PRELIMINARY RESULTS OF MEASUREMENTS OF HEAVY PRIMARIES IN THE REGION OF SUPERSONIC TRANSPORT USING PLASTIC STACKS

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1. INTRODUCTION

So called thin-down hits, meaning the same as stopping heavy primaries, can deposit a radiation dose of some thousand rads near the end of their trajectory. It is of great importance to know the intensities of such thin-down hits for flights at SST-level, because they can possibly bring about a biophysical damage. Though the intensities of heavy primaries are well known at the top of the atmosphere, a calculation of the intensities at SST-level must lead to less accurate results, since the parameters involved in this calculation - e.g. the fragmentation probabilities and the interaction mean free paths of such high energy collision of a nucleus with a nucleus - are not sufficiently accurately known. Therefore the intensities must be measured as done in this work. Preliminary results of the evaluation of this measurement which is in progress, are presented here.

2. MOUNTING OF THE PLASTIC STACK, BALLOON FLIGHTS

In order to measure the low intensity of the heavy primaries in the SST-region it is necessary to exposure a lot of detector material for a longer period of time in this altitude. In this experiment the plastic materials cellulose nitrate (Daicel), cellulose acetate (Bayer) and the polycarbonate Makrofol (Bayer) are used as detectors (Fig. 1). 1500 foils of these plastics were arranged in a stack composed of five identical layers. This stack measures an area of 40 x 40 cm^2 and a height of 25 cm. The balloon flights were carried out in Northern Germany at a geomagnetic rigidity of 2.5 GV by the balloon launching group of the Institut für Kernphysik at the University of Kiel. The stack was flown three times for 6 hours in order to get long exposure times. During the first and the third flight the balloon stayed at an altitude of 40 to 45 g/cm^2, whereas during the second flight it slowly dropped from 40 to 110 g/cm^2. In order to be able to decide whether the stopping particles hit the stack during the third flight or the previous ones the stack was turned upside down before being flown a third time.

3. SCANNING AND MEASURING

Above all it is intended to study the cellulose nitrate parts of each layer in the stack. These foils were arranged in such a way that alternatingly one 125 μ thick foil was placed upon one 250 μ thick foil. The thinner foils are destinated for scanning purposes. They are etched for 6 hours in stirred lye of 6 n NaOH with 0.05 % Benax. In this manner as many tracks as possible are etched until they turn to holes in the plastic foil. The etched foils are taped on a paper which is sensitive to ammonia in such a way that, when the foils are moistened with ammonia on the surface the paper turns black at each point where the plastic foil shows a hole or where the plastic material is damaged in any other way. After having treated the foils in the above mentioned way, only those areas on the foils under which a black spot on the paper has appeared have to be scanned. The tracks found this way then are traced through the thicker foils, which are etched for 4 hours under the same conditions. The charges of the particles can be determined by measuring the pit lengths as a function of the residual range as described by P.B. Price et al.[1].

Small stacks were exposed to 10.2 MeV/n carbon and neon ions of the Yale Heavy Ion Accelerator to calibrate the plastic materials. By measuring the tracks of these ions, which were etched under the same conditions, the track etching velocity could be determined as a function of the Restricted Energy Loss[2)]. The charges of the measured heavy primaries can be determined with an accuracy of $\pm$ 1.

4. RESULTS AND DISCUSSION

4.1 Charge spectrum

The results presented at this conference are obtained from the particles that stopped in the top layer of cellulose nitrate during the third balloon flight at an average altitude of 42.25 g/cm^2. Fig. 2 shows the charge spectrum at the top of the atmosphere[3)]. Two reasons are given for the low share of particles of the M-group ($6 \leq Z \leq 9$) by the experimental conditions.

The first reason is that through the scanning method used in this experiment only heavy ions with charges $Z \geq 9$ are found with a probability of 100 percent. The scanning efficiency is less than 100 percent for particles with lower charges, since these particles only form such short tracks that holes cannot be etched through the thin foils in each case. This lower scanning efficiency increases with decreasing charge of the particles and with increasing zenith angle of their incidence. It is indeed possible to correct the measured intensities for this diminished scanning efficiency, but we did not determine these correction factors yet.

The second reason for the low share of particles of the M-group only holds true for the top layers of the stack. This shall be illustrated by an example. A carbon ion ($Z = 6$) incident on the top of the atmosphere at a geomagnetic vertical rigidity of 2.5 GV has a cut-off energy of approximately 625 MeV/n. It stops when it has penetrated a 60 g/cm^2 thick slap of material. That means that in the first layer of cellulose nitrate (2.8 g/cm^2) of the stack that was flown under 42.25 g/cm^2 air, carbon ions can stop only when they are incident with greater zenith angles. This is similar for charges Z = 7 and Z = 8. If stopped heavy ions are found, which are incident on the stack under zenith angles that must be excluded in the way shown above, then these ions must be fragments of heavier ions which have been more decelerated by their higher energy loss before their fragmentation. Therefore it is possible to study the fragmentation parameters for fragmentations of heavier nuclei in nuclei of charges $6 \leq Z \leq 8$.

4.2 Thin-down intensity for $Z \geq 10$

64 of the 105 stopped particles found in the first layer of the stack have charges $Z \geq 10$ (H-group). Their medium charge is $\bar{Z} = 13$. At the top of the atmosphere the medium charge of the H-group is $\bar{Z} = 18$. Most of the particles with charges $15 \leq Z \leq 23$, which are scarce at the top of the atmosphere, were produced by fragmentation of Z = 24 and Z = 26 in the atmosphere.

Tab. 1 shows the intensities of thin-down hits for various atmospheric depths which are given by various zenith angles for a constant altitude of the balloon flight. E_{min} is the energy that a heavy ion of the medium charge $\bar{Z} = 13$ must have in order to penetrate the 1 mm thick aluminium sheet that covered the stack during the balloon flights. E_{max} is the maximum energy for the ion if it is supposed to stop in the top layer of cellulose nitrate.

Table 1

Measured thin-down intensities for charges $Z \geq 10$ at various depths of the atmosphere

atmospheric depth [g/cm^2]	E_{min} [MeV/n]	E_{max} [MeV/n]	number of particles	thin-down hits $Z \geq 10$ [m^2 s sr(MeV/n)]$^{-1}$
44	37	169	20	$1.08 \cdot 10^{-4}$
48.5	39	178	15	$7.64 \cdot 10^{-5}$
55.5	42	192	14	$5.45 \cdot 10^{-5}$
63.5	46	209	7	$4.94 \cdot 10^{-5}$
74.8	50	231	6	$2.94 \cdot 10^{-5}$
88.5	55	256	2	$1.64 \cdot 10^{-5}$

The measured intensity of stopped particles is divided by the difference of these two energies and expressed in terms of number of stopped particles per m^2 s sr (MeV/n).

In Fig. 3 the measured thin-down intensity for charges $Z \geq 10$ is compared with the results of Fukui et al.[4] who measured 32 particles of the H-group. The two measurements must show a difference caused by the solar modulation of the primary spectra. Fukui et al. have launched their balloons in 1965 and 1966 during the solar minimum at a time when the galactic component of the cosmic radiation had a maximum. Our balloons were flown in 1970 during the solar maximum. We did not convert our measured intensities to solar minimum because the influence of the solar modulation on heavy primary spectra is only known very roughly. A rough estimate shows, however, that one would obtain higher values as given by the best fit line of Fukui et al. Moreover this line seems to be too steep.

5. AIM OF THIS WORK

The aim of this work is to determine the intensities of thin-down hits for heavy primaries with charges $Z \geq 6$ for different energy regions, e.g. for different deep layers in the plastic stack. The frequencies of thin-down hits on the surface and in the interior of the body (embryo) for a SST-traveller shall be determined from these results. The thin-down intensities which are measured in the deeper layers of the plastic stack can be directly compared with the intensities in tissue in the interior of the body, since the fragmentation probabilities and the interaction mean free paths for heavy ions can be assumed to be equal in plastic and in tissue. If the thin-down intensity in the interior of the body is calculated by replacing the tissue by an equivalent amount of g/cm^2 air, then values must be obtained which are too low since fragmentations occur more frequent in air than in tissue.

* * *

REFERENCES

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2) E.V. Benton, Naval Radiol. Defense Laboratory, San Francisco, Report USNRDL - TR - 68 - 14 (1968)

3) M.M. Shapiro, R. Silberberg, C.H. Tsao, Proc. 11th Int. Conf. on Cosmic Rays Budapest 1969, Vol. I 479 (1970)

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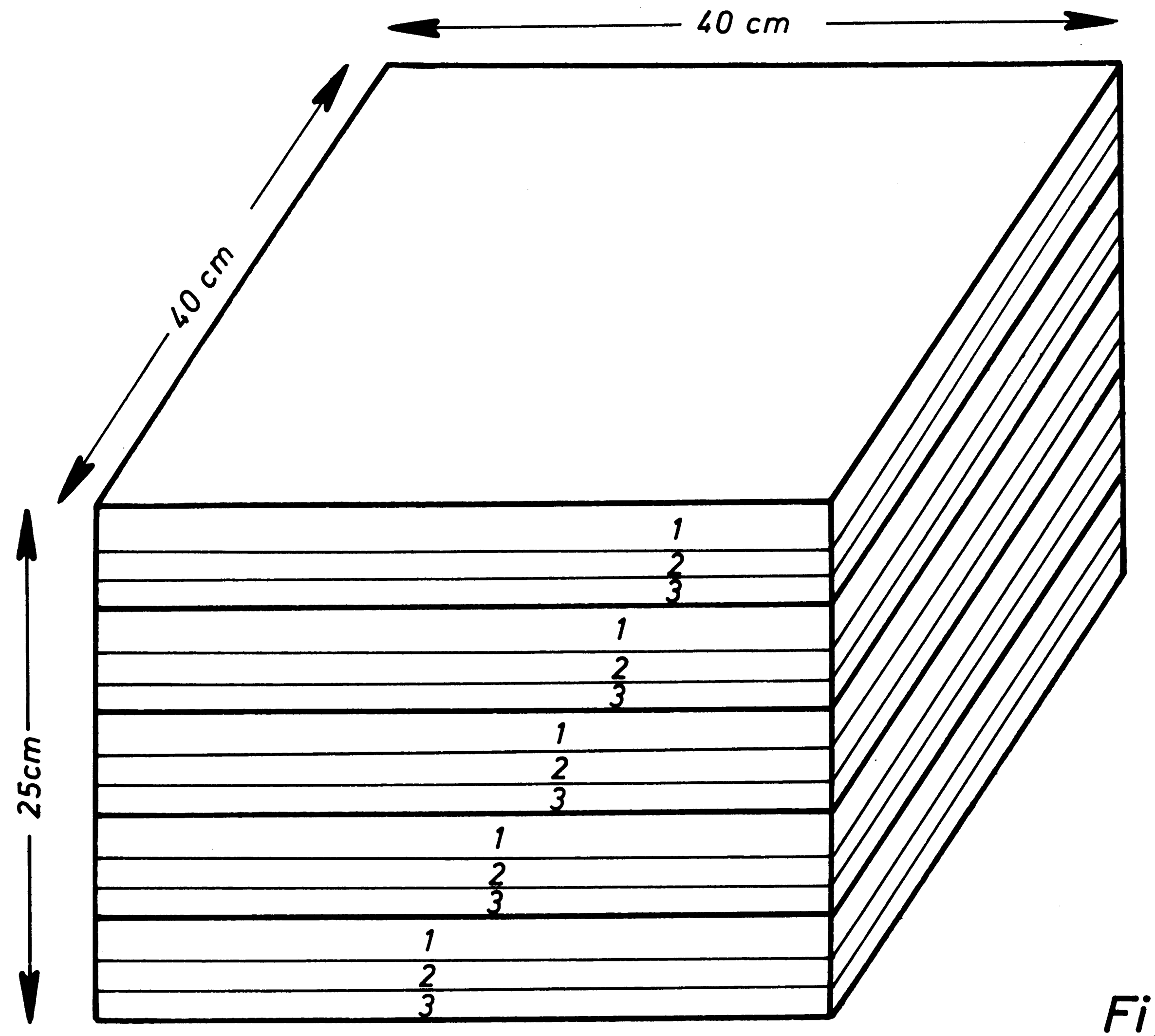
FIGURE CAPTIONS

Fig. 1 Schematic view of the plastic stack

Fig. 2 Heavy primary charge spectrum at SST-level and at the top of the atmosphere

Fig. 3 Measured thin-down intensity for charges $Z \geq 10$ at various depths of the atmosphere

KIEL-SST-STACK



1 Cellulose Nitrate (60 layers 125μ
60 layers 250μ)

2 Cellulose Acetate (60 layers 200μ
30 layers 60μ)

3 Makrofol (60 layers 200μ
Cellulose Acetate 30 layers 60μ)

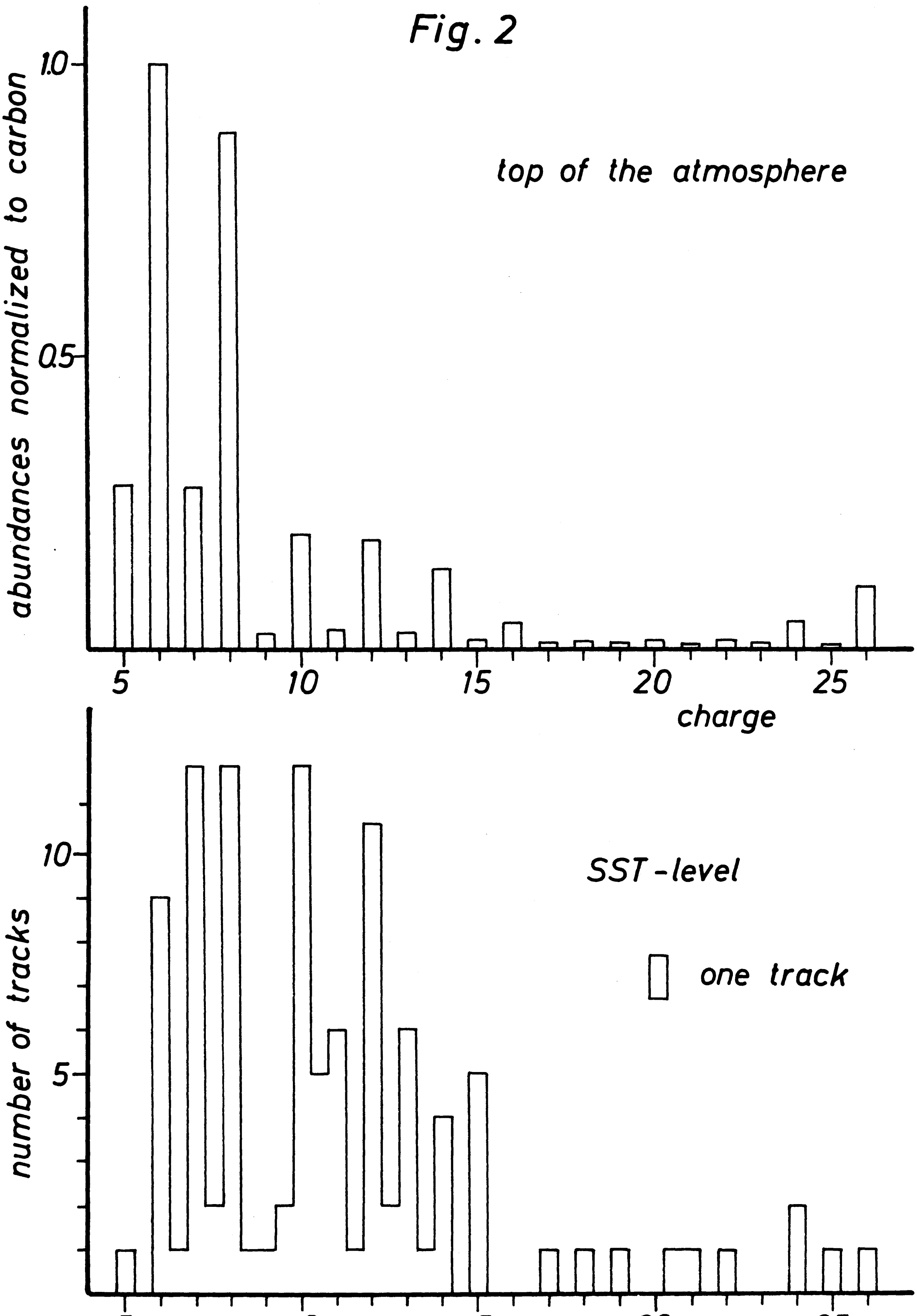
Total Weight 50 kg

Total Volume $4 \cdot 10^4 cm^3$

Total Absorption Length
$30 g/cm^2$

Fig. 1

Fig. 2


1.0
0.5
abundances normalized to carbon
top of the atmosphere
5
10
15
20
25
charge
10
5
number of tracks
SST-level
one track
5
10
15
20
25
charge

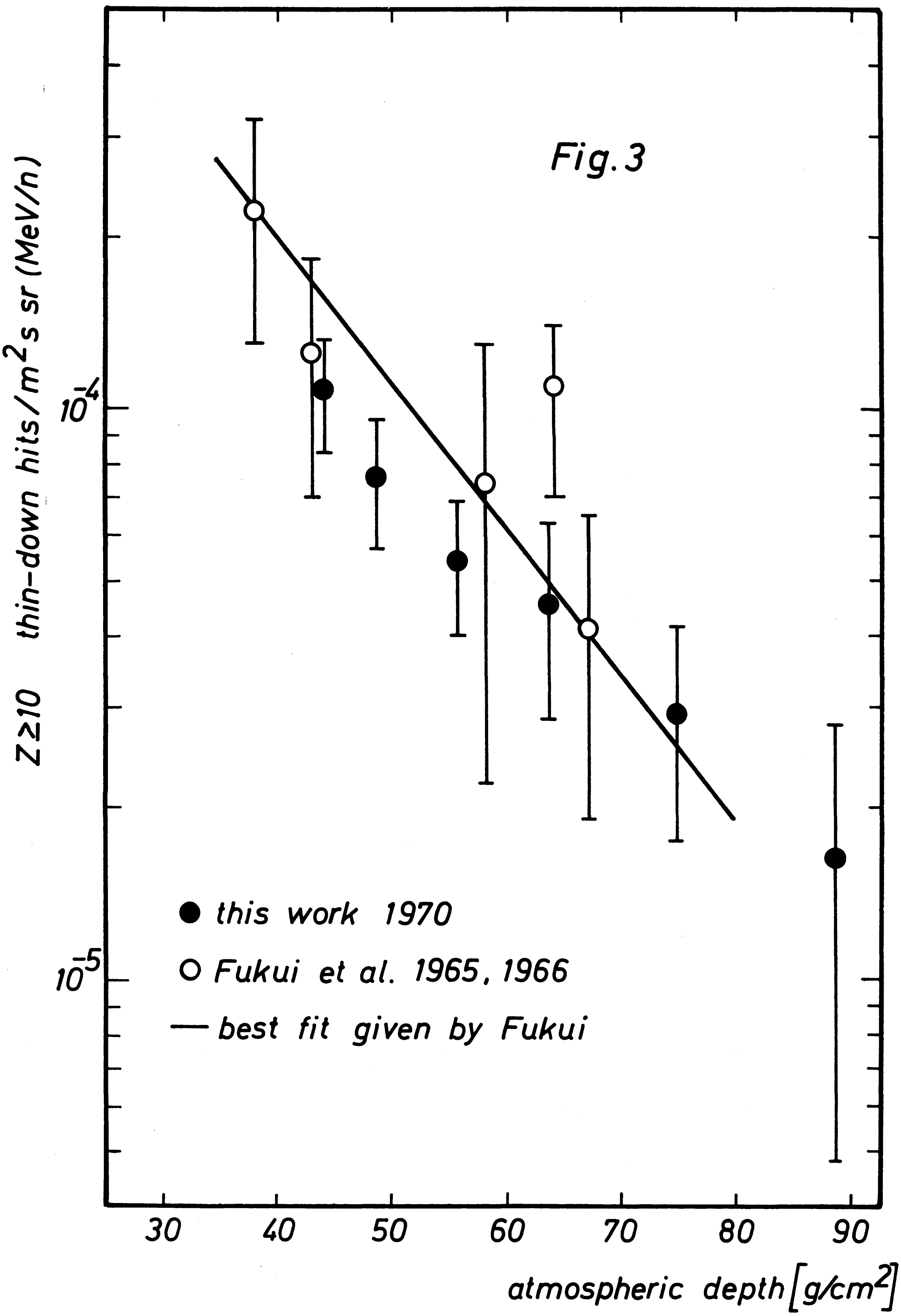


Fig. 3
Z≥10 thin-down hits/m²s sr (MeV/n)
10⁻⁴
10⁻⁵
30
40
50
60
70
80
90
atmospheric depth [g/cm²]
● this work 1970
○ Fukui et al. 1965, 1966
— best fit given by Fukui

Paper : Preliminary results of measurements of heavy primaries in the region of supersonic transport using plastic stacks

ENGELMAN: Vous avez comparé vos résultats aux spectres de charge des rayons cosmiques galactiques, présentés par Shapiro. Je dois signaler à ce propos que des spectres de charge ont été obtenus plus récemment en ballon par le groupe de Saclay, en collaboration avec le groupe de Copenhague, dirigé par le Prof. Peters.

Avez-vous essayé, à partir de tels spectres enregistrés à grande altitude, de calculer le spectre de charge à 40 g/cm^2 en utilisant les sections efficaces de fragmentation des différents noyaux, et de comparer ce spectre calculé à vos résultats expérimentaux?

HEINRICH: Our measured charge spectrum of heavy primaries at SST level is compared with the galactic charge spectrum of Ref. 3 because Shapiro et al. present in this paper a charge spectrum which summarizes a great number of measurements up till 1969.

A theoretical calculation of the heavy primary intensities at SST level must lead to less accurate results, since the fragmentation parameters which are involved in this calculation, are not sufficiently accurately known. But if the intensity at SST level is known with better statistics, you can possibly determine the fragmentation parameters with such a calculation. For this purpose, we have written a computer program and hope that it will be possible to determine the fragmentation parameters when we have got the final results of our measurements. Furthermore, if it is possible to determine such fragmentation parameters, which reproduce the measured results at SST level, you can see what influence the solar modulation has on the heavy primaries of SST level, by modifying the primary spectra in the same manner as the solar modulation does.

YOUNG: To what portion of the two spectra shown in Fig. 2 of your paper did you refer when you mentioned "the low share of particles of the M-group ($6 \leq Z \leq 9$) by the experimental conditions"? What do you mean by "the low share"?

HEINRICH: Only 41 of the measured 105 particles of this work have charges $Z < 10$. As you know from your own measurements, the share of the particles of the M-group should be much greater.

TURNER: Wie gross ist die Dosisleistung der schweren Teilchen gegenüber der von Protonen?

YOUNG: The answer to the question regarding the dose-equivalent due to the galactic heavy ions at the SST level is the following.

In my paper presented at the Working Party on Space Biophysics, which was held at Frankfurt on November 26 and 27, I gave my estimate on the maximum dose-rate due to all cosmic nuclei with $Z \geq 3$ to be 0.5 μrad/h. If we assume RBE to be 20 for these nuclei, we can evaluate the dose-equivalent as about 0.01 mrem/h.

HEINRICH: My opinion is that the effects caused by the microbeams of such stopping heavy ions cannot be described by a total body dose such as, for example, 0.01 mrem/h.