A Radiation Survey Meter Using Cesium Iodide PA-100

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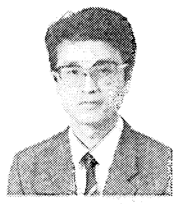
Abstract

This paper introduces the Model PA-100, a radiation survey meter that uses cesium iodide as a solid-state scintillator. Conventional scintillation-survey meters have used sodium iodide as the solid-state scintillator. However, since this requires a radiation-sensitive device in the photomultiplier tube, it had proven difficult to make the equipment compact. The new PA-100 has solved this problem with the use of cesium iodide in conjunction with a photodiode, resulting in a radiation survey meter that is compact, powerful, and efficient.



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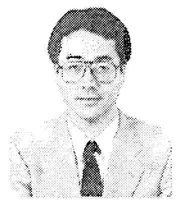

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1. Introduction

A "survey meter" is an instrument for detecting something. It then follows that a "radiation survey meter" is an instrument for detecting radiation. To be a little more precise, a radiation survey meter is an instrument for measuring the number (dose) or density (dose rate: dose per unit time) of rays of radiation emitted in various directions or at a limited spot in a measurement site, and for indicating those values.

A sensor for detecting radiation is built into the radiation survey meter. Generally, a device such as an ionization chamber, a GM (Geiger-Müller) counter, or solid-state scintillator are used as the sensor.

Most scintillation type survey meters currently on the market use a sodium iodide (called "NaI(Tl)" from here on) as the solid-state scintillator. However, the main feature of the PA-100 survey meter, that HORIBA has developed, uses cesium iodide (called "CsI(Tl)" from here on) as the scintillator. The PA-100 also features a compact design, high performance and high reliability, and conforms to the JIS Z 4333 standard. Conventional radiation survey meters are targeted at people in specialist areas in industry. The PA-100, however, is designed for easy handling, which means that almost anybody not in industry can easily measure nuclear radiation.

The measurement range is 0.000 to 9.999 micro sieverts/hr (μSv/h), which allows measurement up to 100 to 200 times regular levels of environmental radiation. The PA-100 is also provided with an analog output terminal. This allows the PA-100 to be connected to a pulse height analyzer for observing the energy spectrum, which, in turn, allows the PA-100 to be used in educational and research applications.

This paper introduces the background to the development, basic principle of operation, and functions of the PA-100.

2. Revived Applications for Scintillators

Radiation incident to a scintillator generates scintillation light. Counting the generated scintillation light allows us to make a radiation survey meter. This will be described later on in this paper. The following items in this section describe the background behind the use of CsI(Tl) as the scintillator in the PA-100.

2.1 Application of CsI(Tl) in Calorimeters

The application of CsI(Tl) as a scintillator was discovered roughly 40 years ago. As CsI(Tl) is a costly substance, CsI(Tl) did not enjoy widespread use. However, from around 1982 onwards CsI(Tl) began to gain attention as being effective as a sensor (calorimeter) in the high-energy physics research[1]; and, in 1985, the sensational thesis "Properties of CsI(Tl)—Renaissance of an Old Scintillation Method" was published.[2] This, indeed, heralded the rebirth of CsI(Tl).

We first began considering the use of CsI(Tl) as a scintillator through our contact with Cornell University. In 1986, a fully fledged report for applying a CsI(Tl) in a calorimeter was published at Cornell University.[3] The report stated that a photodiode was used as the photosensor for detecting light generated by CsI(Tl). The reason for using a photodiode was that a photodiode differs from a photomultiplier tube in that it is not adversely effected by magnetic fields. This allows the photodiode to be situated on the inside of a superconducting magnet, which results in a considerable increase in measurement accuracy. In July of the same year, we received an order of 4,000 large-scale (5 to 6 cm sq. x 25 to 30 cm long) CsI(Tl) scintillators from Cornell University. **Fig.1** shows the external view of one of such CsI(Tl) scintillator.

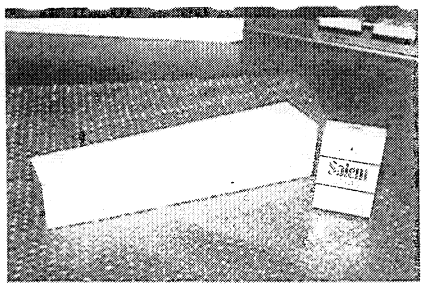


Fig.1 Large-scale Cs(Tl) scintillator at Cornell University

2.2 Application for Radiation Survey Meter

We first started experiments on CsI(Tl) in September 1986. Extremely remarkable results were obtained immediately after starting experiments. **Fig.2** shows the results of measurement at that time. Namely, energy of 100keV or less could not be measured due to noise. This fact indicated that commercialization by combining CsI(Tl) and a photodiode would be extremely difficult for low-energy γ(X)-rays.

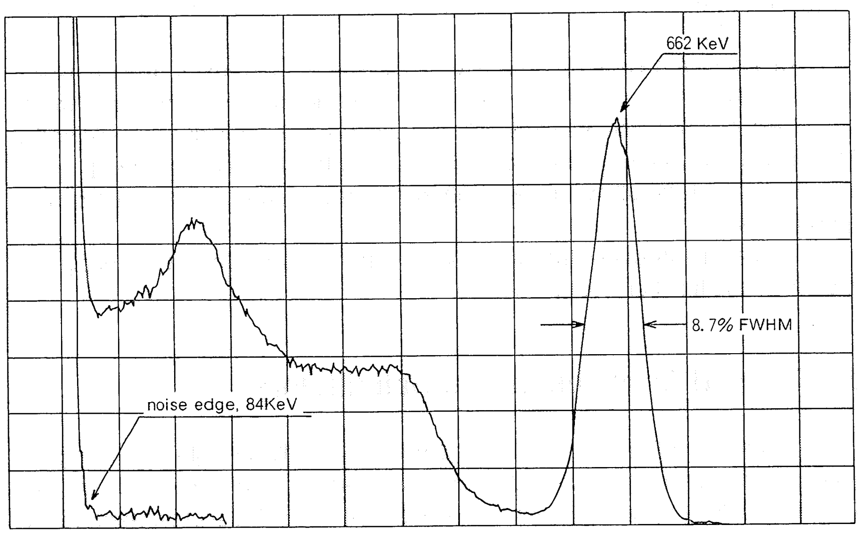


Fig.2 Example of measurement results of ^{137}Cs energy spectrum using photodiode and CsI(Tl) scintillator

However, there was still a ray of hope left. A need for detecting ^{137}Cs (γ-ray: 661keV) had arisen. There was also a wish to make the size of the sensor as small as possible, and downsizing the entire measuring instrument. This would mean the emergence of CsI(Tl) and photodiode. In other words, there was a desire to apply CsI(Tl) to nondestructive inspection for measuring environmental radiation of relatively high energy or a known energy, even if energy of 100keV or less could not be measured. **Fig.3** shows the construction of a sensor at that time.

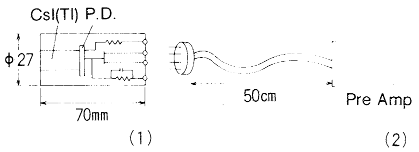


Fig.3 (1)Sensor, incorporating a CsI(Tl) scintillator, a photodiode, and a first stage of the charge sensitive amplifier, and (2) the preamplifier portion, with a separate survey meter head

In early 1988, there were more active movements towards commercializing CsI(Tl). We narrowed down application of CsI(Tl) to the measurement of environmental radiation, and started studying circuitry and selecting photodiodes. In May of the following year, 1989, a prototype radiation survey meter and a pulse height analyzer were completed. **Fig.4** shows an external view of the prototype radiation survey meter. However, this prototype radiation survey meter functioned to count radiation and indicate a value, and did not yet perform such calculations as unit conversion of 1cm dose equivalent rate. In December 1990, we added and modified the functions of this prototype, resulting in the completion of the current PA-100. **Fig.5** shows an external view of PA-100.

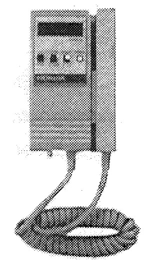


Fig.4 Experimental free-standing radiation survey meter

3. Excellent Combination with Photodiode

The sensors of scintillation type survey meters are made up of a scintillator and a converter that converts light from the (scintilation) to electric signals.

The majority of scintillation type survey meters currently on the market use NaI(Tl) in the scintillator and a photomultiplier in the converter. The PA-100, however, uses CsI(Tl) in the scintillator, and a photodiode in the converter, as described earlier. **Fig.6** shows the constructions of each type of survey meter.

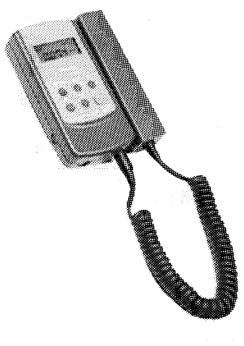
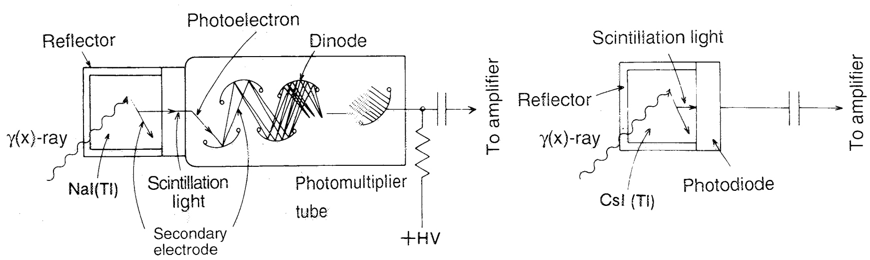


Fig.5 The PA-100 radiation survey meter



(A) Sensor using NaI(Tl) and a photomultiplier tube

(B) Sensor Using CsI(Tl) and a photodiode

Fig.6 Basic configuration of a radiation detector using a scintillator

3.1 Differences between a Photomultiplier and Photodiode

If we compare the structures of the two types of survey meters in **Fig.6**, we can see that a photodiode is overwhelmingly smaller than a photomultiplier, and that a high-voltage power supply is not required in a photodiode, allowing it to be

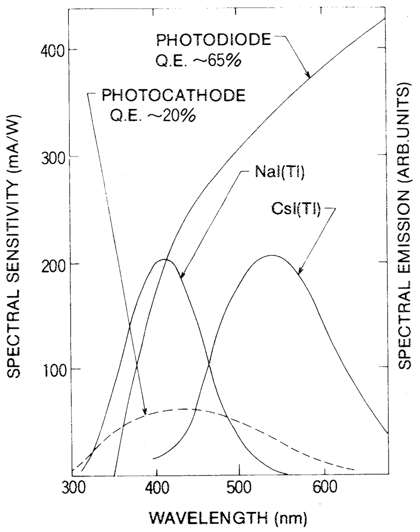


Fig.7 Emission spectral of the scintillators and spectral sensitivity of the light sensor

downsized and designed to be handier. However, the basic and important differences lie in the scintillator and the characteristics of the photomultiplier and photodiode.

Table 1 shows a comparison between often used inorganic scintillators.[4] From **Table1** we can see that the scintillation efficiency of CsI(Tl) and NaI(Tl) is almost the same. A pulse height, when CsI(Tl) is used with a photomultiplier, of only approximately one half that of the pulse height, when NaI(Tl) is used with a photomultiplier, can be obtained. However, when comparing CsI(Tl)-photodiode combination with NaI(Tl)-photodiode combination, the pulse height increases to twice the pulse height. **Fig.7** shows the maximum wavelength of the sensitivity in the photomultiplier near 400nm is compatible with the maximum emission wavelength of 415nm of NaI(Tl); whereas, regarding the maximum emission wavelength of CsI(Tl), the sensitivity of the photodiode is higher than that of a photomultiplier near 540nm.[3] This is all due to the excellent compatibility between a photodiode and CsI(Tl).

Material	Density	Maximum Emission Wavelength (λmax)	Refractive Index at λmax	Decay Time (μs)	Raise Time from 10 to 90% (μs)	Average Light Yield (photon/Mev)	Absolute Scintillation Efficiency of High Energy Electron	Reflective Pulse Height of γ-ray by Bi-alkali P.M.T.
NaI (Tl)	3.67	415	1.85	0.23	0.5	38000	11.3%	1.00
CsI (Tl)	4.51	540	1.80	1.0	4	52000	11.9	0.49
CsI (Na)	4.51	420	1.84	0.63	4	39000	11.4	1.11
LiF (Eu)	4.08	470	1.96	1.4	—	11000	2.8	0.23
BGO	7.13	505	2.15	0.30	0.8	8200	2.1	0.13
BaF_2 slow component	4.89	310	1.49	0.62	3	10000	4.5	0.13
BaF_2 fast component	4.89	220	—	0.0006	—	—	—	0.03[a]
Zns (Ag)(polycrystalline)	4.09	450	2.36	0.2	—	—	—	1.30[b]
CaF_2 (Eu)	3.19	435	1.44	0.9	4	24000	6.7	0.78
CsF	4.11	390	1.48	0.004	—	—	—	0.05
Li glass[c]	2.5	395	1.55	0.075	—	—	1.5	0.10
For comparison, indicated values are for a typical plastic scintillator.								
NE102A	1.03	423	1.58	0.002		10000	3.0	0.25

a: Photomultiplier sensitive to ultra-violet rays
b: Value with respect to alpha particles
c: Change in characteristics

Table 1 Characteristics of a commonly-used inorganic scintillator

3.2 Features of CsI(Tl) and Photodiode

Below follows a summary of the features of the CsI(Tl) and Photodiode

< CsI(Tl) >

(1) Low hygroscopic characteristics
(2) Resistant to mechanical and thermal shock, easy to process
(3) High density, large absorption of γ(X)-rays per unit length
(4) Large amount of light emission (approximately 50,000 scintillation light emissions per 1MeV)
(5) Emission wavelength compatible with that of the maximum sensitivity of a photodiode.

< Photodiode >

(1) High-voltage power supply not necessary (power supply of several tens of volts is adequate)
(2) Magnetic shielding not necessary
(3) Small size
(4) Less costly than a photomultiplier

If we consider all of these features together, the major feature of a combination of CsI(Tl) and a photodiode is that a survey meter is easy to process, assemble, and downsize.

On the other hand, CsI(Tl) and a photodiode still have some problems. (1) As the decay time of the scintillation light from CsI(Tl) is longer than that of other solid-state scintillators, it is unsuitable for measuring high counting rates. (2) The leakage current of photodiodes at the room temperatures is several nA. As the leakage current is a electron carrier that is formed by heat, the photodiode has a strong dependency on heat. Furthermore, as the photodiode has a junction capacity of approximately 70pF, the S/N ratio is worse than that of a photomultiplier, making it difficult to measure in the energy range of 100keV or less.

Decay time is a characteristic of CsI(Tl), and cannot be avoided. However, the leakage current of the photodiode can be greatly reduced by cooling the photodiode. However, in actual practice, CsI(Tl) becomes cooled at the same time that the photodiode is cooled, which results in a reduction in the scintillation efficiency of CsI(Tl). Ultimately, as shown in **Fig.8**, as the properties are the best in room temperatures, it is a fact that it is difficult to counter the problem of the leakage current.

Nevertheless, in applications for measuring radiation of relatively high energy and low counting rate such as environmental radiation, it can be said that the advantage of downsizing outweigh these problems, and that CsI(Tl) and photodiode combination is ideal for measuring environmental radiation.

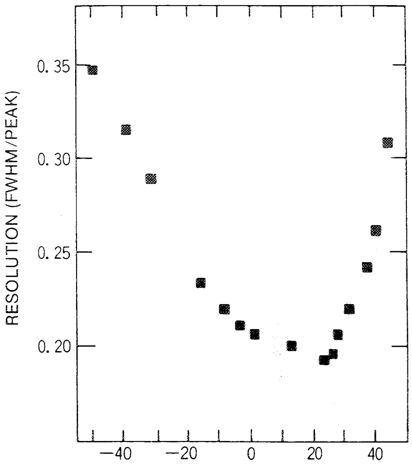


Fig.8 Temperature characteristics of the energy resolution of a CsI(Tl) + photodiode

4. Basic Configuration and Features of PA-100

Besides scintillation type radiation survey meters, there are other types such as ionization chamber and GM counter. These radiation survey meters come in two models, integrated or separate, and are used selectively according to application. However, the majority of radiation survey meters currently on the market are large-scale instruments, slightly difficult to use, and require special knowledge. For this reason, there has been a demand for a compact, high-performance radiation survey meter that can be operated easily by anyone. So that these requests can be satisfied, we have made full use of the advantages of using CsI(Tl) with a photodiode in achieving the PA-100 multi-functional, compact, easy-to-use radiation survey meter.

4.1 Basic Configuration of PA-100

Fig.9 shows a block diagram of the PA-100. γ(X)-rays incident to CsI(Tl) cause scintillation light to be emitted. This scintillation light is converted to electrical signals by the photodiode. After conversion, the signals are amplified and their waveforms are shaped by a preamplifier and linear amplifier, so that the pulse height becomes proportional to the energy of the γ(X)-rays. Only the pulses over a certain energy level are counted by a counter, and the counts per unit time is input to a one-chip microcomputer, where calculation of average values or compensation of sensitivity are processed. Units are converted to 1cm dose equivalent rate, and the measured value is displayed on the LCD in units of μSv(/h).

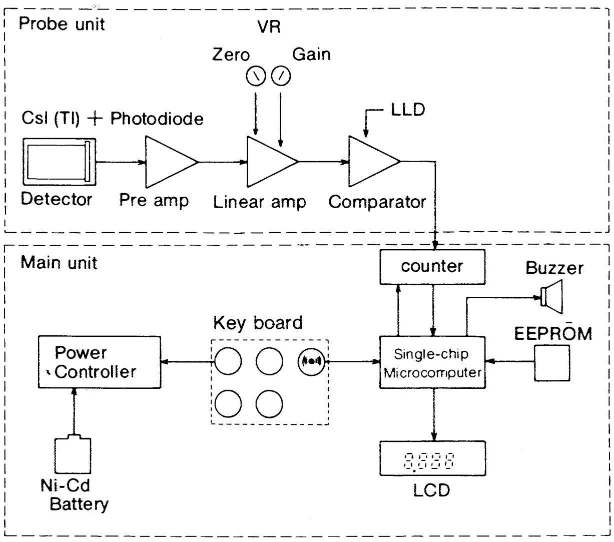


Fig.9 Block diagram

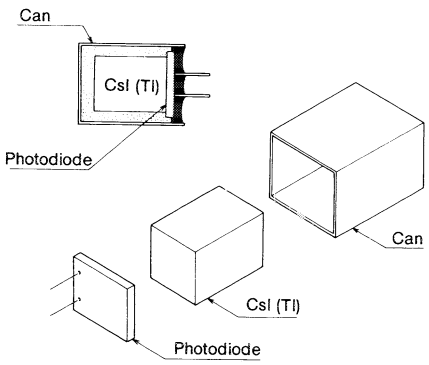


Fig.10 Structure of the PA-100 sensor

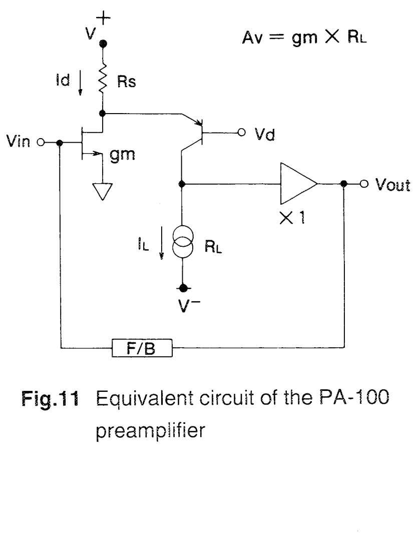


Fig.11 Equivalent circuit of the PA-100 preamplifier

4.2 Configuration of Main Unit

The main unit is made up of a power circuit, digital circuits, and one-chip microcomputer. This one-chip microcomputer processes calculations, and controls LCD display, key input, and sounding of the buzzer. Settings, compensation coefficients and other data are written to EEPROM (Electrically Erasable and Programmable ROM). This allows data to be saved in spite of the status of the batteries, and easily changed.

Four Ni-Cd batteries (size AA) can be inserted at the rear of the main unit. These can be removed from the main unit and recharged by a special charger.

4.3 Configuration of Probe

The probe is made up of a a sensor, pre-amplifier, and linear amplifier. All analog circuits are built into the probe.

Fig.10 shows the structure of the sensor. Reflective material is wound around the CsI(Tl) so that the scintillation light generated by the CsI(Tl) is efficiently condensed on the photodiode.

Fig.11 shows the equivalent circuit of the preamplifier. The preamplifier is a charge sensitive amplifier, and uses a FET having a large transconductance. This is in order to provide as much amplification as possible at the initial stage to increase the S/N ratio at devices such as a photodiode having a large junction capacity and leakage current.

The linear amplifier is made up of a pole-zero cancelling circuit, waveshaping circuit, base line restoration circuit, and a low limit discriminator. If the linear amplifier is for application as only a low counting rate radiation survey meter, the pole-zero cancelling and base line restoration circuits are not required. However, these have been housed in the linear amplifier so that output signals can be output. Consequently, if the output signals of the linear amplifier are input to a pulse height analyzer, the energy spectrum can be observed.

4.4 Functions and Specifications of PA-100

The PA-100 has various functions that allow anyone to carry out measurement through one-touch operation. **Fig.12** shows an external view of the control panel and readout.

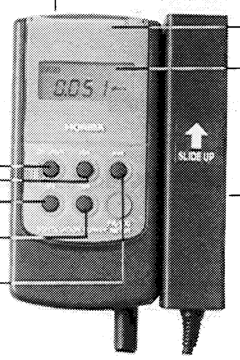


Fig.12 The PA-100 control panel and readout

(1) Display of 1cm dose equivalent rate (μSv/h)
Moving average values are displayed in order to minimize statistical fluctuations of the radiation, and make the readout easier to read. The average values after turning the power ON can also be displayed as an option.

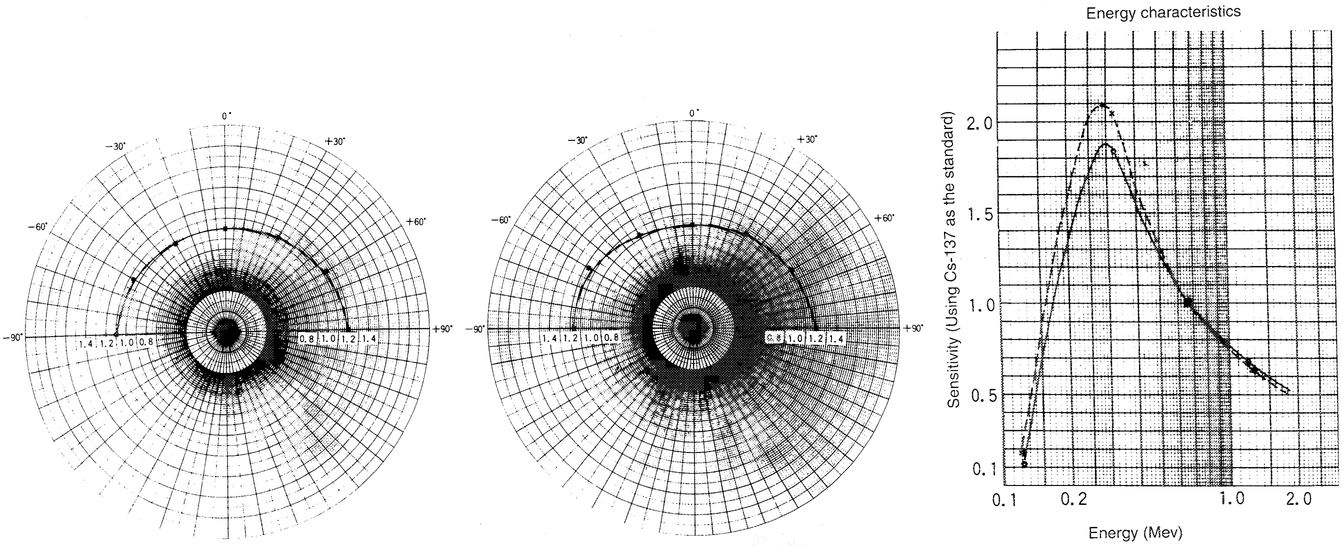
(2) Display of 1cm dose equivalent (μSv)
The integrated value of the 1cm dose equivalent after turning the power ON can be displayed.

(3) Display of measurement time
The measurement after turning the power ON can be displayed in "minutes: hours".

(4) Radiation counting sound
A short, high-pitched sound can be emitted whenever radiation is counted.

(5) Analog output terminal
Linear amplifier signals are output from this terminal. If the PA-100 is connected to a pulse height analyzer, the energy spectrum can be observed.

Table 2 shows the specifications of the PA-100. **Figs.13(A)** to **(C)** show the direction characteristics and energy characteristics.



(A) Vertical characteristics **(B)** Horizontal characteristics **(C)** Energy characteristics

Fig.13 Characteristics of the PA-100 radiation survey meter

Model	PA-100
Measuring Method	Scintillation
Measuring Object	γ-ray
Detector	CsI(Tl) + photodiode
Sensitivity	More than 10 cpm at 0.01μSv/h
Energy Characteristic	0.5 to 3 (150KeV to 1.5MeV)
Directional Characteristics	±25% within ±90° to control axis of probe
Measuring Range	0.000 to 9.999μSv/h (dose equivalent rate)
Display	Digital
Response Time	30sec
Indication Error	±20%
Indication Fluctuation	Less than 10%
Ambient Temperature Range	-5 to 40°C
Storage Temperature Range	-20 to 55°C (within dry condition)
Power Supply	4 x Ni-Cd batteries (size AA):24 hrs continuous operation
Size	Main unit: 140(D) x 27(W) x 34(H)mm Probe: 140(D) x 30(W) x 30(H)mm
Weight	Approx. 400g
Additional Functions	Dose equivalent, measuring time, counting sound, battery alarm, overflow

Table 2 PA-100 specifications

4.5 PA-100 Application Examples

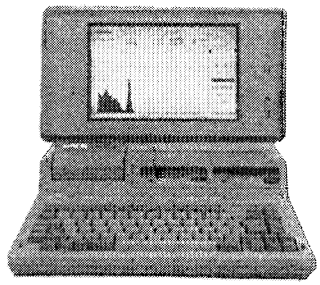
As the PA-100 allows anyone to measure radiation with ease, it is ideal for use not only in educational and research applications but also for general use by people not in industry. The PA-100 is also portable, which means that it can measure anywhere. The separated construction of the PA-100 allows it to be used in combination with a simple portable pulse height analyzer, and be applied in nondestructive inspections. **Fig.14** shows the external view of a prototype pulse height analyzer, and the energy spectrum of ^{137}Cs measured at the PA-100.

5. Conclusion

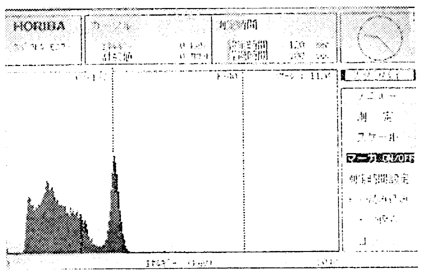
Environmental radiation is emitted from not only in space or the earth, but also from the trace radioactive substances contained in all materials around us. Consequently, we are irradiated to radiation all day and anywhere we are. The strength of the environmental radiation varies geographically. There are some places in Brazil, for instance, whose environmental radiation is equivalent to approximately 10 times that of the permissible dose at the boundary of nuclear power plants. We believe that this is unknown to almost all people.

Even in Japan, a country of advanced scientific and technological achievement that boasts high educational levels, we can state that, generally speaking, people know very little about radiation. We feel that the reason for this lies in the fact that "radiation" is difficult to understand, and difficult to teach. Though much effort has been made to get the nation to understand radiation, the difficulty of that task has been pointed out.[5)]

In these circumstances, manufacturers such as HORIBA are thinking about their role in this. The answer to that can be picked in the above description. That is, we feel that the answer lies in the production of a highly reliable, compact, low-priced radiation survey meter that can be used easily by anyone.



(A) Main unit



(B) Example of readout of ^{137}Cs energy spectrum

Fig.14 Experimental multichannel pulse height analyzer using the PA-100 and a microcomputer

< Bibliography >

1) H.Grassman,E.Lorenz,H.G.moser and H.Vogel "Results from a CsI(Tl) Test Calorimeter with Photodiode Readout Between 1 and 20 GeV" Nuclear Instruments and Methods in Physics Research, A235, P.319-325 (1985)
2) H.Grassmann, E.Lorenz and H. -G.Moser "Properties of CsI(Tl)-Renaissance of an Old Scintillation Material" Nuclear Instruments and Methods in Physics Research, 228, P.323-326 (1985)
3) E.Blucher,B.Gittelman, B.K.Heltsley, J.Kandaswamy,R.Kowalewski, Y.Kubota, N,Mistry, and S.Stone "Tests of Cesium Iodide Crystals for an Electromagnetic Calorimeter" CLNS-86/721,P.1-72(1986)
4) Glenn F.Knoll "Radiation Detection and Measurement Second Edition
5) Hiroshi Tani, Institute of radiation measurements news, No.7(1990)