

Evaluation of Whole Body Counter at Nagasaki University

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A whole body counter was installed at Nagasaki University in 1968. Evaluation of the whole body counter was done by accumulated data during 15 years since its installation. The items used for the evaluation were the background radiation, the resolution and sensitivity of the measurement system. The characteristics of the apparatus has been stable for these years: The background counting rate was 1400 cpm, the relative resolution for 1.4 MeV gamma-rays was 8.5 %, and the sensitivity for 1 kg of potassium chloride (KCl) was 2150 cpm. The number of experimental and clinical measurements for patients was about 350 every year. The most frequent measurements were of K-40 and Cs-137; 74 %. The repeated measurements of potassium concentration for healthy subjects were performed during a long period, and were analyzed.

INTRODUCTION

A whole body counter has been employed for experimental and clinical uses for 15 years since its installation at Nagasaki University School of Medicine in 1968. The main purpose of the installation of the whole body counter was the measurement of gamma-rays from Cs-137 for the analysis of the fall-out intake of residents at Nishiyama district where the fall-out from the atomic bomb was dominant,¹⁰⁾¹²⁾ and the measurements of gamma-rays from K-40 which exists in natural potassium⁴⁾⁷⁾¹³⁾ for the evaluation of senescence of atomic bomb survivors.⁵⁾⁸⁾⁹⁾

In this work, the experiences of 15-year application of the whole body counter at Nagasaki University was summarized. The counting rate of background radiations, the resolution and sensitivity of the measurement system, and the utility of the apparatus during this period were analyzed. Further, the body potassium in healthy subjects was measured repeatedly during one year, in order to know a long-term changes in the potassium concentration.

APPARATUS

The geometry of the whole body counter has been described in a previous report.¹¹⁾ Briefly, the inside dimensions of measurement room are 140-cm in width, 260-cm in length and 210-cm in height with 20-cm thick iron walls. The inner side of the wall is lined with 3-mm thick lead and 3-mm thick Lucite plate. A pair of detectors consist of 8-in diameter by 4-in thick NaI(Tl) scintillation crystals with four of 3-in diameter photomultiplier tubes attached to each crystal. The detectors can be scanned along the long axis of human body for 198 cm during measurements. In 1977, new photomultiplier tubes were replaced. A new 1024-channel analyzer replaced the 400-channel analyzer which had been used since the installation, and the interface between photomultiplier tubes and the multi-channel analyzer were replaced in 1978.

RESULTS

1. Background Radiations (BG)

Two points were considered to improve the efficiency of the measurement of small amounts of radionuclides in the body. The first point was to take fresh air above a three-floor building to the measurement room through a duct. The second point was to select iron of low concentration of Co-60 for the walls of the measurement room.

A solid curve in Fig. 1 showed a spectrum of BG measured for 50 minutes on 5th July 1968. Peaks of Pb-214 and Bi-214 which are daughter nuclides of Rn-222 were observed. The daily changes in the BG counting rate for July 1968 are shown in Fig. 2. The BG counting rate was larger in rainy days as indicated by circled symbols in Figure than sunny days. As one part of the duct for the fresh air ran beneath the earth, and in order to decrease the BG counting rate, that part of the duct was reconstructed to run above the earth in 1969. As shown by the dotted curve in Fig. 1, the spectrum

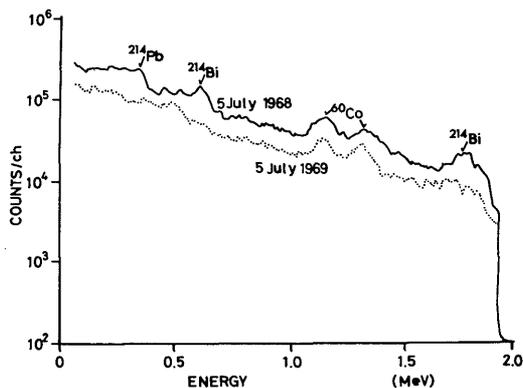


Fig. 1. The spectra of background radiation (BG) measured for 50 minutes on 5th July 1968 and on 5th July 1969.

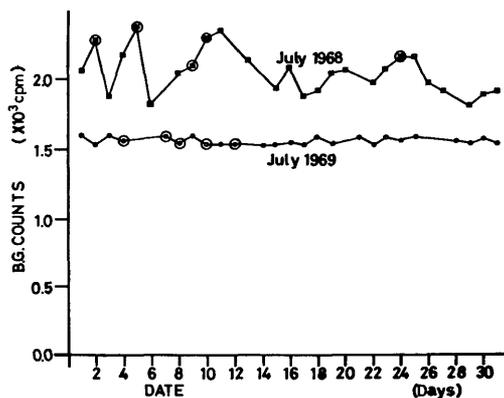


Fig. 2. Changes in the BG counting rate during July 1968 and July 1969. Circled symbols indicate of rainy days.

measured on 5th July 1969 showed decreased peaks of Pb-214 and Bi-214 and the BG counts decreased through a whole range. Fig. 2 showed decreased BG counting rate even in rainy days after the reconstruction of the duct as indicated by circled symbols.

Iron of low concentration of Co-60 was selected to use for the walls, however peaks of gamma-rays from Co-60 (1.17 and 1.33 MeV) were observed in the BG spectrum in 1969, as shown in Fig. 3. In 1983, gamma-rays from Co-60 were hardly detected. During this 14 years, the amount of Co-60 decreased to 1/7, for the half-life of Co-60 is 5.26 years. The BG counting rate from 1968 to 1982 is shown in Fig. 4. In 1977 (point A in Figure), 8 photomultiplier tubes were replaced. In 1978 (points B), the interface and the multi-channel analyzer were replaced, and the energy range for the BG measurement was also changed from 0.1–2.00 MeV to 0.1–2.56 MeV. The BG counting rate at a low energy range (0.1–0.20 MeV) became small after the replacement (see Fig. 3). The BG counting rate in 1977 was reduced by 30 % compared with that in 1968. This reduction was mainly due to the decrease of the amount of Co-60 in the walls. The background index (the BG counting rate in the energy range of from 0.1 to 2.0 MeV divided by the volume of the scintillators) was 0.19 cpm/ml at September 1983.

The effect of shielding of BG by the walls was examined. The BG was measured at 50 cm inside from the door at open and closed conditions of the door. The detected photoelectric peaks in the BG spectrum were of Cs-137 (550–770 keV) and K-40 (1290–1590 keV). The counting rates for Cs-137 were 1896 cpm and 125 cpm at open and closed conditions, respectively; the ratio was 0.07. The counting rates for K-40 were 1004 cpm and 53 cpm at open and closed conditions, respectively; the ratio was 0.05. The average BG counting rate in every month was analyzed from 1978 to 1982. In Fig.

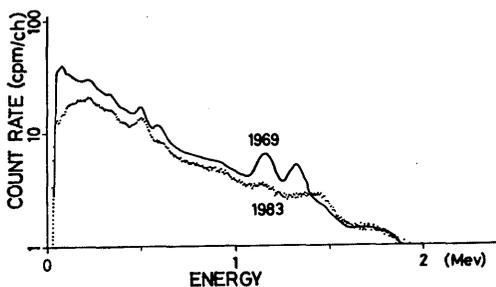


Fig. 3. The spectra of BG in 1969 and 1983.

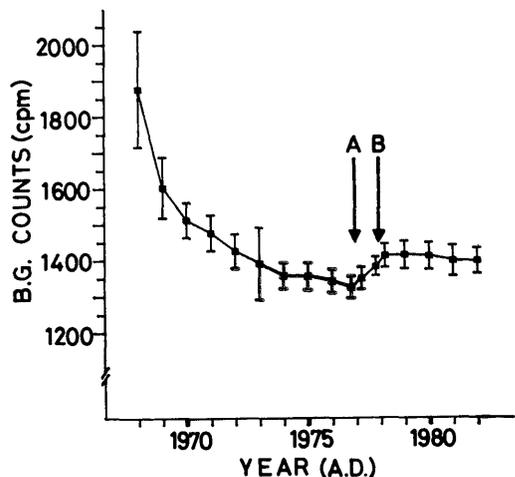


Fig. 4. The change in the BG counting rate averaged for each year. Vertical bars indicate one standard deviation (SD). In 1977 (point A), 8 photomultiplier tubes were replaced, and in 1978 (point B) the interface and the multi-channel analyzer were replaced.

5, one example for 1979 is shown. The reduced BG counting rate was observed at September and November in some years, but a general tendency was not observed.

2. Resolution and Sensitivity

The resolution and sensitivity for gamma-rays from K-40 (1.4 MeV) in potassium chloride (KCl) of 1 kg in a container of 15-cm diameter by 7.5-cm height have been measured. The resolution was evaluated by the full width at half maximum (FWHM) divided by the peak energy, and expressed by the relative values in percent. In Fig.

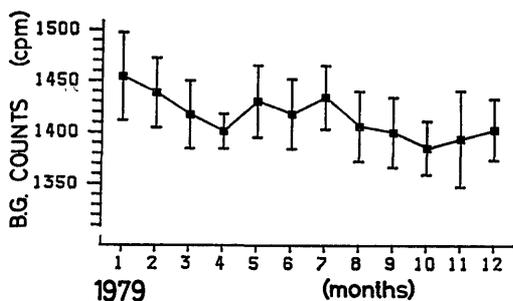


Fig. 5. The change in the BG counting rate in 1979 averaged for each month. Vertical bars indicate one SD.

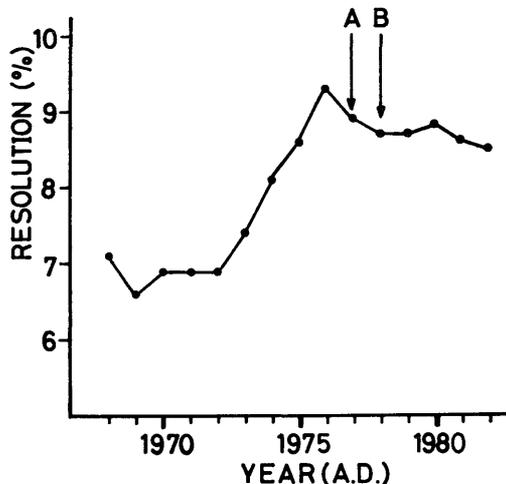


Fig. 6. The change in the resolution of gamma-rays from K-40 (1.4 MeV). The resolution was expressed by relative values in percent of the full width at half maximum (FWHM) divided by the peak energy. Points A and B are as in Fig. 4.

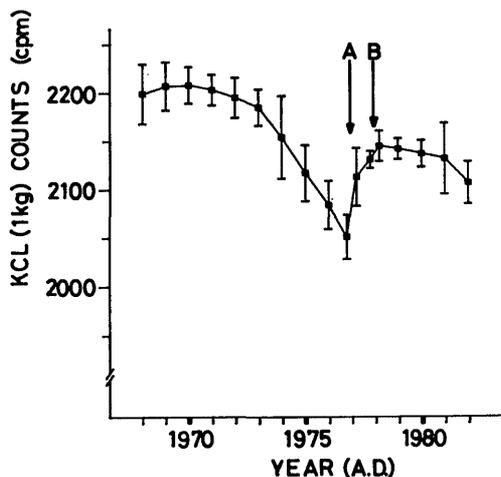


Fig. 7. The change in the sensitivity evaluated by the counting rate for 1kg of potassium chloride, averaged for each year. Points A and B are as in Fig. 4.

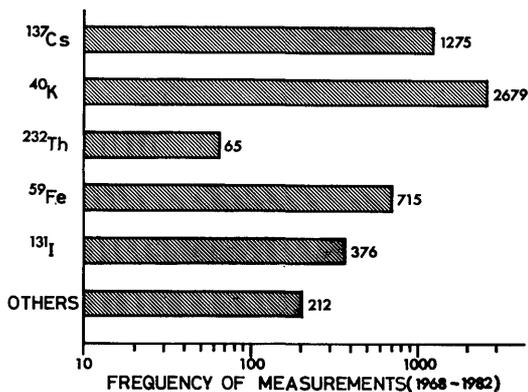


Fig. 8. The frequency of measurements during 1968 and 1982. Total number was 5322.

6, the resolution for K-40 gamma-rays during 1968 and 1982 is shown. The resolution was stable during 1968 and 1972, and became worse from 1973 to 1976, and continued to be stable after 1977. In 1977 (point A in Figure), the photomultiplier tubes were replaced and the adjustment of the measurement system was made. Some improvement was obtained, but the resolution did not resume to the initial one in 1968.

In Fig. 7, the counting rate of the photoelectric peak of gamma-rays from K-40 (1.35–1.57 MeV) during 1968 and 1982 is shown. The counting rate did not vary from 1968 to 1972, decreased from 1973, and became minimum in 1977. After the replacement of the photomultiplier tubes (point A), the counting rate increased and became stable from 1978. The increase in the counting rate in 1977 was due to the increase in the resolution by the replacement of the photomultiplier tubes and the adjustment (see Fig. 6).

3. Utility of the Whole Body Counter

In Fig. 8, the frequency of the measurements from 1968 to 1982 is shown. The whole body counter has been applied experimentally and clinically with average 350 measurements every year. Total number of measurements was 5322; 24 % of the measurement were of Cs-137 for the analysis of the fall-out intake of residents at Nishiyama district. The most frequent measurements were for the estimation of body potassium by measuring K-40 which exists in natural potassium, 50 %. The measurement of Th-232 was for the estimation of body burden in Thorotrast patients. The analysis of Fe-59 absorption⁸⁾⁶⁾ and the estimation of internal radionuclide contamination of workers in a nuclear power station were also performed.

In Fig. 9, the frequency of measurements of Cs-137 and K-40 during 1968 and 1982 is shown according to Departments which sent patients. Department of Radiation Biophysics measured Cs-134 and K-40 for the analysis of fall-out intake of residents at Nishiyama district⁽¹⁰⁾¹²⁾ and of the senescence of the atomic bomb survivors.⁵⁾⁸⁾⁹⁾ Department of Hygiene analyzed the body potassium of students who often do sports and seldom

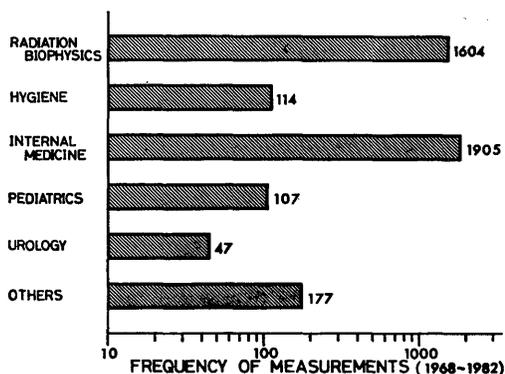


Fig. 9. The frequency of measurements of Cs-137 and K-40 according to Departments which sent patients. Total number was 3954.

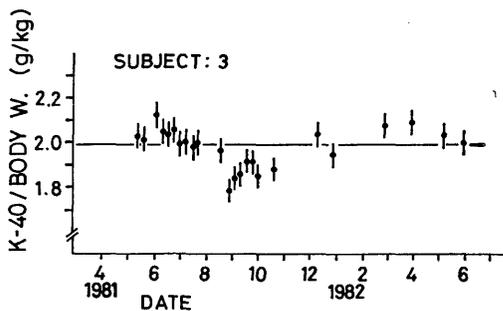


Fig. 10. The change in the potassium concentration for subject 3. Vertical bars indicate one SD of statistical error of counting for each measurement.

Table. Potassium Concentration of Healthy Subjects

Subjects (sex, age)	Body Potassium (g)		Body Weight (kg)		Potassium Concentration (g/kg)		Number of Measurements
	mean	(C.V.)	mean	(C.V.)	mean	(C.V.)	
1 (M,40)	104.1	(0.04)	52.1	(0.01)	2.00	(0.04)	24
2 (M,33)	120.4	(0.04)	59.1	(0.01)	2.01	(0.04)	28
3 (M,23)	139.5	(0.04)	70.5	(0.01)	1.98	(0.04)	24
4 (F,22)	73.4	(0.06)	38.9	(0.01)	1.89	(0.06)	20
5 (F,21)	83.2	(0.07)	44.6	(0.01)	1.86	(0.06)	21
6 (F,23)	82.0	(0.04)	46.4	(0.02)	1.77	(0.04)	27
7 (F,25)	90.5	(0.05)	55.7	(0.02)	1.63	(0.05)	23

C.V.: the coefficient of variation

do sports. As clinical measurements with whole body counter, Department of Internal Medicine sent patients of hypertension, aldosteronism¹⁵⁾ and muscular dystrophy¹⁾ for the measurements. The Department of Pediatric sent patients of muscular dystrophy, and they analyzed body potassium between fat and thin children.

4. Repeated Measurements of Body Potassium of Healthy Subjects

Repeated measurements of body potassium were performed for 7 healthy subjects (3 males and 4 females) from May 1981 to June 1982. The average number of measurements was 27 per person during this period. In Fig. 10, the change in potassium concentration for subject 3 is shown. The seasonal change in the potassium concentration was not observed for all 7 subjects. In Table, the mean values of body potassium, potassium concentration and body weight, and their coefficients of variation (C.V.) are shown. The variation of C.V. was between 0.04 and 0.07 for the body potassium and the potassium concentration. It can be said that a change in the potassium concentration of more than 10 % indicates some physiological change(s) occurred.

DISCUSSION

The whole body counter has other applications of measurement of radionuclides in the body in addition to ones described above. Leukemia can be diagnosed by estimating potassium concentration in the body,¹⁵⁾ and vitamine B₁₂ absorption can be analysed with Co-57 labeled vitamine.¹⁴⁾

To maintain the apparatus in good condition, low humidity and constant temperature in the measurement room and the operation room should be provided, for keeping the NaI crystals and the electric circuit from being damaged. For the whole body counter at Nagasaki University, the humidity is restricted at $55 \pm 3\%$ and the temperature is controlled to be $27 \pm 3^\circ\text{C}$ and $20 \pm 3^\circ\text{C}$ in summer and winter, respectively.

When a patient is measured with whole body counter, it must be checked if the patient have been injected radioisotopes, such as I-131, for the diagnostic purpose before. If a considerable amount of radioisotopes exists in the patient still, their gamma-rays

will interfere the accurate measurement.

The BG counting rate should be measured every day. When a change in the counting rate is observed, its cause must be examined. It is possible that the measurement room is contaminated by radionuclides from the patient who is previously injected the radionuclides. The linearity between gamma-ray energy and its corresponding channel of multi-channel analyzer should be confirmed once a month. The linearity should be also checked after the power stoppage or power cut-off. The power must be supplied day and night without cut-off. At Nagasaki University, the linearity have been checked by gamma-rays from Ba-133 (356 keV), Cs-137 (662 keV), Co-60 (1173 and 1333 keV) and K-40 (1461 keV).

To maintain the apparatus in the condition of the high quality, following three points should be examined periodically, as analyzed in this work: the BG counting rate, the resolution and the sensitivity. The authors think that the whole body counter at Nagasaki University has been maintained well since its installation.

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