NEW LOW LEVEL ENVIRONMENTAL RADIATION MONITORING AROUND NUCLEAR FACILITIES DISCRIMINATING FROM NATURAL RADIATION

Shigeru MORIUCHI, Kazuhiko IMAI
and
Ichiro MIYANAGA
Japan Atomic Energy Research Institute
Tokai-mura, Ibaraki-ken, Japan

Abstract

Recently, gaseous effluents from nuclear reactors and other facilities are controlled in such a low level, that the gamma radiation exposure from them amounts less than 10 mrem/yr at the site boundary.

Natural gamma radiation fluctuates due to the fluctuation of radioactivity in air, the sweeping effect by rain, shielding effect by snow and water content in soil, and other factors. It would be very difficult to measure gamma exposure less than a few mrem/yr from gaseous effluents discriminating from such natural background fluctuations even by using high-pressure ionization chambers.

For monitoring environmental radiations from nuclear facilities, discriminating the fluctuating natural radiation, a NaI(Tl) scintillation exposure rate meter with flat energy response is used. This equipment consists of a 2 x 2-inch NaI(Tl) scintillator and two separate electronic units, one is an exposure rate meter having a pulse height weighting circuit for flattening the energy response and other a single channel pulse height analyser, and was tested to see the stability for a long-run operation in the field and to examine discriminating characteristics.

Natural radiation has wide energy spectrum distribution up to 2.62 MeV, and changes with time rather uniformly in wide energy range. Therefore, one can measure the environmental radiation from nuclear facilities by detecting total gamma radiation in full energy range and natural gamma radiation in the higher energy channel separately and taking the differential between them.

Results of the test was satisfactory for measuring increases in exposure less than 1 mR/yr of gamma radiation from a research reactor under natural fluctuation of background and showed a good stability in a long-run operation in the field.

Introduction

According to the prospective increase of the person-rems of the population exposure around the nuclear power stations, which may play the main role for the increasing requirement of energy, the level of environmental radiation exposure from them recently tends to be controlled as small as 10 mrem/yr compared with 100 mrem/yr of natural radiation. Under these circumstances, efforts are given to improve environmental monitoring technique to measure the small fraction of radiation from nuclear facilities separately from the fluctuation of natural background radiation, particularly by the use of a high-pressure ionization chamber.[1,2]

Beck et al. pointed out that the annual dose at certain point will be given in the fractional time period of the year due to the wind-rose, so the actual dose rate will be sufficient to measure, even when annual dose rate is less than 1 mrad/yr.

The instrument of the environmental monitoring should have the characteristics such as high sensitivity, operation stability in the long range field use and simple treatment of data obtained. From the view points above, the present paper describes a new gamma radiation monitor using a NaI(Tl) scintillator for field use, and especially on the discriminating characteristics from the fluctuation of natural background radiation.

Time variation of natural radiation and its discrimination

Characteristics of the fluctuation of natural radioactivities

The cause of the fluctuation of natural radiation comes from the fluctuation of Rn and Tn daughters in the atmosphere, combined with the meteorological conditions. Because the amount of Rn is about 10 times as large as Tn at ground level, the modulation of natural gamma radiation is mainly due to Rn daughters, though there are some effects as shielding by soil moisture and snow cover.

Predominant gamma emitters of Rn daughters are RaB and RaC because the branching that occurs at RaA and at RaC can be ignored, and the fraction of gamma radiation exposures from RaC is almost 87 % in the equilibrium conditions both from air and from ground surface. In the atmosphere, the equilibrium conditions of RaB and RaC will be kept during slow fluctuations such as diurnal variation due to the stability condition in atmospheric air. The worst condition may occur in the rainfall by its sweeping effect, but the fairly good equilibrium can be expected to be kept between RaB and RaC in rain water on the ground surface. The observation of the differential spectrum from the begining of rainfall shows small decrease of the ratio RaB/RaC with time, but the change of the ratio was negligible. Thus, the fluctuations of natural gamma radiation can be represented by the fluctuations of RaC's radiation even in the most severe unequilibrium condition during rainfall.

Discriminating method using gamma energy spectrum

It was shown that the spectrum of natural gamma radiation did not change depending on rains, and its highest energy is 2.45 MeV from RaC. The highest fraction of individual gamma exposures in the equilibrium condition comes from

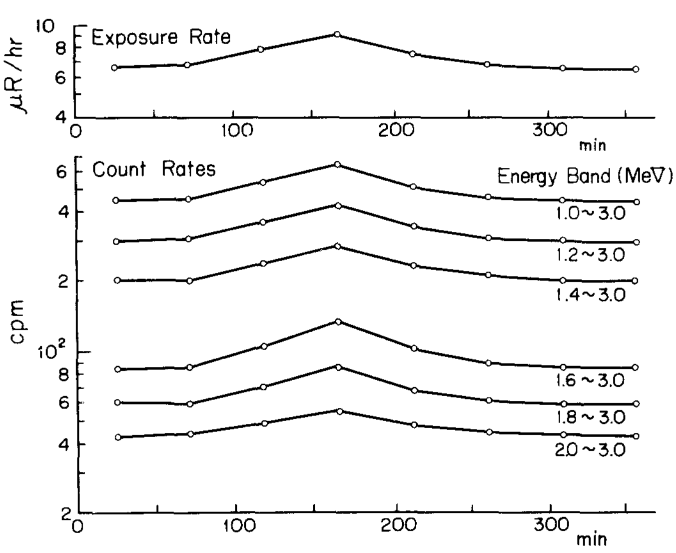

FIG.1. Time variation of background gamma radiation due to rainfall

1.76 MeV of RaC, and exposures from radiations between 1.73 MeV to 2.45 MeV of RaC occupies more than 60 % of total exposure. Gamma emitters of gaseous effluents from nuclear facilities are Ar-41 from research reactors and Kr and Xe from light water reactors. In order to decrease the release of gaseous effluents, most power reactors are equipped with some hold-up systems for them. In general, the short half-lives such as Xe-138 are negligible, and other nuclides of Xe and Kr all have the energies less than 1 MeV, excluding Kr-87,88.

With the consideration of the gamma ray spectrum above, the discrimination of the contribution of gaseous effluens from natural radiation can be performed with pulse height discrimination technique. Fig.1 shows the change with time of exposure rate and count rates above various discriminating level of natural radiation during rainfall, using a 2 x 2-inch NaI(Tl) scintillation counter which was set at 1 m above ground surface. Exposure rates were obtained from pulse height distribution by using Spectrum-Dose conversion operator.[3-6] The level of the background radiation after rainfall was reduced by 0.31 μR/h compared with the level before rain, and the almost all of them may correspond to the fraction of the absorption introduced by rain water in soil. By considering a straight line connecting two points of the background level before and after rainfall, correlation between differential exposure rate and count rates from rainfall can be plotted as shown in Fig.2. The relation between both elements is found to be well proportional in any energy ranges. This shows the relation holds in any atmospheric conditions from the discussion above.

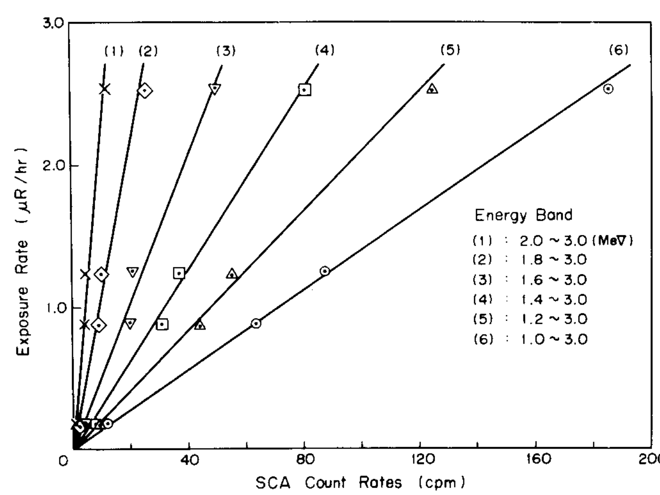

FIG.2. Relation between exposure rate and SCA count rates due to rainfall in given energy band

Features of the instrument for the discriminating measurement

NaI(Tl) scintillation exposure rate meter

We have developed a NaI(Tl) scintillation exposure rate meter, which has a flat energy response, and gave the principle and electronic circuits in several reports.[6-9] In the meter, energy loss spectrum produced in a NaI(Tl) crystal by gamma radiation is converted to exposure by applying Spectrum-Dose conversion function, which is carried out in an electronic circuit built in it.

Sensitivity is inversely proportional to the range of energy where the energy response is flattened, chosen simply by the electronic circuit adjustment. Counting efficiency is 110 cpm per μR/h in the case of a 2 x 2-inch NaI(Tl) crystal and 350 cpm per μR/h in a 3 x 3-inch NaI(Tl) crystal, when the flattening energy range is 60 keV to 3 MeV.

The fraction of counting due to cosmic radiation can be reduced as low as 0.2 μR/h equivalent. The output signal is digital pulse, and consequently the measurement is simple and the accuracy is excellent. The contribution from the

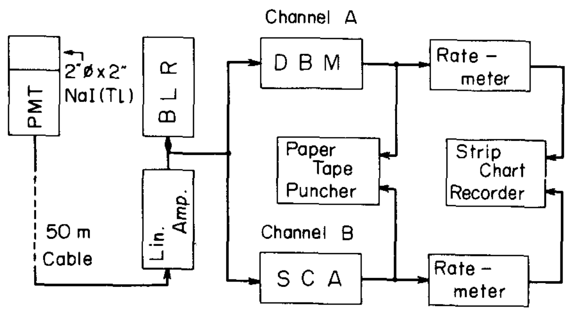

FIG.3. Block-diagram of two channel gamma radiation monitor

material contamination is gamma rays from K-40 in the glass of a photomultiplier tube and a scintillator window, and can be easily reduced to less than 0.1 μR/h by selecting material.

Fig.3 shows the block-diagram of an instrument which can measure gamma radiations of gaseous effluents discriminating from natural radiations. In the figure, channel A is the exposure rate mater with an energy flattening circuit, namely Discriminator Bias Modulation circuit (DBM), and channel B gives count rates from natural radiation between setting level of a lower level discriminator (LLD) and 3 MeV of an upper level one. The differential between two channels gives the radiation from gaseous effluents only.

Long-run stability in a field test

The stability characteristics of the instrument relate mainly to temperature dependency of light emission efficiency of NaI(Tl) (+0.2 ~ +0.3 %/°C) and temperature characteristics and stability of the high voltage unit. Long-run test of stability was carried out in the field over the period of five months, and the sensitivity was checked every day in first one month and every three or four days on the later four months by a checking source. The results showed ±3 %/month covering the test period, in spite of the temperature change over 10°C experienced during day-time and night-time.

Examples of observation and the analysis

In our establishment, gamma radiations concerned are sky shine from a 200 MeV Linear Accelerator and gamma rays from Ar-41 cloud released from research reactors in JAERI and from a neighbouring gas cooled power reactor of JAPCO.

The level of LLD in channel B was set between 1.6 MeV avoiding 1.46 MeV photopeak of K-40 and 1.76 MeV photopeak from RaC'. Data of the measurement were recorded on a strip-chart recorder and a paper tape puncher automatically. The former was put just to observe the counting pattern, and the latter, the punched paper tape was used for the precise evaluation of exposures by computer data-processing.

Fig.4 shows some typical examples of the pattern obtained from both channels A and B. Dotted lines in the figure show background radiation level. Fig.4(a) shows a case that small amounts of exposure rate due to the plume from JAPCO are superimposed on remarkable changes of background radiation from Rn daughters brought down by rain. As Ar-41 release rate from a 65 m stack of this plant is about 0.8 Ci/h, averaged exposure rate just under the plume is presumably less than 0.5 μR/h. By the patterns of two channels, it is seen that the separation of the components is very clear, which a conventional one channel system can never do. The results were evaluated to be 43.2 μR from rainfall and 3.7 μR from the plume during the shown period. In this example the level of LLD is 1.75 MeV, and the conversion factor for rainfall from channel B to channel A is 0.060 μR/h per cpm. Two examples (b), (c) shown in Fig.4 were ones measured at lower discriminator setting 1.63 MeV, and in this case, the conversion factor is 0.045 μR/h per cpm. The pattern (b) in the figure shows mean 30 min-exposures due to Ar-41 cloud from a 40 m stack of a research reactor under well weather condition, with the release rate of about 3.0 Ci/h. The diurnal variations of background radiation due to changes of Rn in air, are observed along with time by channel B. The differences of minimum to maximum are about 0.6 μR/h. In this case, the separation of two components is very easy.

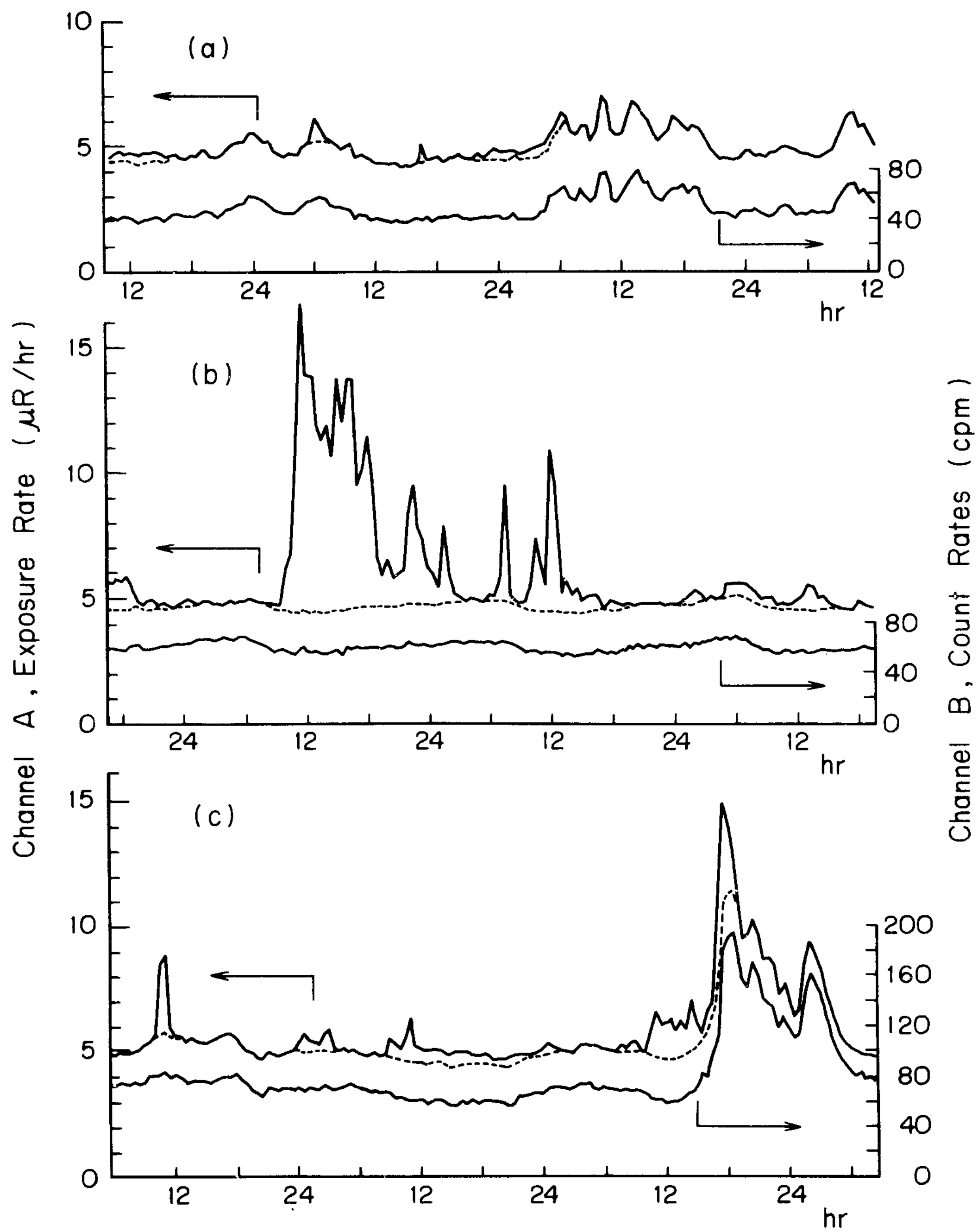

FIG.4. Records of exposure rate and SCA count rates in two channel system

The contribution was evaluated to be 97.7 μR from Ar-41 cloud. The pattern (c) in Fig.4 shows an example that the contributions both from JAPCO and from a Linear Accelerator are overlapped on continuing fine rains and succeeding heavy rains. In this case, the contributions from each radiation sources are 24.4 μR due to plant operation and 78.5 μR due to rainfall. These results show clearly that identification of radiation sources can be easily done without any other informations such as meteorological data and operating condition of plants.

Discussion and conclusion

By a long-run field test over a period of several months, our two channel system was proved to be very useful for discriminating the contribution from nuclear facilities even from short term fluctuations of background radiation, and was sufficiently stable in long field operation. But the two channel system will not be effective if maximum gamma ray energy from gaseous effluents and other radiation sources in interest exceeds the energy 1.76 MeV of RaC. The system is not, therefore, effective when facilities release large fractions of Xe-138, Kr-87 and Kr-88 in effluents. Recently, exposures from fallout due to nuclear weapon tests are fairly constant, since additional fallout deposition becomes very low and nuclides of rather long half-lives become predominant. Hence, the present status of fallout does not affect the operation characteristics of the system.

This system can be constructed easily by using a commercially available NaI(Tl) scintillation detector and NIM standard modules, but only a DBM module must be made individually.

The self-background pedestal of this system caused by K-40 contained in composing glass of a scinfillator and a photomultiplier tube, appears only in channel A, and is less than 0.2 μR/h equivalent. If ones of low potassium glass are selected, it can be reduced to less than 0.05 μR/h. The contribution from cosmic ray is about 0.6 μR/h equivalent in the case of the instrument of which the energy range flattened is up to 3 MeV, and if the pulses higher than 3 MeV is rejected by using an anti-coincidence circuit, its contribution can be reduced to 0.2 μR/h. For example, standard error of counts in 10 minutes integral is ±0.06 μR/h in the case of a 2 x 2-inch NaI(Tl) scintillator and ±0.034 μR/h in the case of a 3 x 3-inch NaI(Tl) scintillator in radiation field of gamma radiation 3.0 μR/h and cosmic ray 3.4 μR/h. In addition, this instrument has another advantage that output data can be recorded and processed with a high accuracy because output signals are given as digital pulses.

Therefore, the minute rise of exposure rate as 0.1 μR/h and integrated exposure less than 1 mR/yr due to gaseous effluents from a nuclear facility can be measured by using the two channel system of a NaI(Tl) scintillation exposure rate mater in spite of fluctuations of background radiation.

Acknowledgment

The authors wish to express their thanks to Mr. Hideo Kobayashi of the Environmental Survey Section for co-operation in the field work.

References

1. DeCampo, J.A., Beck, H.L., and Raft, P.D., USAEC Report HASL-260 (1972).
2. Beck, H.L., DeCampo, J.A., Gogolak, C.V., Lowder, W.M., McLaughlin, J.E., and Raft, P.D., Nuclear Technol., Vol.14 June, p.232 (1972).
3. Moriuchi, S., Miyanaga, I., Health Phys., 12, 541 (1966).
4. Miyanaga, I., Moriuchi, S., J. At. Energy Soc. Japan, 9, 8, 440 (1967).
5. Moriuchi, S., JAERI 1209 (1971).
6. Miyanaga, I., Moriuchi, S., NSJ-Tr 137 (1968).
7. Moriuchi, S., Miyanaga, I., Health Phys., 12, 1481 (1966).
8. Moriuchi, S., Miyanaga, I., J. At. Energy Soc. Japan, 9, 9, 518 (1967).
9. Moriuchi, S., JAERI-M 5374 (1973).