DEVELOPMENT OF MONITORING TECHNIQUE BASED ON SPECTRUM ANALYSIS OF ENVIRONMENTAL GAMMA-RAYS IN THE VICINITY OF A NUCLEAR FACILITY

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1. INTRODUCTION

The rapid increase in the utilization of a nuclear reactor for peaceful purposes requires continuous efforts to protect populations around a nuclear facility from radiation exposure. The requirement calls for intensified efforts to improve methods for radiation monitoring even under a normal operation condition of a reactor.

From this point of view, an analytical monitoring technique had developed for identification of artificial radionuclides and assessment of their radiation exposures in the natural environment(1). Since this technique was based on an analysis of the energy spectrum of the natural environmental gamma-rays, it was quite possible to estimate effective dose equivalents, recommended by the ICRP published in 1977, due to artificial radionuclides.

In the present study, a simple estimation method for exposure due to gaseous effluents from the stack has derived from the analysis monitoring data, and an effective dose equivalent for Japanese adults is determined on the basis of the energy spectrum of exposure caused by gamma-rays from ^{41}Ar radionuclide in the vicinity of the Kyoto University Reactor(KUR).

2. EXPERIMENTAL

The monitoring system for analysis of environmental gamma-rays was composed of a NaI(Tl) scintillation spectrometer, a pulse-height analyzer and a microcomputer system for processing accumulated data. The detector which was held at about 1.2 m from the ground level was concealed with a protection case of 5 cm thick plastic foam to protect given functions against severe atmospheric conditions. The monitored place was located at about 180 m to the north of the stack of 35 m in height. The continuous gamma-ray monitoring was performed in Feburary of 1982.

The pulse-height distributions which were recorded every 1 hour in a magnetic tape were unfolded by the iterative technique using a response matrix, and the true gamma-ray energy spectra were analyzed into their main components, i.e. photons from ^{40}K, ^{238}U-series, ^{232}Th-series and others, by the microcomputer system. Gamma-ray energy spectra from the gaseous effluents were determined by subtracting the natural environmental gamma-ray energy spectra from the measured ones. The terrestrial gamma-ray energy spectra were calculated using the energy and directional distributions of photon flux densities from the isotropic sources of U, Th and K in the soil(2) and gamma-ray fields due to ^{222}Rn daughters on the ground-air interface were determined on the basis of the results in reference 3. The exposure rates were calculated from the well-known formula(4) and the effective dose equivalent rates were determined from the following equation,

$$H_t = \sum_i C(E_i)\cdot f(E_i) \qquad (1)$$

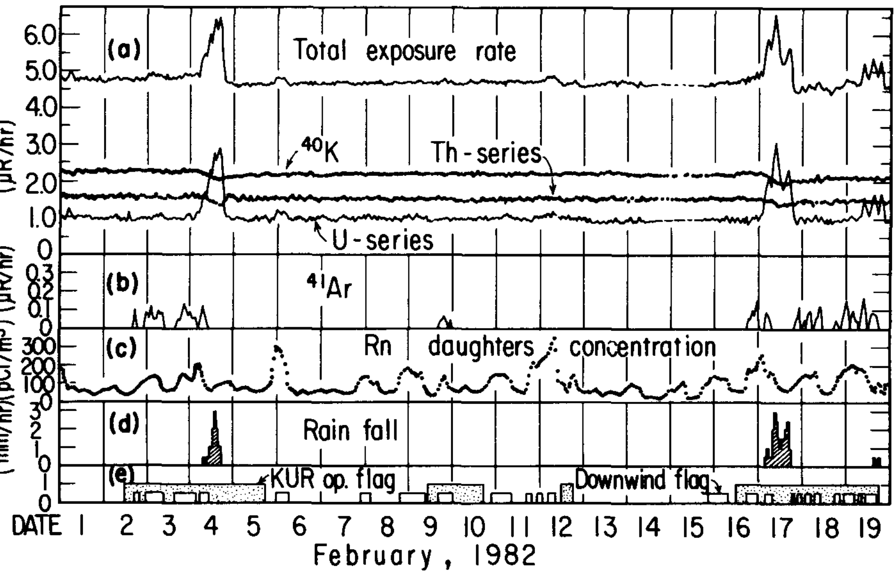

Fig.1 Time histories of total exposure rate and its components, ^{222}Rn daughters concentration, rainfall incidence, KUR operating and wind direction flags.

where C(Ei) is an exposure(0.87 Gy in air) to effective dose equivalent(Sv) conversion factor for an adult Japanese given as a function of photon energy(5) and f(Ei) is an energy spectrum of exposure rate calculated from the photon flux density.

3. RESULTS and DISCUSSION

Sample analysis data for 19 days are illustrated in Fig.1 with ^{222}Rn daughters concentration(c), rainfall incidence(d), wind direction and reactor operation flags(e). The flag of 0.5 means the monitoring place was at downwind from the stack, and that of 1.0 means the KUR was operating at the power of 5 MW. Downwind width adopted in this work were ± 3 points on a 16-points compass. Mean speeds of southerly and northerly winds during reactor operation were 2.2 m/sec and 3.3 m/sec, respectively.

The time variation of the total exposure rate and its components reveals us that the short term variation of the exposure rate can be mainly attributed to the precipitation washout and the variation of the ^{222}Rn daughters concentration in the atmosphere. The exposure rate of about 2.0 μR/hr is increased by the rainfall rate of about 3 mm/hr in Fig.1(d) and the increase of about 0.25 μR/hr is observed owing to the airborne radioactivities of 250∿300 pCi/m^3 in Fig.1(c). On the other hand, the long term variation depending on the moisture content in the soil after rainfall incidence in Fig.1(d) is clearly observed in the time variation of ^{40}K and ^{232}Th-series exposure rates.

Plume exposure rates due to unscattered gamma-rays from ^{41}Ar radionuclide released at the rate of 6 x 10^{-2} Ci/hr is shown in

Fig.1(b). The accuracy of the plume exposure rate was minutely discussed in ref.1 together with the arguments of minimum detectable amount of exposure rate. It is evident from the figure that they were observed when the monitoring place was at the downwind from the stack, furthermore, they were accompanied with the increase of ^{222}Rn daughters concentration. It seems possible from this fact that the movement of ^{41}Ar in the air was mainly controlled by the same meteorological factors as those regulating airborne radioactivities in the natural environment. A relation between a plume exposure rate(E_p) and an inverse of wind velocity(I_v) is shown in Fig.2 Vertical bars represent errors included in the analysis method. Though there are a few data around higher 1/v values, a general tendency of them seems to be shown by a linear relation of Ep(μR/hr) = 0.14 I_v (for release rate of 6 x 10^{-2}Ci/hr). This will be available for assessment of the long term plume exposure rate around a nuclear facility, for example, the relation will be rewritten by the formula,

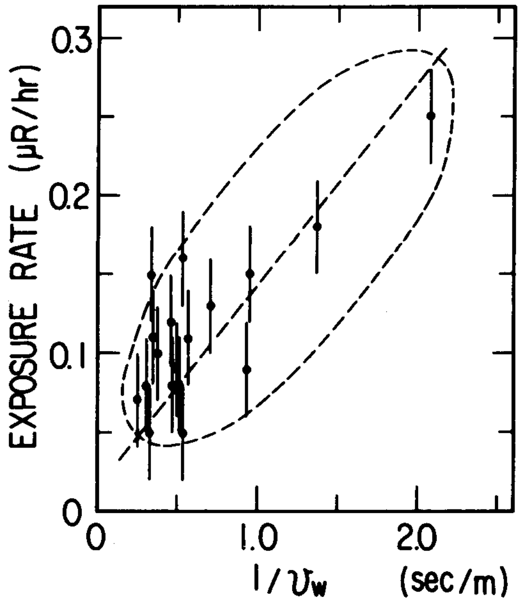

Fig. 2 Relation between a plume exposure rate and an inverse of wind velocity.

$$Ep(\mu R/year) = (2.2 \pm 1.1)\cdot Q\cdot I_v\cdot P_d \qquad (2)$$

when the total amount of gaseous ^{41}Ar(Q Ci/year) and the inverse of the mean wind velocity(I_v) and the downwind probability(P_d) for a year are given. The exposure rates due to scattered photons(E_s) were determined by using the build-up factors(BFs) calculated for the finite line source of ^{41}Ar at an effective stack height of 45 m from the ground level.

Effective dose equivalent(H_t) due to ^{41}Ar were determined by the following equation,

$$H_t = C(1.29)\cdot E_p + C(0.25)\cdot(BF - 1.0)\cdot E_p \qquad (3)$$

where C(1.29) and C(0.25) are exposure to effective dose equivalent (EEDE) conversion factors of Japanese adults for photon energies of 1.29 and 0.25 MeV, respectively(5). Some examples of exposure rates and effective dose equivalent rates are shown in table 1. EEDE conversion factors for isotropic irradiation given in ref.5 were chosen because the exposure caused by the gaseous effluents was considered to be almost isotropical. The last column in table 1 also denotes the deep dose equivalent rate index(H_d) that was recommended by the ICRU published in 1976. Calculations of indices were carried out in the same manner as was adopted in case of the effective dose equivalent rate. The exposure to dose equivalent index conversion

Table 1. Exposure rates, effective dose equivalent rates and dose equivalent rate indices due to plume ^{41}Ar from the KUR stack.

Date	ER (μR/day)	EDER(10^{-2}μSv/day) Male	EDER(10^{-2}μSv/day) Female	DERI(10^{-2}μSv/day) Hd
Feb. 3	1.66	1.43 (0.86)*	1.34 (0.81)*	1.73 (1.05)*
4	0.82	0.70 (0.85)	0.67 (0.82)	0.85 (1.05)
9	0.39	0.34 (0.87)	0.32 (0.81)	0.41 (1.05)
18	1.00	0.85 (0.85)	0.81 (0.81)	1.03 (1.03)

* : Values in the parentheses are ratios to the exposure rates.
ER : Exposure rate.
EDER : Effective dose equivalent rate.
DERI : Dose equivalent rate index (Hd is the deep dose equivalent rate index recommended by the ICRU).

factors which were given in ref.6 were used in the calculation in stead of EEDE conversion factors $C(E_i)$ in the formula (3).

It is evident that the effective dose equivalent rate was the smallest in the three types of quantity information for radiation protection and the ratio of effective dose equivalent or dose equivalent index to exposure was almost constant in spite of the different BF for the line source of ^{41}Ar. The mean values of these ratios are quite similar to those obtained in the natural environment (5). This fact suggests that the unique conversion factor from exposure to effective dose equivalent will be employable for estimation of radiation exposure due to background gamma-rays and photons from ^{41}Ar released artificially.

4. CONCLUSIONS

From the investigations described in the present report, conclusions are as follows,

1. The short term variation in the time series of exposure rate could be separated successfully from the long term ones using the analytical gamma-ray monitoring technique.

2. General tendency of the relation between the plume ^{41}Ar exposure rate and an inverse of wind velocity was confirmed as was applicable to estimation of the long term plume exposure around the KUR site.

3. The effective dose equivalent rate was determined on the basis of the energy spectrum of the plume exposure rate, and it was concluded that the same conversion factor, from exposure to effective dose equivalent, as that given by the natural environmental gamma-rays could be available for estimation of effective dose equivalent due to artificial radionuclide of ^{41}Ar.

References

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