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EXPERIMENTAL ASSESSMENT OF COSMIC RAY IONIZING COMPONENT AT GROUND LEVEL BY MEANS OF HPGe AND NaI(T1) SPECTROMETRY

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Jae-Shik JUN*, Toshi NAGAOKA and Shigeru MORIUCHI

日　本　原　子　力　研　究　所
Japan Atomic Energy Research Institute

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Experimental Assessment of Cosmic Ray Ionizing Component at Ground Level by Means of HPGe and NaI(Tl) Spectrometry

Jae-Shik JUN*, Toshi NAGAOKA and Shigeru MORIUCHI

Department of Environmental Safety Research
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

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Experimental assessment of cosmic ray ionizing component at ground level has been carried out by use of high purity germanium(HPGe) and NaI(Tl) scintillation spectrometry systems, and empirical equations connecting dose rate obtained by an ionization chamber to corresponding count rate measured by the spectrometers in the energy region of 3 to 100 MeV were derived. A spherical ionization chamber of 14 litre in volume was used simultaneously with a 3"ϕ spherical NaI(Tl) and GAMMA-X HPGe detectors in order to make distinction between the dose rate of gamma ray below 3 MeV and that of cosmic ray ionizing component detected in higher energy region. Various cosmic ray dose rates and corresponding count rates were made available by applying shielding effect of a multi-storied building, including measurements at outdoor flat and a mountain top. As a result $Y = 30.25\ X_G + 1.42$ and $Y = 19.83\ X_N + 1.32$ were derived, where Y is dose rate due to cosmic ray ionization in $nGy \cdot h^{-1}$, and X_G and X_N are corresponding count rates in cps measured by HPGe and NaI(Tl) spectrometers, respectively, in the region of 3 to 100 MeV. And it appeared that 93 to 95% of total spectrometric counts were summed up in the energy region below 40 MeV of the cosmic ray spectra measured by both detector systems. Dual-valued slope of overall attenuation of cosmic ray ionization intensity was also found with a reflection point at penetrating

* Chungnam National University

depth equivalent of about 1600 $kg \cdot m^{-2}$ on the basis of power law model.

Keywords: Cosmic Ray, Dose Rate, Spectrometry, HPGe Detector, NaI(Tl) Detector, Gamma Ray

純Ge検出器及びNaI(Tl)シンチレーション検出器による地上レベル宇宙線電離成分の実験的評価

日本原子力研究所東海研究所環境安全研究部
田　載植*・長岡　鋭・森内　茂

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純Ge検出器及びNaI(Tl)シンチレーション検出器を用いて，地上レベルの宇宙線電離成分を評価した。また，電離箱で測定した線量率と3～100MeVのエネルギー領域の計数率とを結びつける実験式を求めた。

実験では，14ℓ球形電離箱，3”φNaI(Tl)シンチレーション検出器及びγ－X純Ge検出器の同時測定を行い，3MeV以下のγ線線量率とそれにより高エネルギー領域の宇宙線電離成分とを分離して評価した。屋外平坦地，山頂に加え，多層構造ビル内で様々な宇宙線遮蔽条件を選ぶことにより種々の宇宙線線量率レベルでの測定を行った。

実験から，使用した純Ge検出器については$Y=30.25X_G+1.42$，3”φ球形NaI(Tl)シンチレーション検出器については$Y=19.83X_N+1.32$の関係を得た。ここで，Yは宇宙線電離成分による線量率（nGy／h），X_Gは純Ge検出器の3～100MeV領域の計数率（cps），X_Nは3”φ球形NaI(Tl)シンチレーション検出器の3～100MeV領域の計数率（cps）である。宇宙線計数率の内40MeV以下の成分は，両検出器とも93～95％を占めた。また，全宇宙線電離強度と大気等価深度との関係は，1600kg／m²の点で傾斜が変ることが観測された。

東海研究所：〒319－11　茨城県那珂郡東海村白方字白根2－4
*忠南大学

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1. INTRODUCTION

Since ionizing component of cosmic rays comprises one of the major part of natural radiation environment in addition to gamma rays of terrestrial origin, many investigators have so far carried out the measurements and evaluations of cosmic ray exposure at ground level under indoor and outdoor conditions. Gold[1] succeeded in obtaining muon dose rate using a spherical xylene liquid scintillation detector at Argonne site, which amounts as high as 40-60% of the environmental gamma ray dose rate in that particular area. Miller and Beck[2], and Nagaoka[3] measured indoor cosmic rays as well as gamma ray exposure rates using pressurised ionization chamber, intrinsic germanium and NaI(Tl) scintillation spectrometers. In their measurements, however, the contribution of cosmic ray to the spectrometers only in the energy region below 4 MeV was taken into account. Wang and Chen[4] used a high-pressure ionization chamber for the evaluation of cosmic ray dose rates at several different places in altitude, including water reservoirs and airliners. The work of Bouville and Lowder[5] is an extensive estimation of world's population exposure to cosmic rays based on the evaluation of existing data on cosmic rays in the atmosphere and in interplanetary space. Lin et al.[6] measured cosmic ray induced ionization intensity by subtracting exposure rate obtained through gamma spectrometry using a 3"ϕ spherical NaI(Tl) scintillation detector from that obtained by a 20 litre standard ionization chamber. In their another work[7] they deduced a simple linear equation for estimating the intensity of cosmic ray ionizing component in terms of $nGy \cdot h^{-1}$ from the count rate of the spherical NaI(Tl) spectrometer in the energy range higher than 3 MeV.

In this study an attempt was made for the measurement of cosmic ray ionization exposure at ground level by use of high purity germanium(HPGe) semiconductor detector, together with a 3"ϕ spherical NaI(Tl) detector, which is nowadays very commonly employed in gamma spectrometry in general as well as environmental radiation study mainly because of its superior energy resolution. The primary purpose of this study is to look for and confirm the feasibility of HPGe spectrometry of cosmic ray ionizing component, and to derive an empirical equation for the assessment of air dose given by cosmic ray ionization at ground level from the number of events counted by the HPGe detector in the energy scale greater than 3 MeV. Derivation of similar equation for the NaI(Tl) detector is also to be followed.

A series of comparative study on the gamma ray dose rates assessed by several different methods of converting spectrum measured in the energy region below 3 MeV to dose rate is included.

2. MEASUREMENTS

2. 1 Scope of Measurements

In consideration of 99.6% of incident cosmic ray induced events are counted in the region of 3 to 100 MeV[7,8] with a small peak at 33 MeV[7,9] or 47 MeV[8] when a 3″φ spherical NaI(Tl) scintillation detector is used in the measurement of cosmic rays at ground level, the energy region of interest in this study was first set up from 3 to 100 MeV, although the detection property of HPGe detector may differ from that of NaI(Tl) detector for the cosmic ray ionization exposure. In order to figure out the detection probability of the HPGe detector for the cosmic ray ionizing component in the energy region of 3 to 100 MeV, a series of a prior simultaneous test operation was carried out with the use of 3″φ spherical NaI(Tl) detector system. As a result of the test the relative detection efficiency of the HPGe detector was tentatively found to be around 67 % that of the NaI(Tl) system, which is much higher than it was expected, when the dynamic range of energy measurement of the HPGe detector system is extended is nowadays very commonly employed in gamma spectrometry in general as well as environmental radiation study mainly because of its superior energy resolution. The primary purpose of this study is to look for and confirm the feasibility of HPGe spectrometry of cosmic ray ionizing component, and to derive an empirical equation for the assessment of air dose given by cosmic ray ionization at ground level from the number of events counted by the HPGe detector in the energy scale greater than 3 MeV. Derivation of similar equation for the NaI(Tl) detector is also to be followed.

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The cosmic ray ionization exposure was to be measured and quantified in terms of air dose rate by subtracting the dose rate due to gamma rays of energy below 3 MeV, which was measured by the 3"φ spherical NaI(Tl) detector and assessed by means of G(E) function method[10,11], from total dose rate measured simultaneously by a 14 litre spherical ionization chamber, which detects essentially all incident ionizing particles including cosmic rays. Thus obtained dose rates of cosmic ray ionization exposure were to be compared with total counts measured by the HPGe detector in the energy region greater than 3 MeV in order to look for correlationship between those two quantities. Although the gamma ray dose rate assessed by G(E) funtion method was to be used for eliminating gamma ray contribution from total dose rate measured by the ionization chamber, each spectrum measured at energy below 3 MeV by the NaI(Tl) detector was converted to dose rate by four different methods including G(E) function method in order to make a comparative study. Three others are total spectrum energy analysis, energy band analysis and spectral stripping methods. The spectra measured by HPGe detector system at energy below 3 MeV were also used for the assessment of gamma ray exposure rates by G(E) operation method and the outcomes were included in the comparative study.

2. 2 Instrumentation

The experiment was designed to be performed by simultaneous use of the 14 litre spherical ionization chamber developed in JAERI, the 3"φ spherical NaI(Tl) and the HPGe detectors. The last two detectors were used in association with each separate unit of portable multichannel pulse height analysers (MCAs), and the output of the ionization chamber was read by a vibrating reed electrometer system.

The HPGe detector used in this study was in size of 55.2 mm diameter×52.0 mm length with 1.0 mm Al absorbing layer, and it was used in conjunction with a portable 4096 channel MCA(EG&G ORTEC 7500A). Useful energy range of the detector is recommended from 3 keV to 10 MeV by the manufacturer, while conversion gain and maximum output of the assembled preamplifier (ORTEC 167N) are nominally known to be 200 mV/MeV and + 7 V for a single event, respectively, which means that the highest measurable energy is intrinsically limited to about 35 MeV. In order to overcome this limit and extend the dynamic range of the HPGe detector for the measurement of higher energy signals, a pulse height attenuator(JAERI Model 171) had to be used for suppressing pulse height to one fifth the output from the dectector system so as to enable all pulses corresponding to up to about 100 MeV or greater to be registered in the MCA. The 3″φ spherical NaI(Tl) detector was used in association with a separate MCA (CANBERA 10) in 512 and 1024 channel region.

The ionization chamber used in this study was a spherical type of 14 litre in volume, developed specifically for precise measurement of low level environmental radiation dose rate by Japan Atomic Energy Research Institute (JAERI), which made of air equivalent wall material of charged particle equilibrium thickness(12). The entire measurement system was arranged as shown in Fig.1.

2.3 *In-situ* Measurements

For the derivation of dose rate - count rate relationship and relevant regression equation, it is necessary to establish a condition of having various cosmic ray dose rates and corresponding variation of count rates. In order to achieve this purpose it was decided to apply the shielding effect of a multi-storied building like the Research Building No.3 of JAERI, in which we could use six different floors, including two stories of basement. Points of measurements in the building are indicated in Fig. 2.

While the points of measurement were selected along the median line of the sectional view, namely at corridor of each floor where it was available, rest three points had to be selected in the laboratory or conference rooms which are apart a little from the median line. In the latter case, however, the points were selected at least 5 m inside the room from the window to avoid inconsistancy of cosmic ray exposure rate appearing within 4 m from the windows of building(3). The height of center of the detectors was chosen at 1 m from each floor and the distances from the walls to detectors were kept further than 1m. Integrated cosmic ray penetrating depth equivalent at each point of measurement in the building, relative to zero depth taken at outdoors of JAERI near the sea level, was estimated taking into account all concrete structure and ceiling materials in reference to the original blueprint, and the values are shown in Table 1. The measurements in outdoor(in a JAERI garage with essentially negligible shielding) and on a mountain of 1.01 km in height(Yamizo-san) were also made. In the case of estimating penetrating depth equivalent at Mt. Yamizo, mean air density of 1.18 $kg \cdot m^{-3}$ was assumed within the height(13).

In each cycle of measurement at each point, background gamma ray spectra up to 3 MeV were measured for 30 minutes immediately before and after the measurement of cosmic ray ionizing component by NaI(Tl) and HPGe detector systems in order to figure out their dose rates("gamma ray mode") which were to be subtracted from the total dose rate measured by the ionization chamber, while the ionization chamber was operated under a steady condition for the period of entire cycle of spectrometric measurements of cosmic ray and gamma ray exposure. For the measurement of cosmic ray ionization, the conditions of HPGe and NaI(Tl) detectors were to be changed so as to cover the energy range of 3 to 100 MeV and count large enough number of events. This condition of measurement is called "cosmic ray mode". Mean period of time spent for an entire cycle of measurement at each point is as shown in Table 2.

3. RESULTS AND DISCUSSION

3. 1 Spectra of Cosmic Ray Ionizing Component

Typical pulse height spectra measured in cosmic ray mode by the GAMMA-X HPGe and the 3"ϕ spherical NaI(Tl) detector systems are shown in Figs. 3 and 4, respectively. In those Figs., the energy scales were established by use of 1.461 MeV(^{40}K) and 2.614 MeV(^{208}Tl) gamma ray peaks as other investigators did.(7,9) As shown in Fig. 3, the distribution of pulses greater than that of about 39 MeV are saturated around 40 MeV scale due to the limited range of pulse registration, nevertheless all output pulses below 100 MeV were made to be counted by use of the pulse height attenuator. In Fig.3, however, there appeared a small peak at about 35 MeV, and this is quite comparable with similar peak of 33 MeV shown in the spectrum of Fig.4, which coincides with that predicted by calculation(9) and measured by others(7). This comparability is further more convincing when we take the variety in published values of peak energy(7,8,9) and unknown true value into account. With a little thoughtful notice it is easily conjecturable that the spectrum of Fig.3 should be stretched out up to 100 MeV in a similar fashion shown in Fig.4, if the range of registration were not limited. In order to obtain full energy spectrum of cosmic ray ionizing component covering 3 to 100 MeV region by use of HPGe detector system some modifications are necessary on preamplifier circuit for adjusting the gain of charge amplifier by varying the capacitance of feedback capacitor. This work is left to be attempted in near future. The distribution of percentage count in all the spectra measured were estimated at 5 MeV interval except for 3 to 10 MeV count large enough number of events. This condition of measurement is called "cosmic ray mode". Mean period of time spent for an entire cycle of measurement at each point is as shown in Table 2.

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Numerical values of mean percentage count distribution taken from nine spectra each measured by HPGe and NaI(Tl) detectors, respectively, are summarized in Table 3. As shown in this Table in the case of HPGe spectrometry the percentage count in 3 to 40 MeV interval sums up about 95.5 %, while it becomes about 93.2 % in the case of NaI(Tl) which satisfactorily coincides with Lin's data[7] of 93.02 % although it might not be the representative value of indoor measurements.

The distribution of the mean percentage count with measured energy interval are plotted in Figs. 7 and 8, respectively. In the Figs. 5 to 8, the percentage counts in 5 to 10 MeV interval were leveled off from those in 3 to 10 MeV, excluding contributed count portion in 3 to 5 MeV interval.

3.2 Counts-Dose Relationship of Cosmic Ray Component

For all the spectra measured, count rates were estimated from the integrated counts of energy region higher than 3 MeV in the spectra and those count rates were compared with cosmic ray dose rates evaluated by the ionization chamber through subtraction of gamma ray dose rate from the total dose rate measured simultaneusely. As mentioned previousely the gamma ray dose rate used here was assessed by means of G(E) function method.[10,11] Resultant data are shown in Table 4. With these data it was found that correlation coefficients between the dose rate of cosmic ray ionization exposure and spectrometric count rates in 3 to 100 MeV region measured by the GAMMA-X HPGe and the 3"ϕ spherical NaI(Tl) detectors are +0.9913 and +0.9924, respectively, which seem to be quite satisfactory to derive meaningful regression equations. The derived equations are

$$Y = 30.25\ X_G + 1.42 \quad (1)$$

and

$$Y = 19.83\ X_N + 1.32, \quad (2)$$

where Y is dose rate given by cosmic ray ionizing component in $nGy \cdot h^{-1}$, and X_G and X_N are spectrometric count rates in cps(counts per second) measured in the energy region of 3 to 100 MeV by HPGe and NaI(Tl) detectors, respectively. The graph of the two equations is shown in Fig. 9. Eq.(1) strongly implies the possibility of detecting ionizing component of cosmic ray at ground level with HPGe semiconductor detector, and evaluating the dose given by the component with satisfactory accuracy. It is quite understandable that this possibility is very much attributed to fairly large ratio of CR_{Ge}/CR_{NaI} which amounts to 0.653 on average as shown in Table 4.

3.3 Attenuation of Cosmic Ray Ionizing Component

The vertical attenuation of cosmic ray ionization intensity in air and the building was examined for our particular case of study. Fig. 10 shows the attenuation curves obtained by three different detectors used here. Zero point of penetrating depth equivalent was taken at outdoors of JAERI Research Building No.3 built near the sea level, and reflection points are appeared on all the three curves at 420 $kg \cdot m^{-2}$, which is equivalent to total penetrating depth of about 1600 $kg \cdot m^{-2}$ from the first or highest-valued points of measurement in each curve. This depth of reflection, presumably occured by the attenuation of soft component, agrees fairly well with those showed by experimental measurement[7] and theoretical calculation[9]. In this study, however, an attempt was made to estimate the slopes of overall attenuation curves for the cosmic ray ionizing component based on the power law model for cosmic ray ionization or flux attenuation.[14,15] According to the graphical study the slopes of overall attenuation curves were estimated roughly to be 3.2×10^{-4} and 1.9×10^{-4} for the depth smaller and larger than 1600 $kg \cdot m^{-2}$, which correspond to the attenuation of softer and harder component of cosmic ray ionization, respectively.

3.4 Assessment of Gamma Ray Exposure Rates

As mentioned earlier in sec. 2.3, measurements of "gamma ray mode" were performed before and after the measurements in each cycle at each point with both GAMMA-X HPGe and 3"φ spherical NaI(Tl) spectrometers.

Of the gamma ray spectra obtained by the two detector systems, those measured by NaI(Tl) detector were converted into dose rate($\dot{D}$) by four different methods, namely, G(E) operation ($\dot{D}_{GNa}$)[10,11], total spectrum energy analysis($\dot{D}_T$), energy band analysis ($\dot{D}_E$) and spectral stripping ($\dot{D}_S$) methods, while for the spectra measured by HPGe system G(E) function method was only used to figure out corresponding dose rate (D_{GGe}). Resultant data are tablated in Table 5. As shown in the Table, the deviation of each mean indoor dose rate is within the range of 5.8 to 6.0 % in the case of those measured by NaI(Tl) detector, while for D_{GGe} the deviation becomes larger to be 6.9 %.

In order to look for the quantitative differences between the dose rates assessed by different methods, the ratios of each dose rate relative to $\dot{D}_{GNa}$ which was used for subtracting gamma ray contribution from total output of gamma and cosmic ray ionization measured by the spherical ion chamber, are summarized in Table 6. In this Table the largest difference shown is dose rate assessed by energy band analysis, of which difference amounts to more than 12 % as a whole. The other three ratios spread from 0.6 to 6.0 % in overall mean with the ratio close to unity in the case of $\dot{D}_s/\dot{D}_{GNa}$, 2.5% smaller in $\dot{D}_T/\dot{D}_{GNa}$ and 6.2% larger in $\dot{D}_{GGe}/\dot{D}_{GNa}$. There might be several factors causing these discrepancies with a particular possible cause of angular response in the case of $\dot{D}_{GGe}/\dot{D}_{GNa}$[16].

A further comparison was made between $\dot{D}_E$ and $\dot{D}_s$ both of which consist of component contribution of gamma rays from ^{40}K, U and Th decay products, as shown in Table 7. The total ratio indicates that $\dot{D}_E$ is 12.3 % larger than $\dot{D}_S$, which is very similar amount of difference shown in Table 6 where $\dot{D}_E/\dot{D}_S$ appear to be 1.128, while $\dot{D}_S/\dot{D}_{GNe}$ is close to unity. And in Table 7 it is easily understood that this discrepancy stems mainly from the component contribution of U decay series.

4. CONCLUSION

Throughout this study the followings were found and understood.

1) The analysis of percentage count of the spectra measured for ionizing component at ground level by NaI(Tl) and HPGe spectrometer shows that 93 to 95% of integral spetrometric counts are summed up in the energy region below 40 Mev, varying spectrum shape with penetrating depth. The peak of the spectrum around 30 MeV, getting the energy slightly lower, becomes more distinctive with increasing the penetrating depth equivalent.

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measurement of natural background radiation having energies much higher than 3 MeV, which mainly consists of muons and electrons. So far this has not been a subject of interest for most researchers. HPGe semiconductor detector enables us not only to simply detect the ionizing component of cosmic rays, but also evaluate the dose given by the component with satisfactory accuracy.

3) On the basis of power law model of cosmic ray flux in the atmosphere, the slope of attenuation curves of cosmic ray ionization intensity at ground level were found to be dual-valued with a reflection point at penetrating depth equivalent of about 1600 $kg \cdot m^{-2}$, which shows quantitatively different attenuating patterns of softer and harder component of cosmic ionizing radiation at ground level.

4) According to a comparative study on four different assessment methods of gamma ray dose rate from the spectrum measured by NaI(Tl) detector, discrepancy between the outcomes ranges from 0.6 to 6.2 % with an exception of 12.8 % shown by that of energy band analysis method.

5) For the measurement of full energy spectrum of cosmic ray ionizing component covering 3 to 100 MeV by use of HPGe detector system it is necessary to modify the assembled preamplifier circuit for adjusting the gain of charge amplifier. This work is left to be solved in near future.

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Table 1 Points of cosmic-ray ionizing intensity measurement and their estimated penetrating depth equivalent.

Name of the point	Symbol of the point	Estimated penetrating depth equivalent ($kg \cdot m^{-2}$)[a]
Mt.Yamizo	Mt.Y.	-1192[b]
Outdoor, JAERI	Outd.	0
4th Floor	4F	420
3rd Floor	3F	997
2nd Floor	2F	1958
1st Floor	1F	2409
Basement 1st F, room	$B1_R$	2600
Basement 1st F, corridor	$B1_C$	2860
Basement 2nd F.	B2	3260

a) Relative to zero depth taken at outdoors of JAERI near the sea level.

b) Mean air density of 1.18 $kg \cdot m^{-3}$ is assumed within the height[13].

Table 2 Mean period of time spent for a cycle of cosmic ray ionization intensity measurement.

Detector used	Period of time spent (hours)	Remark
Ion Chamber, 14 ℓ spherical	15.6 ± 5.9	
HPGe, GAMMA-X	14.1 ± 4.3	plus additional 1 hr for "gamma ray mode"
NaI(Tl), 3″φ spherical	14.2 ± 4.4	〃

Table 3 Mean percentage count of cosmic ray ionizing component taken from nine spectra observed at 5 MeV interval.

Energy region (MeV)	HPGe Spectra		NaI(Tl) Spectra	
	P.H. region(ch.)	Percentage count	P.H. region(ch)	Percentage count
3-10	294-981	24.4±3.7	29-92	25.1±3.8
10-15	982-1472	10.2±0.9	93-138	11.2±1.2
15-20	1473-1962	9.2±0.3	139-184	11.5±1.1
20-25	1963-2453	8.7±0.3	185-230	13.2±2.2
25-30	2454-2943	9.3±0.8	231-276	14.4±2.5
30-35	2944-3434	12.9±1.9	277-322	11.7±2.0
35-40	3435-3924	20.7±5.1	323-368	6.1±2.1
(1st sub total)		(95.5±5.1)		(93.2±1.7)
40-45	3925-4095	4.5±3.8	369-414	2.7±0.8
45-50			415-460	1.4±0.4
50-55			461-506	0.8±0.2
55-60			507-552	0.6±0.2
60-65			553-598	0.4±0.1
65-70			599-644	0.3±0.1
70-75			645-690	0.2±0.1
75-80			691-736	0.2±0.1
80-85			737-782	0.1±0.1
85-90			783-828	0.1±0.1
90-95			829-874	0.1±0.1
95-100			875-920	0.1±0.1
(2nd sub total)		(4.5±3.8)		(6.8±1.7)

Table 4 Cosmic ray ionization intensity measured by 14 litre spherical ionization chamber, GAMMA-X HPGe and 3"φ spherical NaI(Tl) detectors, as a function of penetrating depth equivalent.

Estimated depth equivalent($kg\cdot m^{-2}$)	$\dot{D}_{CR}$ a) ($nGy\cdot h^{-1}$)	CR_{Ge} b) (cps)	CR_{NaI} c) (cps)	CR_{Ge}/CR_{NaI}
3260	15.83	0.50	0.75	0.667
2860	16.77	0.53	0.82	0.646
2600	18.07	0.57	0.88	0.648
2409	20.11	0.58	0.90	0.644
1958	22.12	0.61	0.94	0.649
997	24.93	0.78	1.21	0.645
420	25.82	0.82	1.25	0.656
0	31.25	1.05	1.56	0.673
-1192 d)	46.25	1.45	2.24	0.647
Average				0.653 ± 0.010

a) Dose rate of cosmic ray ionizing component measured by ion chamber.

b) Total count rate in 3-100 MeV region measured by HPGe detector.

c) Total count rate in 3-100 MeV region measured by NaI(Tl) detector.

d) Mean air density of 1.18 $kg\cdot m^{-3}$ is assumed within the height[14].

Table 5 Gamma ray dose rate ($nGy \cdot h^{-1}$) measured and assessed by different methods.

place	$\dot{D}_{GNa}$	$\dot{D}_T$	$\dot{D}_E$	$\dot{D}_S$	$\dot{D}_{GGe}$
B2	63.76	62.19	71.86	63.03	68.39
B1c	59.98	58.50	68.45	61.66	64.55
B1R	57.33	55.90	64.08	56.09	57.45
1F	54.70	53.30	62.93	56.32	57.40
2F	63.88	62.28	70.97	62.89	65.61
3F	64.92	63.28	74.73	67.34	69.26
4F	58.24	56.73	66.46	60.82	63.45
(indoor mean)	(60.40±3.60)	(58.88±3.52)	(68.50±3.98)	(61.16±3.67)	(63.73±4.41)
Outd.	40.83	39.59	45.62	40.50	44.60
Mt.Y.	29.04	28.22	31.81	28.00	31.42

$\dot{D}_{GNa}$: Measured by 3″φ spherical NaI(Tl) spectrometer and assessed by G(E) function method.

$\dot{D}_T$: Measured by 3″φ spherical NaI(Tl) spectrometer and assessed by total spectroum energy analysis.

$\dot{D}_E$: Measured by 3″φ spherical NaI(Tl) spectrometer and assessed by energy band analysis.

$\dot{D}_S$: Measured by 3″φ spherical NaI(Tl) spectrometer and assessed by spectral stripping method.

$\dot{D}_{GGe}$: Measured by GAMMA-X HPGe spectrometer and assessed by G(E) funtion method.

Table 6 Ratio of $\dot{D}$'s measured and assessed by different methods relative to $\dot{D}_{GNa}$.

Place	$\dot{D}_T/\dot{D}_{GNa}$	$\dot{D}_E/\dot{D}_{GNa}$	$\dot{D}_S/\dot{D}_{GNa}$	$\dot{D}_{GGe}/\dot{D}_{GNa}$
B2	0.975	1.127	0.989	1.073
$B1_C$	0.975	1.141	1.028	1.076
$B1_R$	0.975	1.118	0.978	1.002
1F	0.974	1.150	1.030	1.049
2F	0.977	1.111	0.985	1.027
3F	0.975	1.151	1.037	1.067
4F	0.974	1.141	1.044	1.089
(Indoor Mean)	(0.975±0.001)	(1.134±0.015)	(1.013±0.026)	(1.055±0.029)
Outd.	0.974	1.122	0.996	1.097
Mt. Y.	0.972	1.095	0.964	1.082
(Outdoor Mean)	(0.973±0.001)	(1.109±0.014)	(0.980±0.016)	(1.090±0.008)
Overall Mean	0.975±0.001	1.128±0.018	1.006±0.028	1.062±0.029

Table 7 Gamma ray dose rates ($nGy \cdot h^{-1}$) with component contribution assessed by energy band analysis ($\dot{D}_E$) and spectrum stripping ($\dot{D}_S$) methods from the spectra measured by 3"φ spherical NaI(Tl) scintillation detector.

Place	$\dot{D}_E$				$\dot{D}_S$				$\dot{D}_E/\dot{D}_S$			
	K	U	Th	Total	K	U	Th	Total	K	U	Th	Total
B2	25.49	29.06	17.32	71.86	23.28	23.06	16.70	63.03	1.095	1.260	1.037	1.140
$B1_C$	24.00	28.20	16.29	68.45	21.38	24.70	15.58	61.66	1.121	1.142	1.045	1.110
$B1_R$	21.62	24.92	17.53	64.08	19.62	19.72	16.75	56.09	1.102	1.263	1.047	1.142
1F	21.11	24.79	17.04	62.93	19.13	21.18	16.01	56.32	1.103	1.170	1.065	1.117
2F	25.35	26.40	19.23	70.97	22.79	21.63	18.48	62.89	1.113	1.221	1.040	1.129
3F	21.39	34.94	18.32	74.73	19.01	31.14	17.19	67.34	1.125	1.122	1.066	1.110
4F	22.83	25.64	17.99	66.46	20.49	23.13	17.21	60.82	1.114	1.108	1.046	1.093
(indoor mean)	23.11 ±1.72	27.71 ±3.31	17.67 ±0.88	68.50 ±3.98	20.81 ±1.60	23.51 ±3.45	16.85 ±0.87	61.16 ±3.67				
Outd.	15.60	17.90	12.18	45.62	14.03	14.68	11.79	40.50	1.112	1.219	1.033	1.127
Mt. Y.	9.10	12.31	10.40	31.81	8.00	9.66	10.34	28.00	1.137	1.275	1.006	1.136
Overall mean of the ratio									1.114 ±0.012	1.198 ±0.060	1.043 ±0.017	1.123 ±0.015

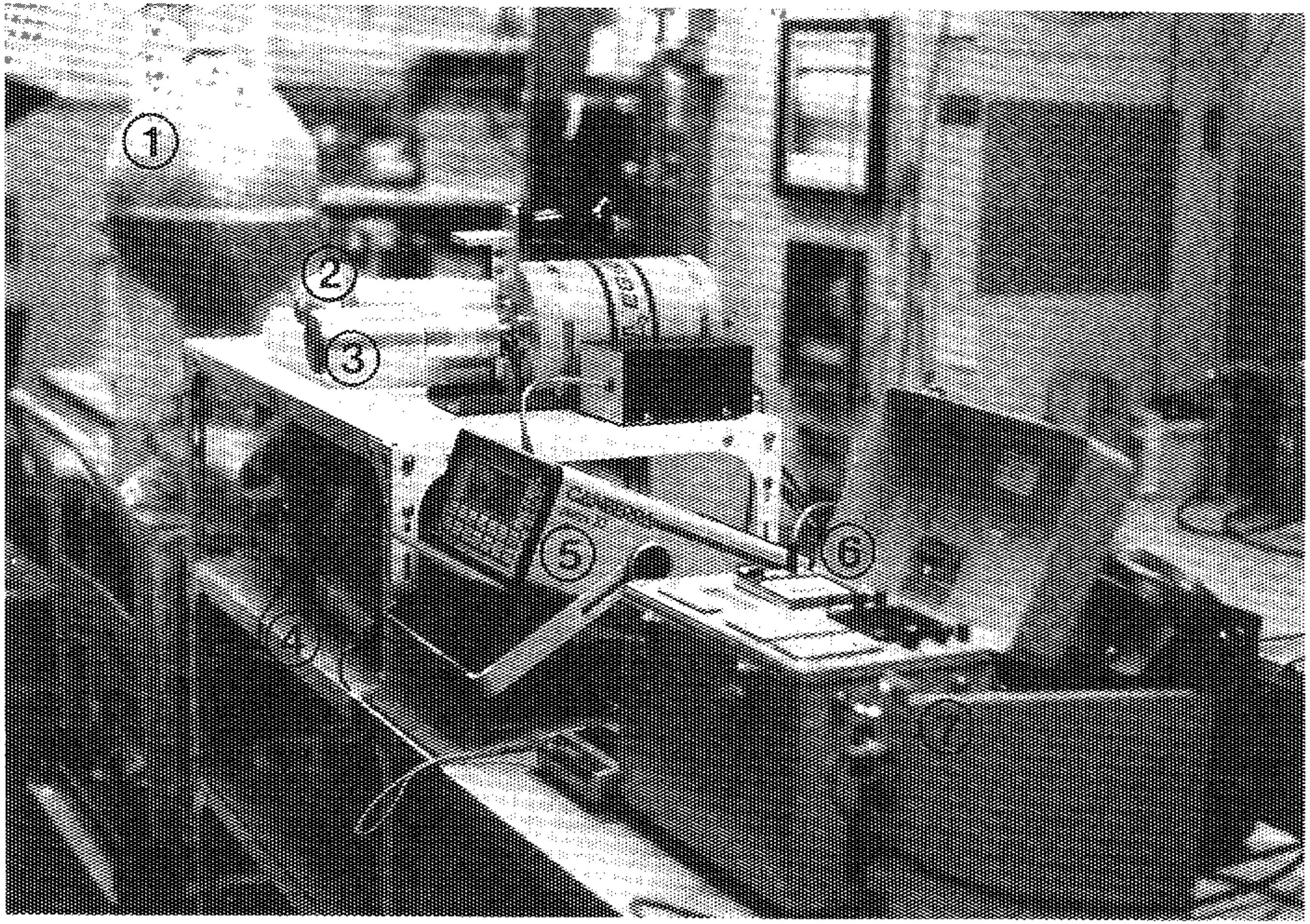

Fig. 1 Arrangement of ionization chamber and spectrometry systems for the measurement of cosmic ray ionizing component. ① ionization chamber, ② 3"ϕ spherical NaI(Tl) scintillation detector, ③ GAMMA-X HPGe detector, ④ electrometer system, ⑤ MCA for NaI(Tl), ⑥ MCA for HPGe, ⑦ pulse height attenuator.

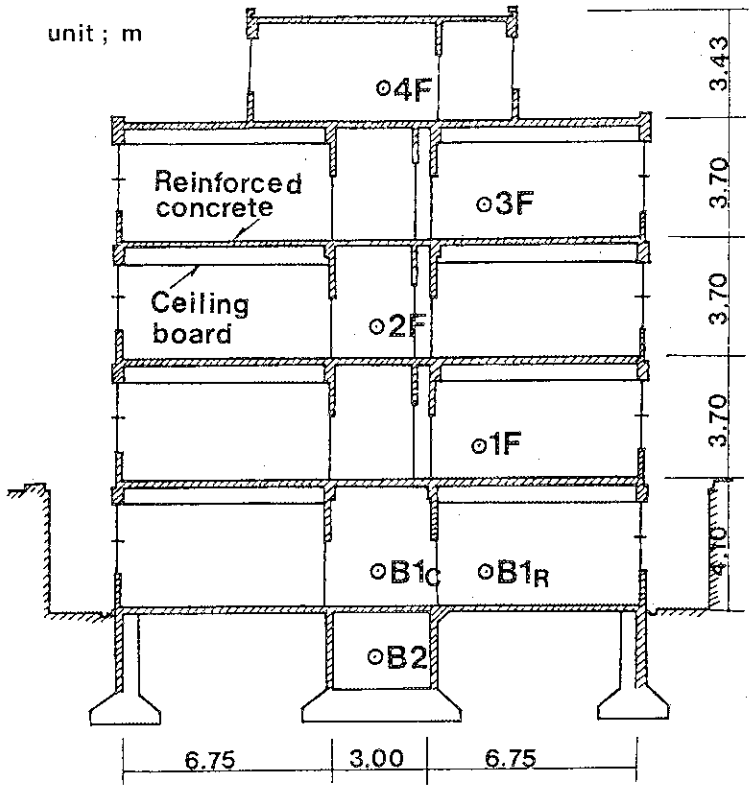

Fig. 2 Vertical view of structure and distribution of cosmic ray measurement points in the Research Building No.3 of JAERI.

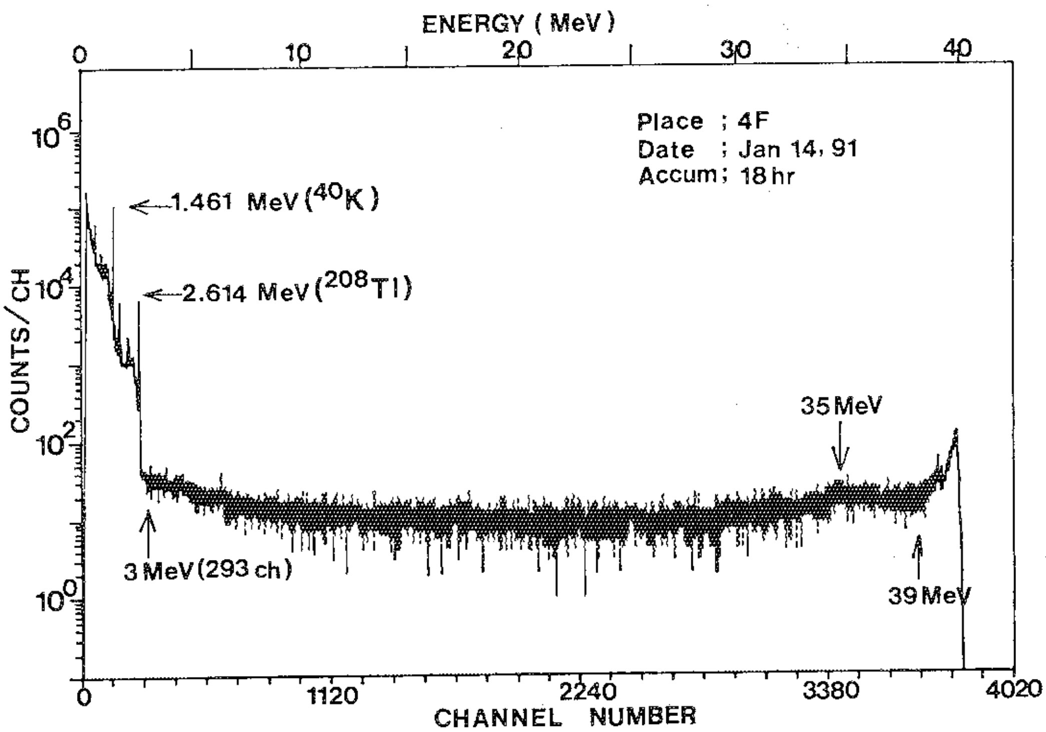

Fig. 3 A spectrum of cosmic ray ionizing component measured by GAMMA-X semiconductor detector.

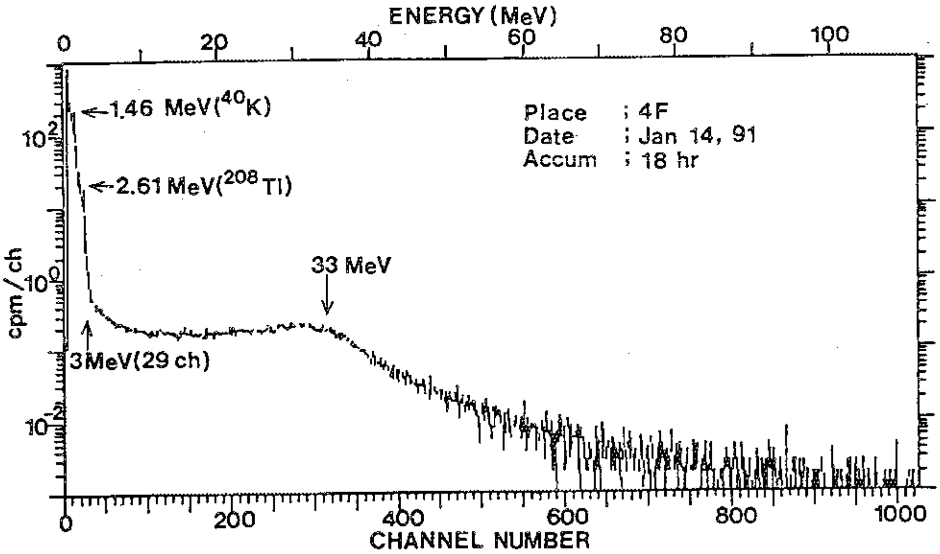

Fig. 4 A spectrum of cosmic ray ionizing component measured by 3"ϕ spherical NaI(Tl) scintillation detector.

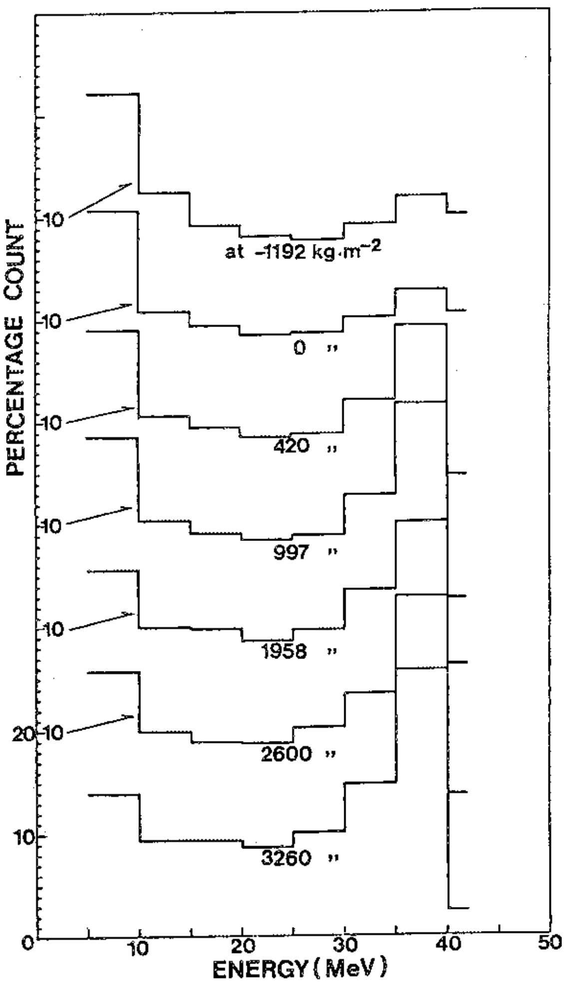

Fig. 5 Percentage count spectra of cosmic ray ionizing component measured by GAMMA-X HPGe spectrometer at varying penetrating depth equivalent.

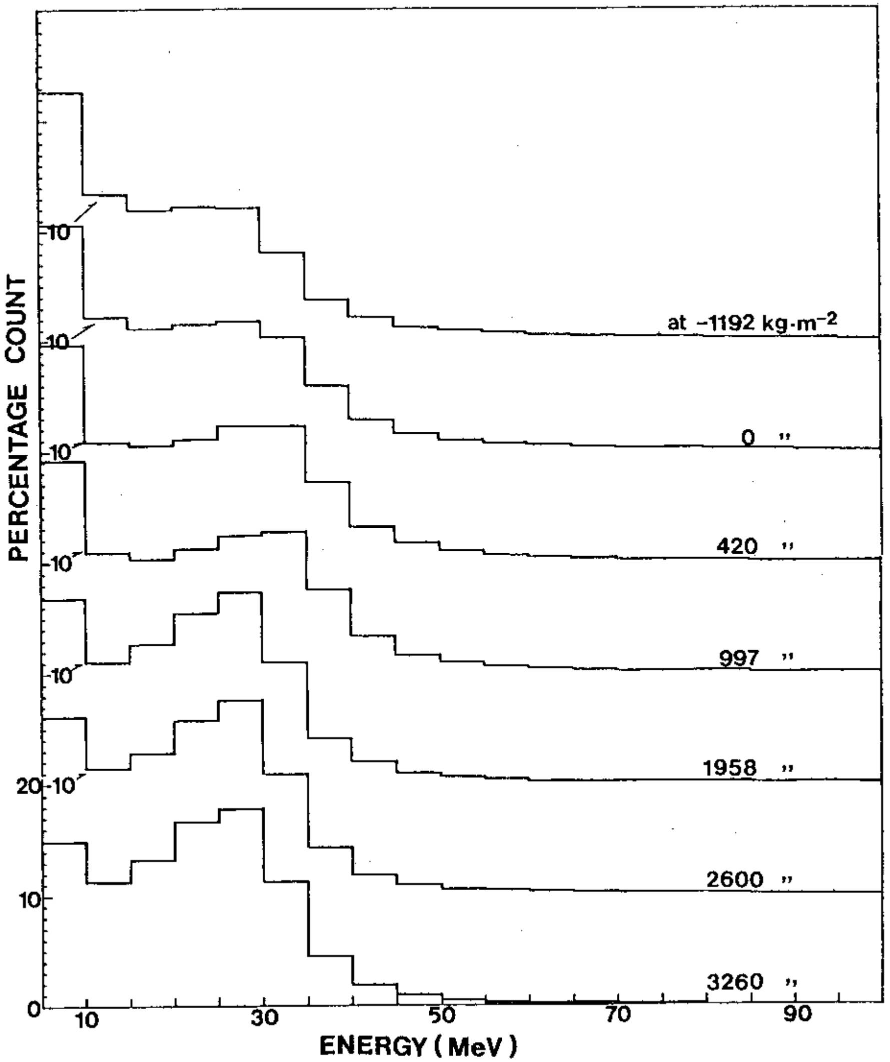

Fig. 6 Percentage count spectra of cosmic ray ionizing component measured by 3″ϕ spherical NaI(Tl) spectrometer at varying penetrating depth equivalent.

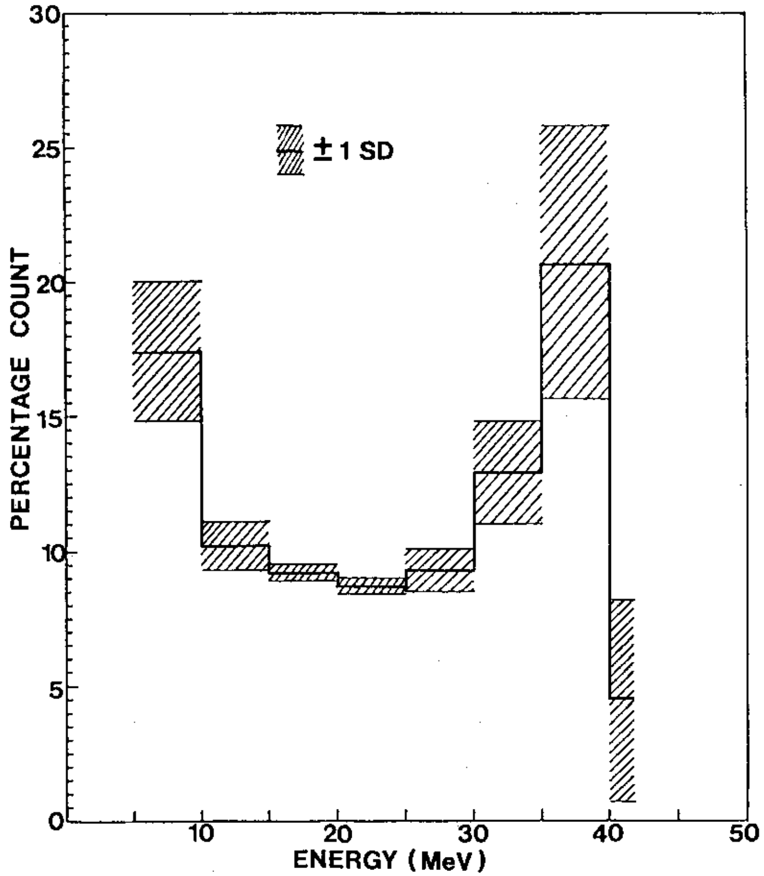

Fig. 7 Mean percentage count spectrum of cosmic ray ionizing component observed by GAMMA-X HPGe spectrometer.

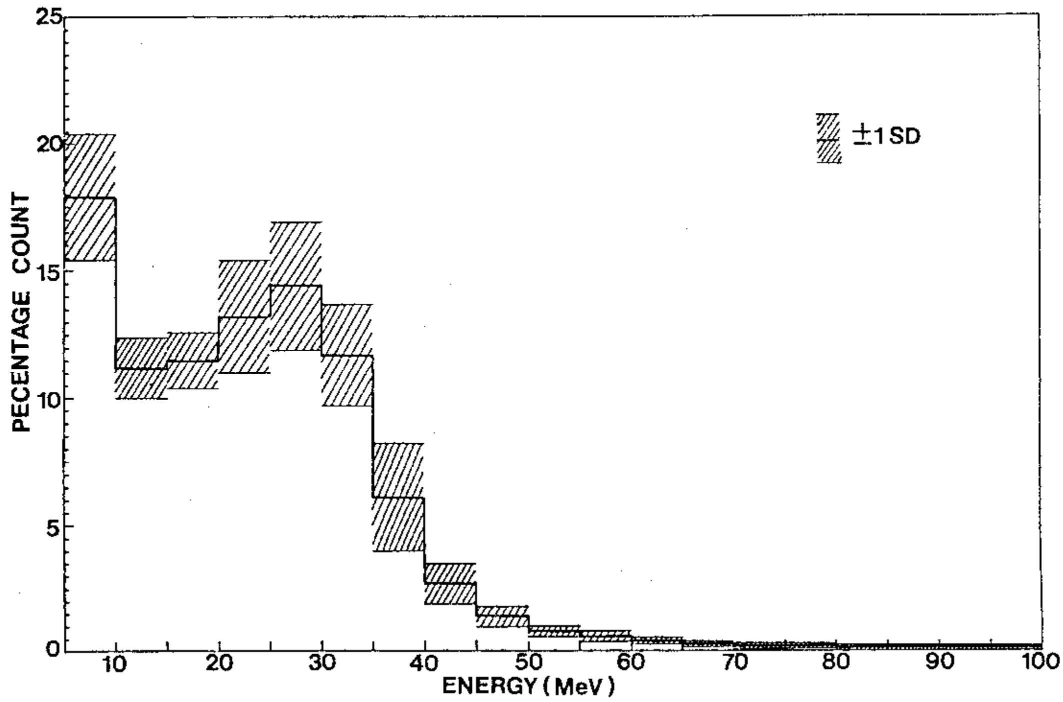

Fig. 8 Mean percentage count spectrum of cosmic ray ionizing component observed by 3"ϕ spherical NaI(Tl) spectrometer.

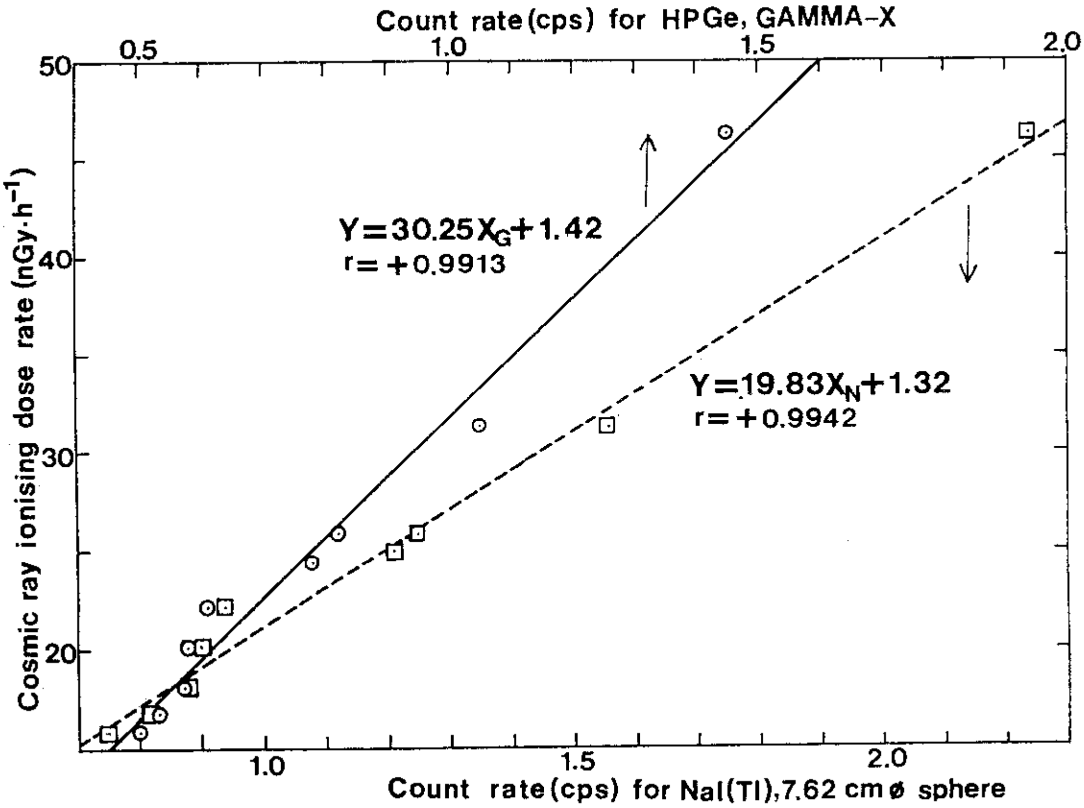

Fig. 9 Cosmic ray ionizing component, dose rate measured by 14 litre spherical ionization chamber (Y) vs. count rate measured by GAMMA-X HPGe (X_G) and 3"ϕ spherical NaI(Tl) (X_N) scintillation detector.

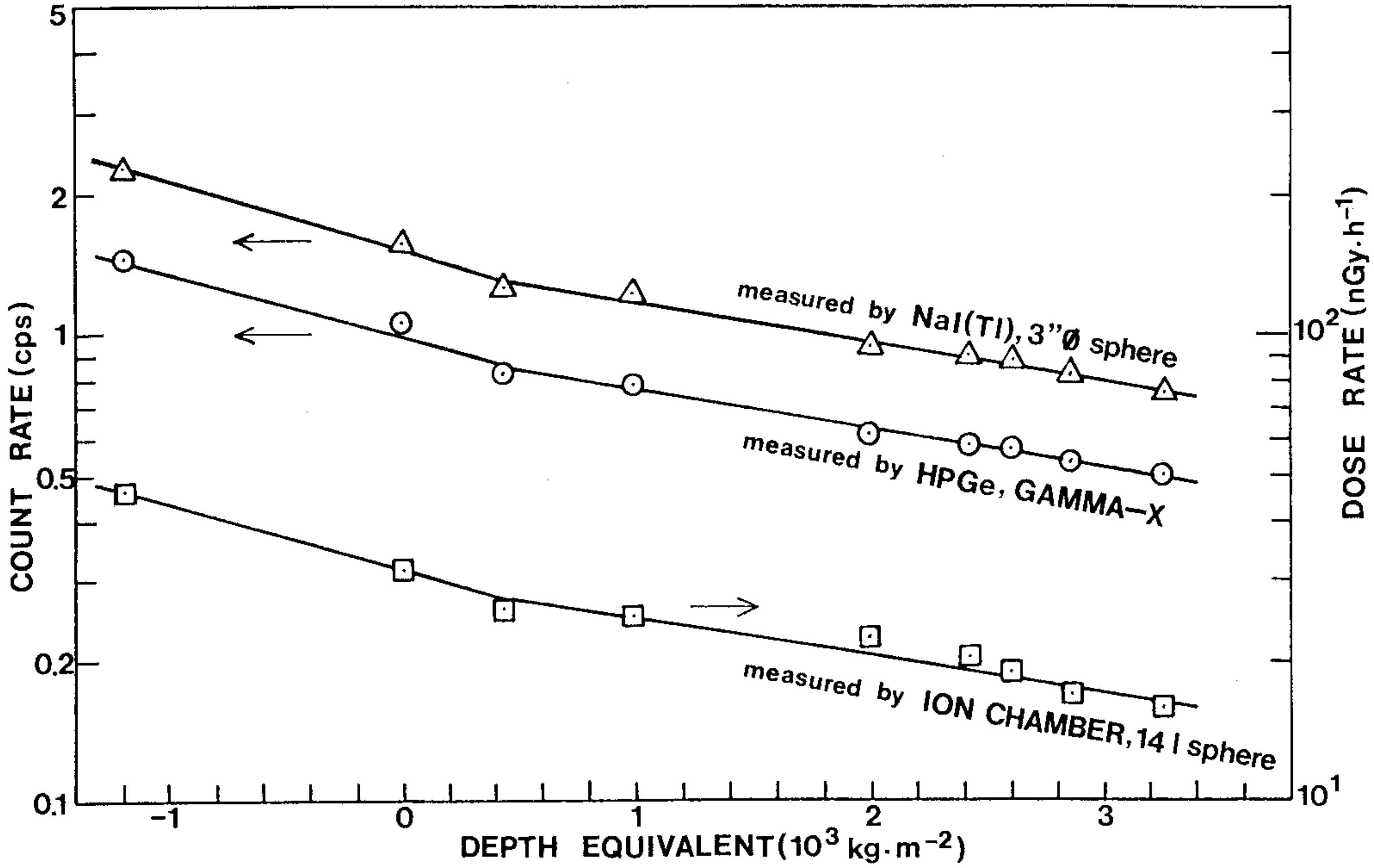

Fig. 10 Overall attenuation of cosmic ray ionization intensity as a function of penetrating depth equivalent.