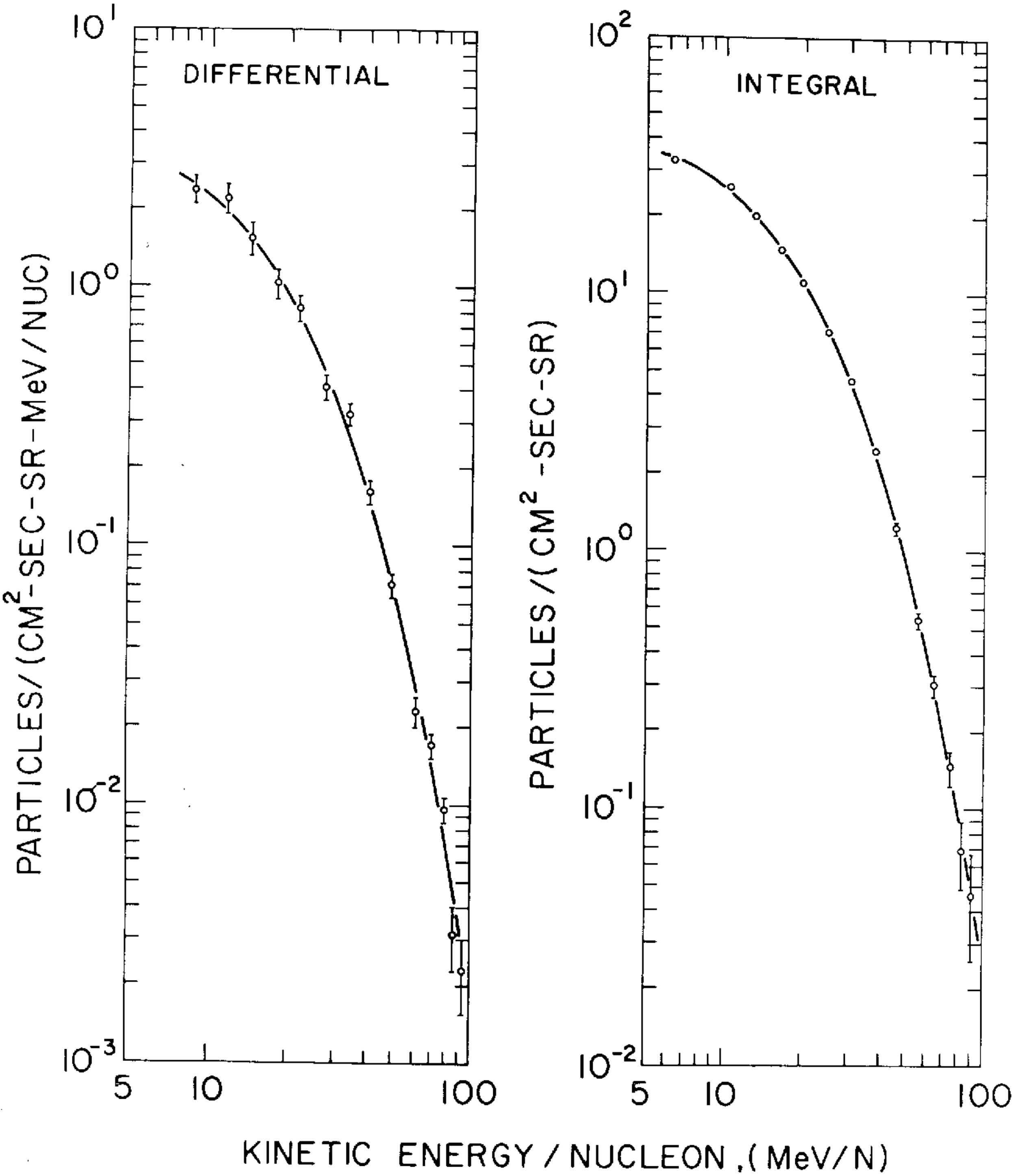

DIFFERENTIAL
INTEGRAL
PARTICLES/(CM²-SEC-SR-MeV/NUC)
PARTICLES/(CM² -SEC-SR)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10²
5
10
100
KINETIC ENERGY / NUCLEON ,(MeV/N)

Fig. 4

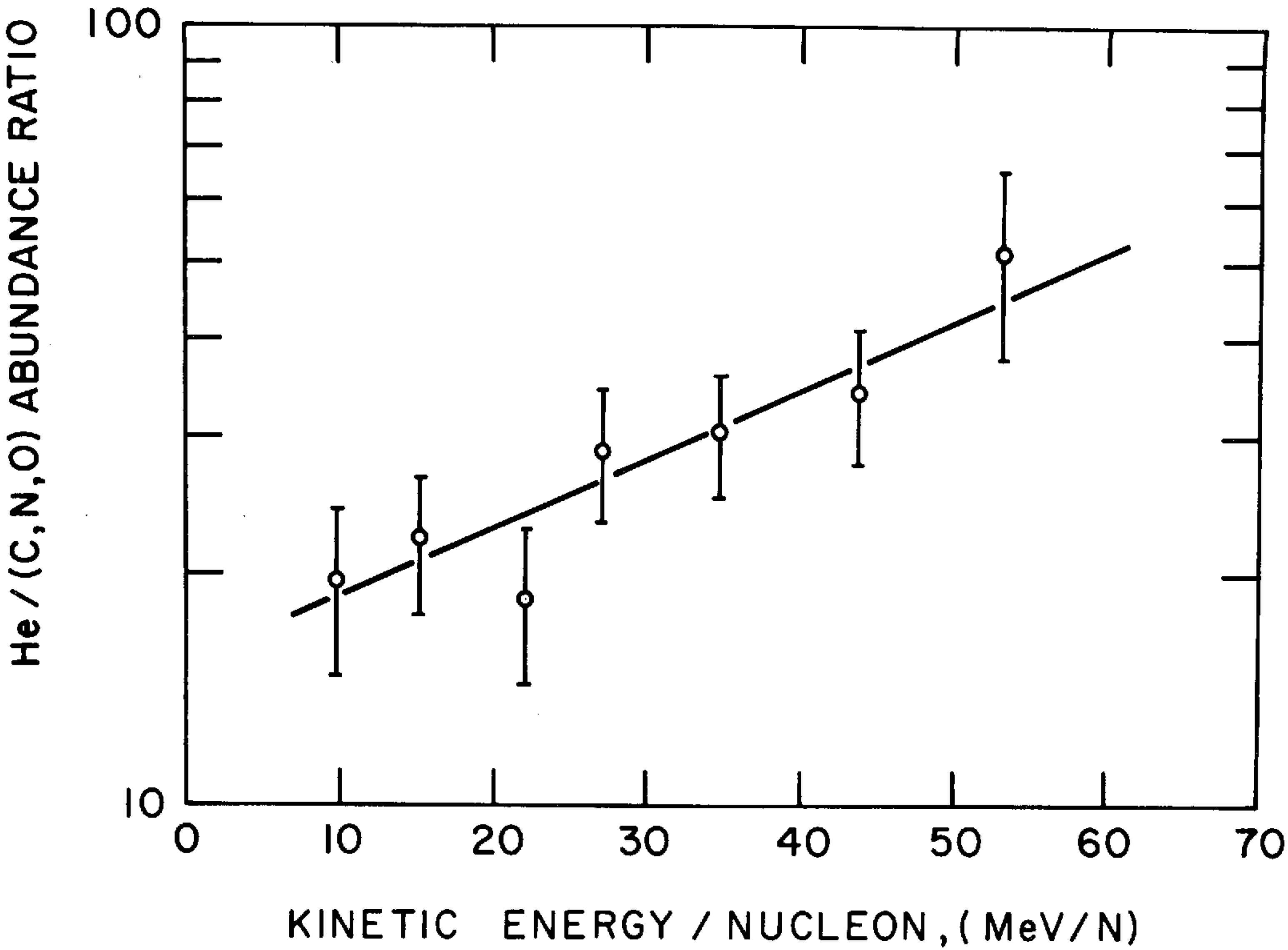
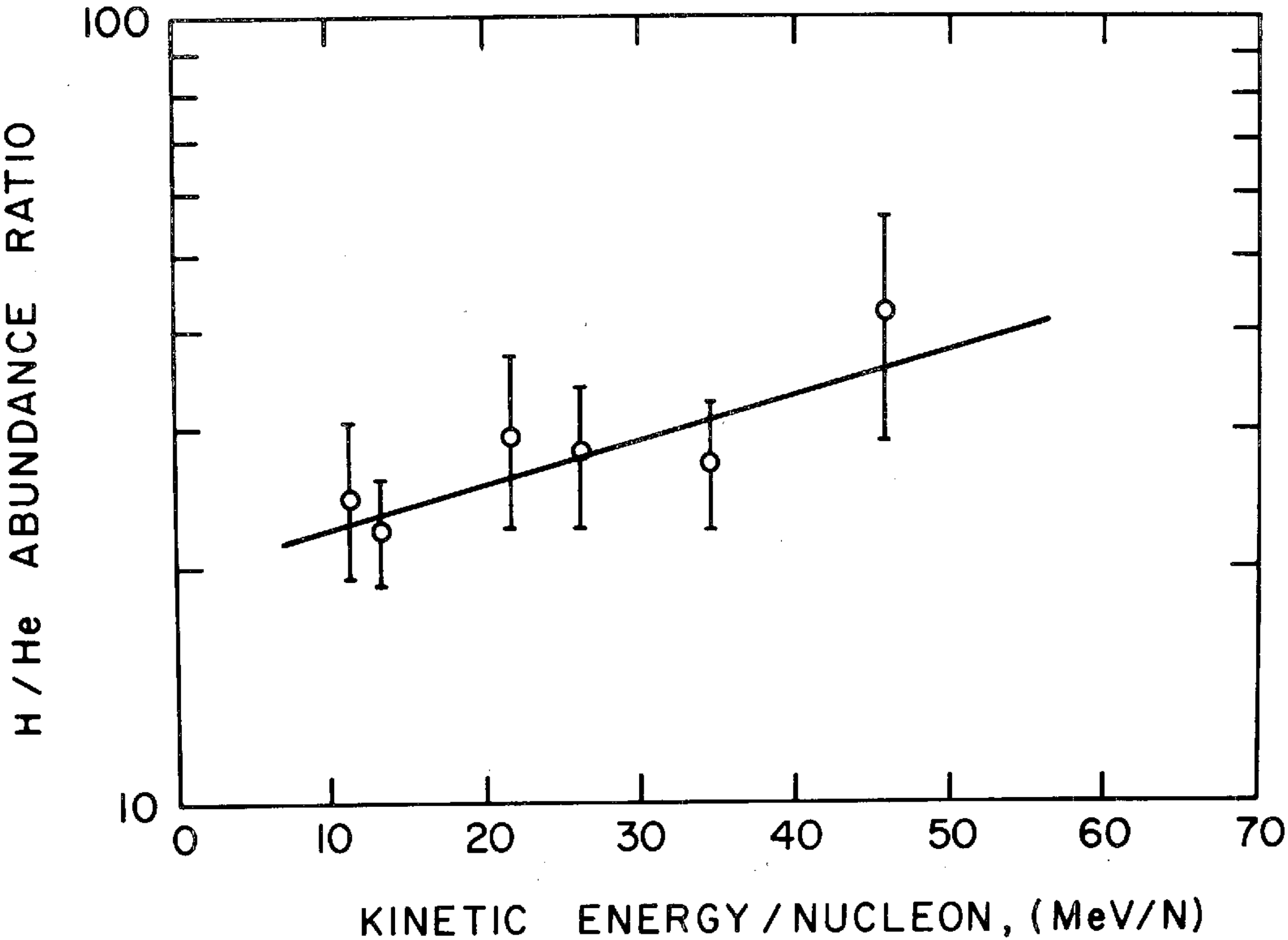
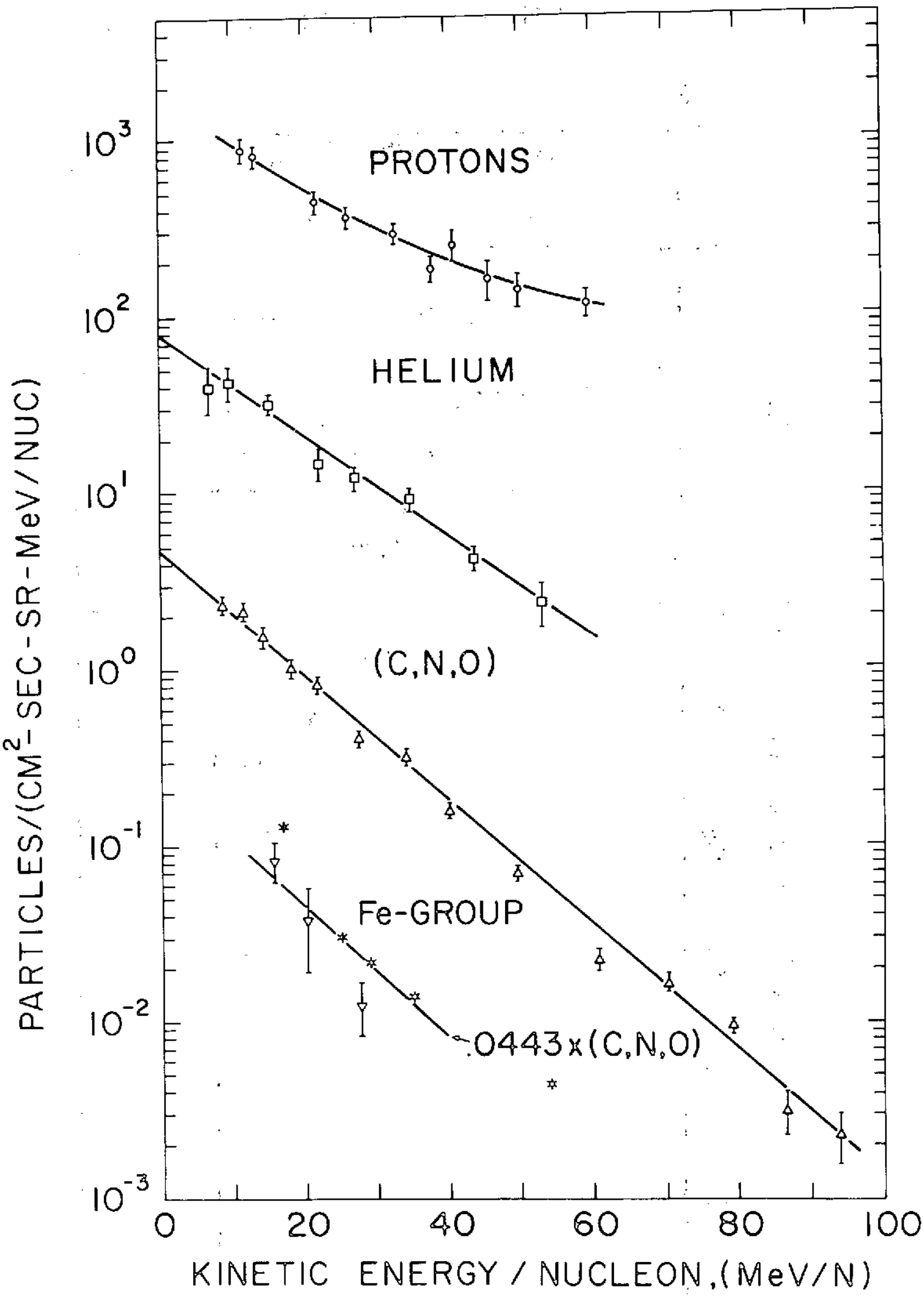

He / (C, N, O) ABUNDANCE RATIO
100
10
0
10
20
30
40
50
60
70
KINETIC ENERGY / NUCLEON, (MeV/N)

Fig. 5



H / He ABUNDANCE RATIO
100
10
0
10
20
30
40
50
60
70
KINETIC ENERGY / NUCLEON, (MeV/N)

Fig. 6



PROTONS
HELIUM
(C,N,O)
Fe-GROUP
.0443 x (C,N,O)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
0
20
40
60
80
100
PARTICLES/(CM^2-SEC-SR-MeV/NUC)
KINETIC ENERGY / NUCLEON, (MeV/N)

Fig. 7

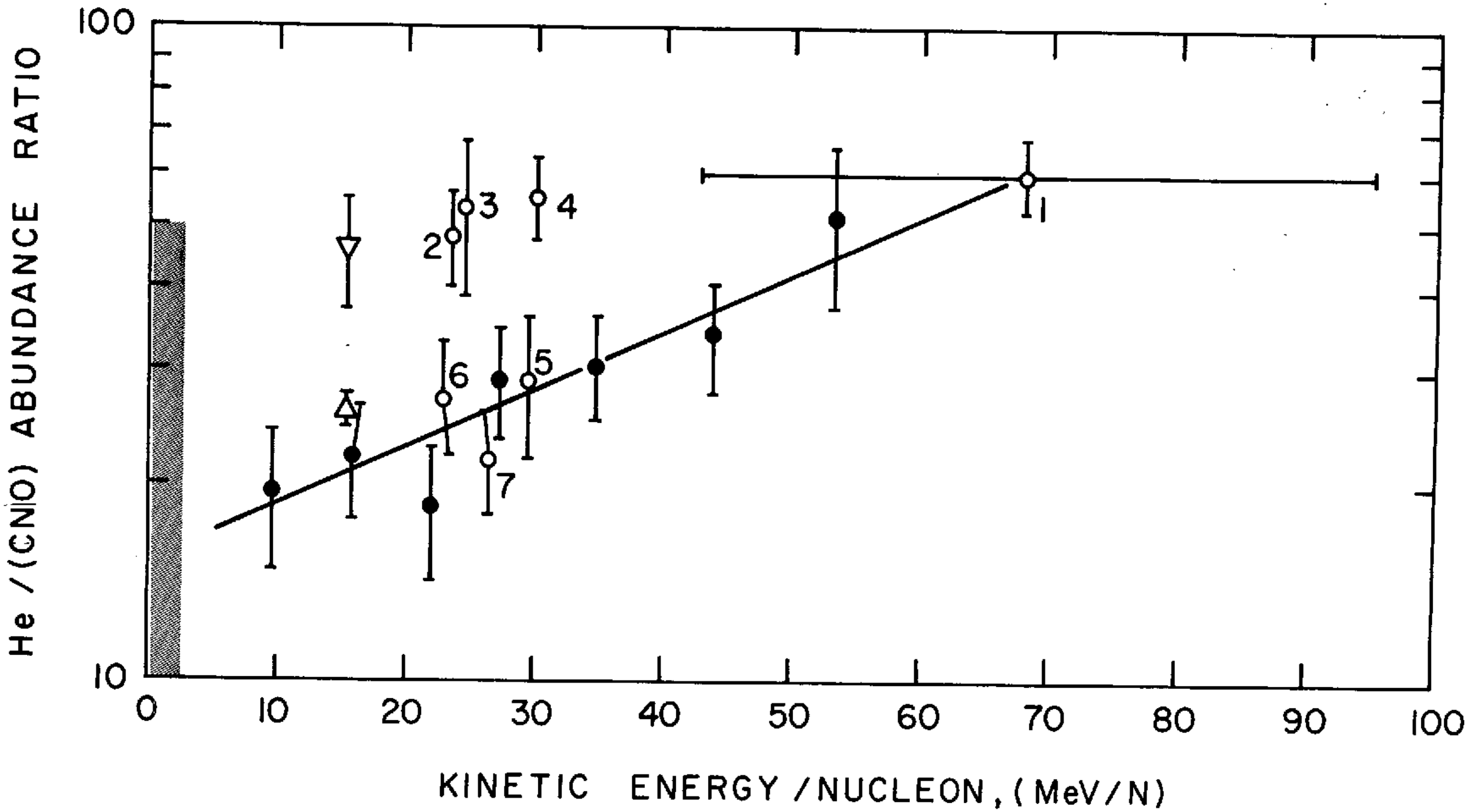

He /(CNO) ABUNDANCE RATIO
100
10
0
10
20
30
40
50
60
70
80
90
100
KINETIC ENERGY / NUCLEON, (MeV/N)
1
2
3
4
5
6
7

Fig. 8

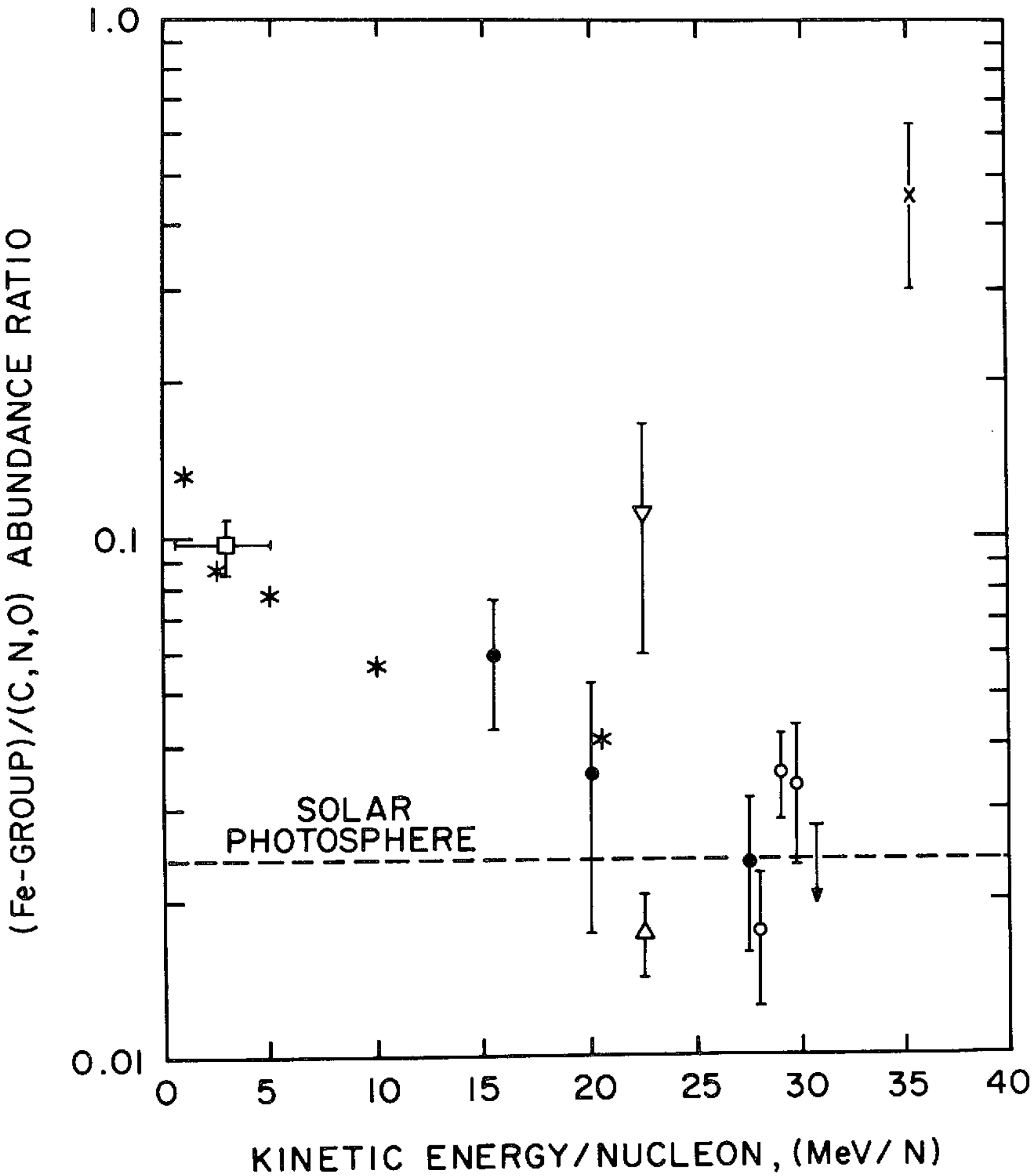

1.0
0.1
0.01
(Fe-GROUP)/(C,N,O) ABUNDANCE RATIO
SOLAR
PHOTOSPHERE
0
5
10
15
20
25
30
35
40
KINETIC ENERGY/NUCLEON, (MeV/N)

Fig. 9