NUCLEAR SPECTROMETER TO DETERMINE PRIMARY COSMIC RAY FLUX AS A FUNCTION OF CHARGE

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In march 1972 a cosmic ray telescope was launched on the first astronomical ESRO satellite TD1. This telescope was designed to study the elemental composition of $2 \leq Z \leq 28$ nuclei for energies ≥ 200 MeV/n using a combination of energy loss measurements in silicon detectors and Cerenkov yield in a sapphire counter.

The absolute flux of M nuclei above 1 GeV/nucleon are given. We also give the abundances relative to oxygen of $5 \leq Z \leq 14$ nuclei and the relative abundance to iron of $16 \leq Z \leq 28$ nuclei in the same energy range.

1. Introduction: Recently much effort has been devoted to the measurement of the chemical composition of cosmic nuclei.

In the relativistic region, most of the results have been obtained from balloons (1), (2). Measurements from satellites only exist for the light nuclei, $Z \leq 14$ (3), (4). A synthesis of all the results can be found in (5). Now measurements obtained from balloons at a residual atmosphere of several g/cm^2 must be corrected for nuclear interactions suffered by the incident nuclei before they reach the detector. Our incomplete knowledge of the interaction cross-sections causes the results to be rather imprecise, especially for the elements included between silicon and iron. Hence, measurements from satellites are particularly important in this range of the charge spectrum.

In this article we present preliminary results on the abundances of nuclei from Boron to Iron at energies greater than 1 GeV/nucleon. The results have been obtained since 17 March 1972, with a telescope carried on the satellite TD-1.

2. Experimental apparatus: The identification of each nucleus in the telescope is obtained by an energy-loss measurement in two sdid-state detectors, and by measuring the Cerenkov radiation in a piece of sapphire. This detector allows an unambiguous identification for all the nuclei having charge between Z = 2 and Z = 30.

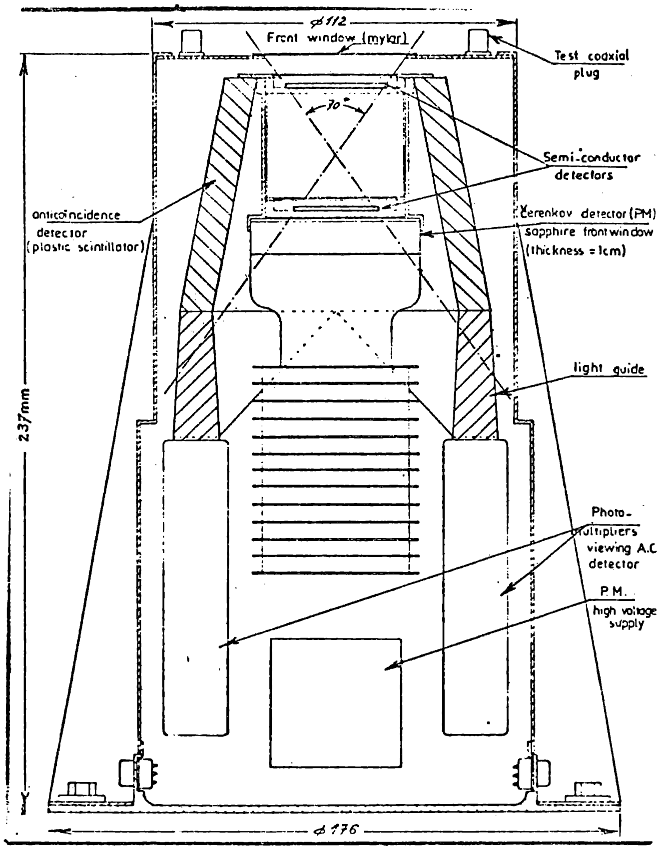


Fig 1 Schematic representation of the S 67 detector system

The detector is shown schematically in fig. 1. It is composed of :

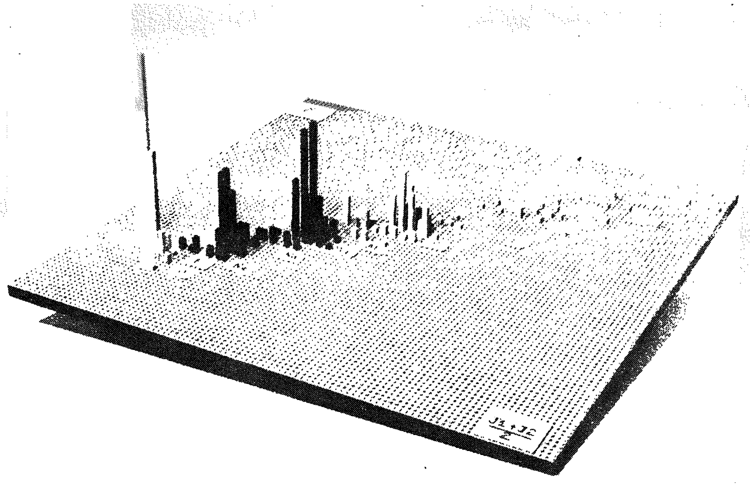
- 2 silicon solid-state detectors. Their thickness is 1mm and their diameter are respectively 3.1cm and 2.1cm.
- 1 photomultiplier with a sapphire window 1cm thick. The sapphire window is the Cerenkov radiator. Its index of refraction is n=1.76, hence it is capable of detecting particles with energy greater than 210 MeV/n.
- 1 shield of scintillating material surrounding the other 3 detectors. It is viewed by 2 photomultiplier tubes. The rôle of the scintillator is to indicate wether a nuclear interaction takes places as a particle traverses the detector assembly.

The geometric factor of the assembly is 1.6cm^2 ster. The telescope has a half-angle of 35°.

3. Results : The data are presented in the form of a diagram in two parameters. The first parameter is the mean response of the two solid-state detectors, the second parameter is the response of the Cerenkov counter. In certain cases we have selected the nuclei detected during the time that the geomagnetic cut-off was greater than a given value P_o.

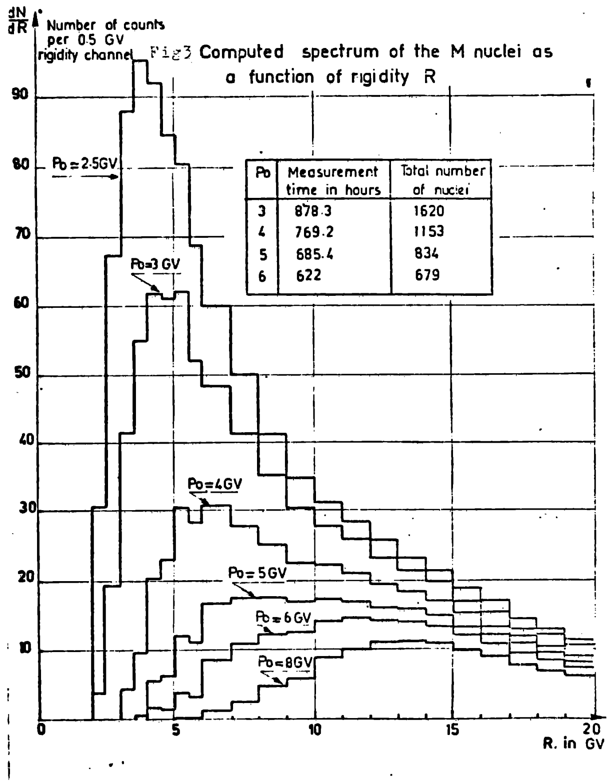
Figure 2 shows a photograph of the 3-dimensional model of that part of the charge spectrum from oxygen to argon, with P_o= 3 G V.

Fig. 2



Abundance of the M-nuclei (C, N, O) and of Boron

The abundances have been determined from diagrams obtained for the following values of P_o, $P_o = 3, 4, 5,$ G.V.



Po	Measurement time in hours	Total number of nuclei
3	878.3	1620
4	769.2	1153
5	685.4	834
6	622	679

Fig3 Computed spectrum of the M nuclei as a function of rigidity R

Taking into account on the one hand the variation of the cut-off P during the time of the measurement and on the other hand the fact that the integral flux of the nuclei as a function of rigidity R is of the form $\Phi = AR^{-\gamma}$, we have calculated the spectrum of the M-nuclei as a function of R for given values of P_o, supposing that when $R > 3$ G V, the integral flux of M-nuclei is

$$\Phi = 43.\, R^{-1.43} \text{part/m}^2.\ \text{ster. sec} \quad (5)$$

The spectra are shown in figure 3. The integrated abundances have been calculated. The ratio of the experimental abundances to the calculated integral abundances (see table 1), is equal to 1.15 ± 0.03 and is independant of P_o, where $\Phi = 49.5\ R^{-1.43}$ part/m2. ster. sec.

As a function of P_o, table 1 shows:

- for each element, the number of nuclei and the experimental abundance compared to that of Oxygen

- the experimental abundance of M-nuclei and their calculated abundances.

The relative abundances B/O, C/O, N/O, taking into account the errors indicated, are in good agreement with the published values (5) for $R > 3$ G V.

TABLE 1

Po in G. V.	B	C	N	O	M Nuclei	
					exp.	calcul.
3	216 ± 16	712 ± 29	192 ± 15	716 ± 29	1620 ± 37	1429
	0.30 ± 0.035	0.99 ± 0.08	0.27 ± 0.03	1		
4	148 ± 13	511 ± 25	138 ± 13	482 ± 24	1131 ± 31	960
	0.3 ± 0.04	1.06 ± 0.1	0.28 ± 0.04	1		
5	118 ± 11	376 ± 21	105 ± 11	353 ± 20	834 ± 26	717
	0.33 ± 0.05	1.065 ± 0.12	0.3 ± 0.05	1		

Abundance of nuclei from charge Z=9 to Z=14 and of Iron

The abundances, corrected and referenced to the abundance of oxygen are regrouped in table 2 for $P_o = 3$ and 4 G. V. Since values for aluminium, sodium and fluorine, depend on a small number of counts, the values are shown in table 2 without errors, nevertheless there is an indication that the values agree with those already published.

TABLE 2

Po in G. V.	F	Ne	Na	Mg	Al	Si	Fe
3	7	128 ± 13	15	168 ± 14	24	129 ± 13	89 ± 10
	0. 01	0. 18 ± 0. 025	0. 02	0. 23 ± 0. 03	0. 03	0. 18 ± 0. 025	0. 125 ± 0. 02
4	7	84 ± 10	12	118 ± 12	18	87 ± 10	71 ± 8
	0. 01	0. 174 ± 0. 03	0. 02	0. 245 ± 0. 035	0. 03	0. 180 ± 0. 03	0. 145 ± 0. 023

The ratios Ne/0, Mg/0, Si/0, Fe/0 are comparable to those most recently published (5). For these we have Ne/0 = Si/0=0. 16 to 0. 18, Mg/0 = 0. 2 to 0. 25 and Fe/0 = 0. 11 to 0. 15.

Abundances of iron group nuclei , Z = 15 to Z= 28

The results shown in table 3 are the number of nuclei after correction and the abundance with respect to Iron.

TABLE 3

S	Cl	A	K	Ca	SC	Ti	V_1	Cr_1	Mn	Fe	Ni
55	16	26	16	61	7	30	14	24	18	262	12
0. 21 ± 0, 04	0. 06	0. 1	0. 06	0. 23 ±0. 05	0. 03	0. 11	0. 055	0. 09	0. 07	1	0. 05

The results obtained without limitation on the value of the cut-off P_o, result in a longer measuring time and three times the number of events.

In this case the lower energy threshold has been determined by the response of the detectors and is equal to 1 GeV/nucleon. However the separation of the elements and the precision of the threshold are not as good as those for P_o = 3 G.V.

The less-abundant elements Z = 15 and Z = 27 can not be separated with respect to silicon and iron.

Our results indicate that sulfur and calcium are the most abundant elements after iron. We have S/Fe and Ca/Fe $\sim$ 0.2 It can be seen (5) that there is disagreement among the several results obtained from balloons for the iron group. However those published by Webber and Meyer (6) are close to our results.

Our data are as yet preliminary, they represent about 20 % of the data which will be available to us at the end of 1973.

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