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With the completion in 1964 of the new building for the National Institute of Radiation Protection, the long-planned, low-activity laboratory was set up in the basement. The laboratory consists of the counting room, 5m x 10m, in which the various whole-body counters are situated and of ancillary rooms with a bath, showers and facilities for changing clothes (Fig. 1). During the planning of the building, various rocks were investigated in order to find a material with as little γ-radiation as possible, suitable as ballast material to be used in the concrete construction work of the walls, floor and ceiling of the counting room. A mineral from Hofors (later named hoforsite) was found to be well suited for the purpose. Further, by using a cement with low activity (Limhamns), a concrete with a very low content of radium, thorium and potassium was produced. The background in this counting room, measured with a Ø 5" x 4" NaI(Tl) crystal, over the energy range 0.1-4 MeV gave only 8 % of the background counting rate of a normal room in the same building (ref. 1). The ceiling and floor are constructed of 80 cm thick hoforsite concrete, while the walls are 60 cm thick hoforsite and 20 cm thick normal concrete.

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The paints, varnishes etc. used in the laboratory were chosen for their low activities. The counting room is kept at a constant temperature within $\pm 1^{o}$C and is ventilated with air which has passed through both a coarse filter and an absolute filter. The intake for this air on the outside of the building is four meters above ground level. The pressure in the counting room is kept slightly above that of the surrounding rooms to prevent inward leakage.

In the "hoforsite" room, the following instrumentation exists for whole-body counting.

A) A pressurized ionization chamber, designed by Sievert (ref. 2, 3 and 4) and transferred from its former site at the low-activity laboratory at the sewage disposal plant at Henriksdal in Stockholm. This apparatus consists of a stretcher surrounded by 12 cylindrical tubes, 40 cm in diameter and 200 cm long, filled with nitrogen gas at 20 kg/cm^2. The ionization current through the tubes is measured with an electrometer tube circuit and a potentiometric recorder. The counting geometry is good, approaching 4π, thus facilitating good precision in quantitative measurements since the distribution of the activity has little effect on the result. The duration of the measurements is approximately 10 minutes and the sensitivity has been adjusted for the registration of a total body content of the order of μCi.

B) An "open-booth" counter, transferred from the former building of the Institute of Radiophysics (Fig. 2). The shielding for this counter consists of 10 mm thick sheets of iron. The side walls and the ceiling are 15 cm thick, the back wall 10 cm thick and the floor 20 cm thick. A ∅ 5" x 4" NaI(Tl) crystal, mounted on a movable carriage, is shielded by a 10 cm thick lead mantle. The aperture can be varied either by moving the carriage or by shifting the crystal in relation to the lead mantle. In order to reduce the background in the low-energy region, all the inner surfaces of the iron shielding are lined with sheets of lead 3 mm thick. To reduce the background the "open-booth" counter was placed in front of a water tank in its former position in the old building. The removal to the "hoforsite" room resulted in an even lower background over the energy range 0.1-4 MeV. Both the crystal and the photomultiplier were replaced when the counter was moved to the new building. Together with the new multichannel analyzer these measures provided improved facilities for measurement, as illustrated in fig. 3.

The data read-out equipment is the same as for the scanning apparatus and is described on p. 5.

The main advantage of the "open-booth" counter is that the construction cost is lower than for whole-body counters enclosed in iron or lead cabins. Its main disadvantage is that the results are markedly dependent on the distribution of the activity in the body. The results of the measurements depend, among other things, on the sitting position of the subject during the measurements. For this reason quantitative measurements are difficult to make. The apparatus has been described previously by Lindell (ref. 5).

C) The whole-body scanner, which has three ∅ 5" x 4" NaI(Tl) crystals placed symmetrically around a stretcher, in a plane perpendicular to the longitudinal axis of the stretcher (Fig. 4). The whole apparatus is surrounded by a lead shield in the form of a small cabin with a sliding door. A more detailed description of this counter is given below.

Of these three whole-body counters, the "open-booth" counter has the highest sensitivity. It is used in conjunction with the ionization chamber in radiation protection measurements on persons engaged in work with radioactivity. An identification of the nuclide and to a certain extent also a quantitative estimate can be made with the "open-booth" counter. When the nuclide has been identified the ionization chamber is advantageous for quantitative measurements, provided that the amount of activity is of the order of 1 μCi or more. The whole-body scanner is mainly used for research projects such as studies on uptake and localization of various nuclides and labelled organic substances. Furthermore, this apparatus is suitable for measurements in more complicated cases of internal contamination.

The costs of the low-activity laboratory are given in Table 1. The workshop of the Institute carried out all the interior construction work, such as moving the "open-booth" counter and ionization chamber apparatus from their previous localities, construction of dividing walls, setting up of lead shielding and the scanning mechanism. The total amount of work involved is estimated at 9 "man-months".

Table 1

Compilation of costs for the low-activity laboratory, excluding the "hoforsite" concrete, ionization chamber and furniture. Prices as in 1965, if not otherwise stated.

"Open-booth" counter	Radiation shield of iron and lead (1958)	11,000
	Crystal with photomultiplier (1964)	15,000
Whole-body scanner	Radiation shield of lead	32,000
	Mechanism, incl. motors	9,000
	3 crystals with photo-multipliers	40,000
Electronics	2 multichannel analyzers (Intertechnique)	130,000
	Other electronic and read-out units	65,000
	Total Skr	302,000

DESCRIPTION OF THE WHOLE-BODY SCANNER

The lead cabin surrounding the whole-body scanner has walls and ceiling 4 cm thick and a floor 8 cm thick and a total weight of 15 tons. The cabin has a lead sliding door with two port-holes which can be opened from both inside and outside. To minimize the unpleasant feeling of being shut in, experienced by the person being measured, the inside walls have been painted a light colour and a loud-speaker for music as well as an intercom have been installed.

The detectors, three ∅ 5" x 4" NaI(Tl) crystals are mounted on a large vertical aluminium ring surrounding a horizontal stretcher. The distance from the surface of the detectors to the central axis is 400 mm. In 1969 it was found advisable to shield the crystals more efficiently from direct and scattered radiation from the sides by screening each crystal with a cylinder of lead 28 mm thick.

The crystals can be made to scan back and forth along the length of the stretcher over an adjustable range of up to 146 cm. The scanning speed is constant at 21.4 cm/min. The crystals can also turn backward and forward through an angle of 120^{o} in a plane perpendicular to the direction of scanning in 23 seconds. This movement can be made to take place while the lengthwise scanning is in progress. The scanning mechanism generates a pulse every 5 mm of scanning distance. One use of these pulses is to indicate the position of the crystals.

All the detectors are connected to one and the same high-voltage supply, but they have individual fine high voltage adjustments and protection against excess voltage. The pulses from the detectors are fed in parallel into one and the same amplifier and thus enter the pulse height analyzer at the same input. By stopping the pulses between the detector and the amplifier any one of the three detectors may be connected or disconnected as required.

The 400-channel analyzer is manufactured by Intertechnique (type SA 40 B) and is used as a pulse height analyzer with an energy calibration of 10 keV/channel, thus facilitating the measurement of spectra in the energy range 0.1 to 4 MeV. By increasing the amplification, the lower energy limit can be decreased to about 40 keV. This limit is set by the absorption in the metal capsule of the crystal. The resolution of the three detectors together is approximately 10.5 % at 0.662 MeV. The multichannel analyzer can also be used as a multiscaler with adjustable energy intervals. The storage of the pulses registered within an interval can be controlled by an external signal, so that the pulses enter successive channels. By using a clock to control the storage of the pulses, the disintegration of a short-lived activity can easily be followed on the screen of the oscilloscope of the multichannel analyzer. If, on the other hand, the position of the crystals along the length of the stretcher is chosen to guide the storage of the pulses, then the counting-rate can be seen on the oscilloscope screen as a function of position along the length of the stretcher. When the multichannel analyzer is employed as a multiscaler, there is no compensation for the dead-time, but as this is only approximately 16 µsec., it can in most cases be neglected.

The whole-body scanner and the "open-booth" counter have a common data processing station, consisting of an electric typewriter, a XY-plotter, a magnetic-tape calculator and a punched-tape station. The transfer of the data onto a magnetic tape is very fast, about 3 seconds for 400 channels, compared with 2-6 minutes for the other units in the read-out equipment. It is thus particularly valuable when a fast series of measurements is required. The magnetic tape calculator can also be used for simple data processing, such as the addition or subtraction of spectra and the summation of intervals. In order to facilitate the processing of counting data, the information is fed onto a punched-tape, which gives the further possibility of feeding the spectra back into the multichannel analyzer.

The whole-body scanner can be used either as a whole-body counter or as a scanner. For a whole-body measurement, the person lies in a supine position with his shoulders at a fixed point on the stretcher. During the measurement the crystals turn back and forth through an angle of 120^{o} while at the same time scanning along the length of the stretcher over a distance of 100 cm. Usually the person is scanned eight times during a measuring period of about 40 minutes. The detectors, which are not provided with collimators for whole-body measurements, generate a cylindrical surface around the subject being measured. Because of this "4π" geometry the apparatus is relatively insensitive to differences in the distribution of activity in the body. The calibration constants normally used are calculated from measurements on phantoms containing homogeneously distributed activity. In cases where the activity in the body under investigation is very inhomogeneous, a special calibration is carried out on a phantom with the same nuclide and distribution.

The measurement of activity profiles can be made either by step-wise scanning, or by continuous scanning. In step-wise scanning the detectors are not moved along the length of the subject to be measured during the counting, but the turning movement of the detectors may be used if desired. The time taken for a measurement within a chosen energy interval, or for a measurement of a γ-ray spectrum, may be adjusted so that the desired accuracy is attained for each position. Normally, step-wise scanning with turning is employed in the measurements of profiles, since the turning movement of the detectors has a smoothing effect on the activity distribution in the plane perpendicular to the direction of scanning, and also because this technique makes it possible to take up the whole γ-spectrum for each position. The fact that the duration of each count can be selected is a further advantage, although the long measuring time is a major disadvantage.

In continuous scanning, the detectors do not perform the turning movement, only a continuous movement along the length of the stretcher. The counting rates within adjustable energy intervals are fed into successive channels of a multichannel analyzer. The rate of scanning cannot be regulated, but it is possible to store the result of several runs and thus improve the counting statistics. Continuous scanning is relatively fast, approximately

5 minutes for each 100 cm scanned. This speed facilitates the study of rapid redistributions of activity but necessitates a high counting rate.

BACKGROUND MEASUREMENTS

For the measurement of small amounts of radioactivity a low and constant background level of ionizing radiation is of the utmost importance. The choice of building materials used in the construction of the walls, ceiling and floor of the laboratory has reduced the background radiation to about 1/10th of that in other rooms in the same building. A further reduction to 1/10th has been achieved by the erection of the lead cabin surrounding the scanning apparatus, thus giving a background count approximately 1 % of the level in the other rooms. Variations in the background, particularly that part due to ^{214}Bi (RaC) have been reduced by filtering the air intake. Temperature stabilization of the room is essential because of the temperature sensitivity of the detectors and the electronic equipment.

The total absorption peaks which occur in the background γ-spectrum of the whole-body scanner are ^{40}K, ^{214}Bi (RaC), ^{208}Tl (ThC′) and the annihilation peak at 510 keV. The "open-booth" counter has a further peak at about 3.2 MeV, presumably due to an internal α-contamination in the crystal (ref. 6). The average background in the ^{40}K energy interval during the period from April to December 1970 in the "open-booth" counter was 19.4 cpm, with a standard deviation of S = 1.6 %. The corresponding value for the whole-body scanner during the period from November 1969 to December 1970 was 81.0 cpm, with S = 0.7 %. The total count within the energy interval 0.1-4 MeV is about 390 cpm for the "open-booth" counter and about 1700 cpm for the whole-body scanner.

The presence of a water phantom affects the background counting-rate since the radiation is scattered by the phantom. This difference is hardly detectable in the whole-body scanner, but becomes significant in the "open-booth" counter for γ-ray energies below about 0.5 MeV. As no difference is detectable with or without a water phantom above an energy of 0.5 MeV, the results of measurements of 800 minutes' duration without a water phantom are taken as the background for measurements of total body content of radioactive elements with γ-ray energies above 0.5 MeV. Regular measurements of the background are made at least once a week and serve as a check on the proper functioning of the apparatus.

By studying the time variation of the counting-rate in various energy intervals of the background, it is possible to obtain an indication of the stability of the equipment. This has been done, giving the following results.

a) Neither in the "open-booth" counter, nor in the whole-body scanner can a seasonal variation be detected.

b) In the "open-booth" counter, the counting rates in the energy intervals for ^{208}Tl (ThC′) (2.40-2.68 MeV), ^{214}Bi (RaC) (1.66-1.86 MeV) and ^{40}K (1.37-1.55 MeV) have been stable since 1966. The random variations exceeding those of the counting statistics have ranged between 1 and 2 % and may be due to variations in cosmic ray intensities, activity variations or instabilities in the electronics. The counting rate in the ^{137}Cs energy interval (0.58-0.73 MeV) for the period 1966-1968 has shown greater variations. These have been shown to be due to badly adjusted electronics. Since 1969 this deficiency has been eliminated and the variations in the ^{137}Cs energy interval have been comparable to those in the other energy intervals.

c) For the whole-body scanner, a decrease in the background in the energy intervals of ^{137}Cs, ^{214}Bi (RaC), ^{208}Tl (ThC′) and, to a certain extent, ^{40}K has taken place. The reason for this change in the background appears to be an early contamination by ^{228}Th ($T_{1/2}$ = 1.9 years). Where and how this contamination occurred is uncertain. Since the reconstruction of the scanner in 1969 when, among other things, the crystals were shielded with lead cylinders, this change in the background count has been detected only in the ^{208}Tl (ThC′) energy interval. The ^{40}K interval has been the most stable of these energy intervals.

A check on the sensitivity of the scintillation instrumentation is made regularly by measurement of point sources of various isotopes. Measurements on ^{226}Ra sources form part of every energy calibration, giving a check on the linearity and stability of the apparatus and ensuring immediate detection of any changes.

CALIBRATION MEASUREMENTS, FIGURES OF MERITS AND ERRORS

The calibration measurements were carried out as follows.

I. Measurements of IAEA point sources. The counting was carried out in such a way that the sources were set up in the geometric centre of the whole-body scanner and of the ionization chamber apparatus. In the case of the "open-booth" counter, the sources were placed in a standardized position in front of the crystal.

II. Measurements of phantoms consisting of plastic bottles containing water or solutions of ^{40}K or ^{203}Hg.

III. Measurements of phantoms made of plastic containers with elliptical cross-sections, filled with water or solutions of ^{40}K or ^{137}Cs.

IV. Measurements of the phantoms in II above, with point sources of ^{137}Cs or ^{226}Ra imbedded between the chest and the abdomen sections.

V. Comparative measurements with other institutes (ref. 7, 8, 9, 10).

A special stand was constructed for the phantoms measured according to II, III and IV in the "open-booth" counter.

The results of calibration measurements from III and IV gave the contribution factors from ^{40}K and ^{226}Ra in the other energy intervals. After the direct calibration of the whole-body scanner for ^{40}K and ^{137}Cs, the "open-booth" counter was calibrated with the aid of two series of measurements on the control group. This calibration was made using the ratio of the $^{137}Cs/^{40}K$ γ-peaks, thus eliminating part of the uncertainty introduced by the differences in the sitting position of the person being measured. The ionization chamber was calibrated by measurements made according to II and III. Furthermore, some experiments were undertaken with in vivo measurements in the "open-booth" counter and in the ionization chamber on persons contaminated with radium (ref. 11).

Fig. 5 shows the efficiency of the apparatus as a function of the γ-ray energy. The dashed curve, drawn parallel to the curves for the point sources, gives a good indication of the sensitivities of the whole-body scanner and the "open-booth" counter, for in vivo measurements on a single isotope homogeneously distributed in the body.

The dependence on mass of the efficiency has been investigated for ^{40}K in the whole-body scanner by measuring parts of the plastic bottle phantom over the same scanning distance as in normal measurements. The result shows a linear dependence on the mass, but the influence of the length of the phantom will be studied further.

In order to compare the whole-body scanner with a conventional two-crystal apparatus of stretcher type, a ^{137}Cs source, in air, was measured in various positions in the plane of the crystals. In the area around the origin, having a cross-section corresponding in size to a normal person, counts were taken every three centimetres in the x- and y-directions. Further out towards the periphery, the points were taken every five centimetres. The results are shown in Figs. 6 and 7a - 7c. It can be seen from Fig. 7c that the turning movement of the crystals gives the isoresponse curves in air a nearly circular form. The ratio of the counts in the peak to the total counts and the resolution for ^{137}Cs in different positions in the plane of the crystals remains practically unchanged within a cross-section corresponding to that of a normal person.

A number of parameters (background equivalent activity, minimum measurable activity and minimum detectable activity) are usually applied for the comparison of whole-body counters. The definitions and values for the ionization chamber, the "open-booth" counter and the whole-body scanner are given in ref. 7. Here the figure of merit g and G will be treated:

$$g = \frac{1}{t_S\, r^2} \qquad \text{and } r^2 = \frac{\sigma_S^2}{S^2} = \frac{1}{S^2}\left(\frac{S+B}{t_S} + \frac{B}{t_B}\right) \qquad 1.$$

σ_S^2 = variance for the error in the counting statistics
B = background in cpm
t_B = time taken for the background measurement
t_S = time taken for the measurement of S
S = net cpm for the measurement

For $t_B >> t_S$ and $S << B$, the well-known expression

$$g = \frac{S^2}{B}$$

is found.

A more general, dimensionless figure of merit was proposed in 1962 by Lindell (ref. 5)

$$G = \frac{\left(\frac{\sigma_S}{S}\right)^2_{B=0,\ \eta=1}}{\left(\frac{\sigma_S}{S}\right)^2} = \frac{g}{a} \qquad 2.$$

where η represents the efficiency and a = γ-rays/min. from the radiation source.

From Eqs. 1 and 2 it is seen that

$$G\ a\ r^2\ t_S = 1$$

which can be used directly in the comparison of all types of whole-body counter.

In the equations treated above only the errors in the counting statistics have been taken into account. If the relative error in the background, apart from the error in the counting statistics, is called r_Δ, then the modified figure of merit will be

$$G_{mod} = \frac{1}{a} \frac{S^2}{S + B\left[1 + \frac{t_S}{t_B} + 2\ B\ r_\Delta^2\ t_S\right]}$$

Both g and G are functions of the γ-ray energy and of the γ-activity. By studying G the following relationships can be found. If $t_B \gg t_S$ and $\eta \cdot a \ll B$ then it is easy to show (ref. 7) that G = f(a) can be approximated by a straight line $G \approx a\eta^2/B$. Further, it is found that, if $a \rightarrow 0$ then

$$\frac{(\frac{dG}{da})_{ob}}{(\frac{dG}{da})_{ws}} \longrightarrow \frac{B_{ob}}{B_{ws}} > 1$$

which implies that the "open-booth" counter (ob) can detect lower in vivo activities than the whole-body scanner (ws), provided that the activity is homogeneously distributed.

In addition to its use in comparisons of whole-body counters, the figure of merit can be used for selection of the optimum energy interval for specified measuring situations and is particularly useful in measurements of bremsstrahlung.

Table 2 is a compilation of counting errors for a single in vivo measurement on ^{40}K and ^{137}Cs in the "open-booth" counter and in the whole-body scanner. The error in the reproducibility for the "open-booth" counter has been taken from ref. 12. In the case of the whole-body scanner this error has been estimated by a comparison of measurements of ^{40}K on about 20 persons in two measuring series. The individual biological variation of potassium has been neglected in the calculation, which implies an overestimation of the error in the reproducibility. The error in the contribution factor from other energy intervals and the error in the calibration constant have been calculated from the results of repeated measurements on phantoms. For the whole-body scanner the correction factor for the differences in bodily constitution may be of the order of 5 %. The error in this factor is difficult to estimate, but is not expected to influence the total error markedly.

Table 2

Summary of the errors for a single in vivo measurement[a)]

		"OPEN-BOOTH" COUNTER Percentage of body burden		WHOLE-BODY SCANNER Percentage of body burden	
		^{40}K	^{137}Cs	^{40}K	^{137}Cs
Standard deviation due to counting	σ_1 [b)]	5	8	6	11
The error in reproducibility	σ_2	4[c)]	4[c)]	3	3
$(\sigma_1^2 + \sigma_2^2)^{1/2}$		6	9	7	12
The error in the correction factor due to the contribution from ^{40}K in the ^{137}Cs interval	σ_3	-	1.8	-	1.3
The error in the correction factor due to the contributions from ^{214}Bi in the ^{40}K and ^{137}Cs intervals respectively	σ_4	negligible		negligible	
Calibration error	σ_5	3.6	4.0	3.9	4.0
$(\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2 + \sigma_5^2)^{1/2}$		8[d)]	10[d)]	8[d)]	13[d)]

a) The calculations have been made for 140 g potassium and 10 nCi ^{137}Cs, assuming that the measuring time of the background is much greater than the measuring time of the subject (30 minutes).

b) Standard deviation due to counting in the ^{214}Bi interval is included.

c) According to ref. 12.

d) The error in the correction factor for differences in body constitution is not considered.

EXAMPLES OF MEASUREMENTS AND INVESTIGATIONS CARRIED OUT

Radiation protection measurements

Two of the three whole-body counters at the Institute, the "open-booth" counter and the ionization chamber, are intended for measurements on persons whom it is suspected have become contaminated with radioactive material. Routine checking measurements are carried out on the laboratory personnel of certain institutions where a significant risk of contamination is considered to exist. These measurements, which are usually made with the "open-booth" counter, normally only show up the radioactive nuclides ^{40}K and ^{137}Cs although at one time small quantities of ^{65}Zn were detected in measurements on the personnel of a cyclotron laboratory. Measurements carried out in addition to the above routine checking include those on persons who are suspected of having become contaminated in accidents involving radioactive substances. Examples of such measurements are given in a report on an incident involving 5 Ci ^{233}Pa (ref. 13).

The control group

Measurements of the ^{137}Cs level have been carried out since 1959 on a control group consisting of personnel at this Institute, a total of 600 measurements spread over 43 series. Somewhat less than half of the group consisted of women and the age of the members ranged from 20 to 60 years. The exact composition of the group has varied over the years. In estimating the average for each series of measurements, a correction for the composition of the group has been applied by determining an individual weight factor. Since the group has not been chosen at random, it cannot be regarded as representative for the Stockholm area. The measurements nevertheless give a good indication of the variation with timeof the ^{137}Cs body burden and to a certain extent also of its magnitude. Furthermore, the results of these measurements form a basis for a background value to be used in measurements on contaminated persons.

From 1959 until 1966 the measurements were made in the "open-booth" counter and since 1966 in the whole-body scanner. The individual weight factors obtained in 1963 and in 1966 showed good agreement (Fig. 8), in spite of the fact that only 60 % of the persons were common to both groups. From 1967 an increased spread appeared in the ^{137}Cs level in the members of the group. This could be attributed to various causes, such as the difference in the biological half-life for males and females (for adult males 105 $\pm$ 25 days, for adult females 84 $\pm$ 28 days ref. 14), changes in the contribution from various food-stuffs to the total cesium intake (ref. 15), and possible changes in dietary habits. These factors can cause changes with time in the weight factors. The change in the method of measuring is not believed to be the cause of the greater individual spread since this was first noted after two series of measurements had been carried out in the whole-body scanner. In 1969 a new estimate of weight factors was made using the $^{137}Cs/^{40}K$ ratio, since this was the ratio for which the "open-booth" counter had been calibrated. The spread of the $^{137}Cs/^{40}K$ levels among the individuals in the group was less than the spread of the corresponding cesium content. Fig. 9 shows that the agreement between the weight factors for 1969 and 1966 is not as good as between the previous two estimates (Fig. 8). This could be expected on account of the increased spread among the individual cesium levels.

Fig. 10 shows the variation with time of the ^{137}Cs level for the whole group. The lowest and highest values measured in each series are also given. It can be seen from the diagram that the effective half-life during the period from 1964 (when a maximum was reached) until 1969 is approx. 2 1/3 years for the whole group. These values are higher than those reported from Denmark (1 1/2 years ref. 16), USA (3/4 years, ref. 17), Switzerland (1 1/4 years, ref. 18), UK (1 1/8 years, ref. 19). Such diverging values reflect differences in cesium contents in food-stuffs and in dietary habits.

The weighted average of the $^{137}Cs/^{40}K$ ratio in the male group is about 1.4 ± 0.1 ($1 \cdot \sigma$) times higher than in the female group, calculated over the whole period (1959-1970). This value agrees with that given in UNSCEAR 1969 (1.2 - 1.4) (ref. 20). A certain variation with time seems apparent (Fig. 11), in that an increased spread among the series of measurements occurred from 1967. This increase does not seem to be related to the technique of measurement, since it was not noted until the whole-body scanner had been in use for a year. The cause seems to lie in the factors pointed out above, namely, the difference in the biological half-life between males and females, and the change in the contribution to the cesium level in the diet from different food-stuffs.

Distribution and retention studies

Investigations of this type have been carried out using the whole-body scanner, which was equipped with various types of collimator for profile and distribution studies.

In co-operation with J. Hursh of Rochester University, USA, various experiments were undertaken to determine the uptake and retention of ^{212}Pb in humans (ref. 21). Profile measurements were made using simple slit collimators of lead, making it possible to detect differences between the distribution of ^{212}Pb administered orally and intravenously. Profile and localization studies of methyl mercury labelled with ^{203}Hg were carried out in association both with B. Åberg et al and with J. Miettinen et al.

The measurements with Åberg et al (ref. 22, 23), were made on three volunteers, each of whom took 2.6 µCi monomethyl mercury nitrate orally. The profile curves showed a concentration of the mercury activity mainly in two locations, namely the head and the liver region. The concentration in the head accounted for 10 % and that in the liver region for 50 % of the total body content. The measurements, which were continued over 100 days, showed that no substantial redistribution of the mercury took place. The estimated biological half-lives for methyl mercury for various parts of the body, however, indicate only a slight relative increase of methyl mercury in the head. The biological half-life of methyl mercury for the whole body was found to be about 70 days.

In an experiment carried out by Miettinen et al (ref. 24,25), 15 volunteers were each given about 2 µCi of protein-bound methyl mercury. Profile and distribution measurements on 5 of these persons showed the same concentration areas as in the investigation named above. The lowest whole-body content in the profile measurements was about 0.2 µCi ^{203}Hg. A typical profile curve is shown in Fig. 12, where the total activity in the volunteer is about 1 µCi.

Experiments to study the clearing processes and the distribution in humans of monodisperse plastic aerosols labelled with ^{51}Cr have been undertaken. The aerosol, which had a diameter of approximately 7 µ, was administered to a volunteer by inhalation. About an hour after the intake, the content of the isotope in the lungs was about 20 % of the total body content directly after the exposure. The retention curve showed a fast and a slow clearing process. The intake was about 0.5 µCi ^{51}Cr and the practical limit of detection for retention studies was found to be about 0.05 μCi.

In profile and localization studies in vivo using γ-active isotopes, it has been found that the most accurate results are obtained if an energy interval is chosen at the total absorption peak of the γ-radioactive element. The bremsstrahlung from a pure β-ray emitter has a continuous energy spectrum, thus complicating the choice of the energy interval for optimum bremsstrahlung measurements. Measurements on patients who have been treated with ^{32}P for polycytemia vera have been undertaken by Snihs, Swedjemark and Tribukait (ref. 26).

The profile and retention studies which have been carried out show that only relatively small amounts of radioactivity need be administered to volunteers in order to obtain a clear picture of the distribution and retention patterns. In radiation protection work results from these measurements are of great value for the determination of total doses and dose distributions. Experiments using radioactive tracers for measurements in vivo can be so designed that they give results both of biological interest and of use in radiation protection work.

Summary

In the low-activity laboratory of the National Institute of Radiation Protection there are three types of whole-body counter; an pressurized ionization chamber, an "open-booth" counter and a whole-body scanner. In particular the whole-body scanner, which is of multi-detector complex-motion scanner type, is described. The results from background measurements, calibration measurements and other measurements are reported. The size and distribution of the measuring errors in an *in vivo* measurement are estimated.

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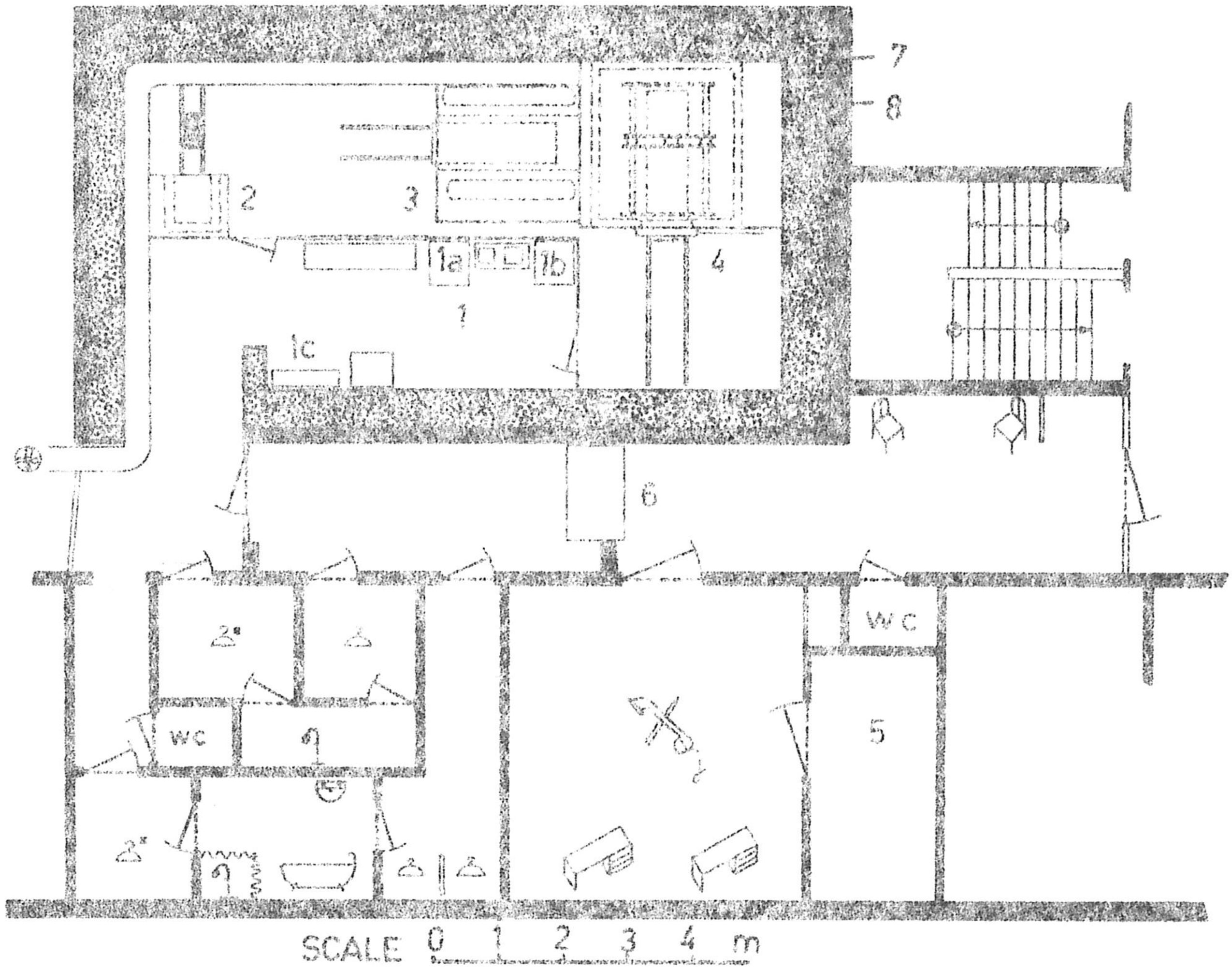

Fig. 1 Plan of low-activity laboratory for whole-body counting.

1. Monitor operations room

1a-c. Electronic equipment

2. "Open-booth" counter

3. Ionization chamber

4. Whole-body scanner

5. Records

6. Background monitor, change of shoes

7. Ordinary concrete

8. Low-activity concrete

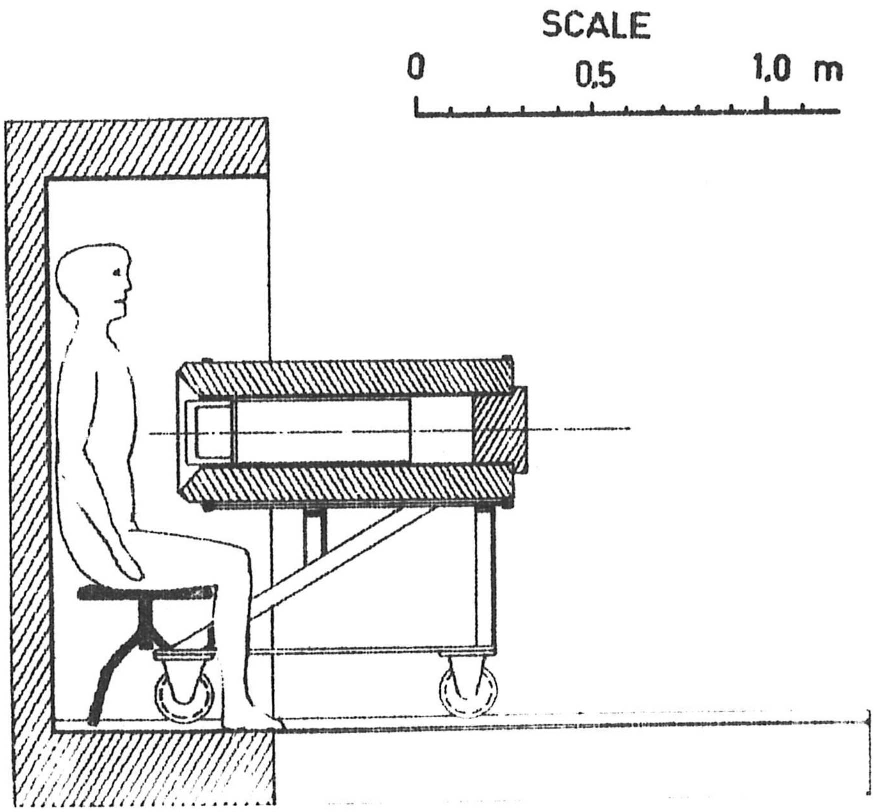

Fig. 2 "Open-booth" counter.

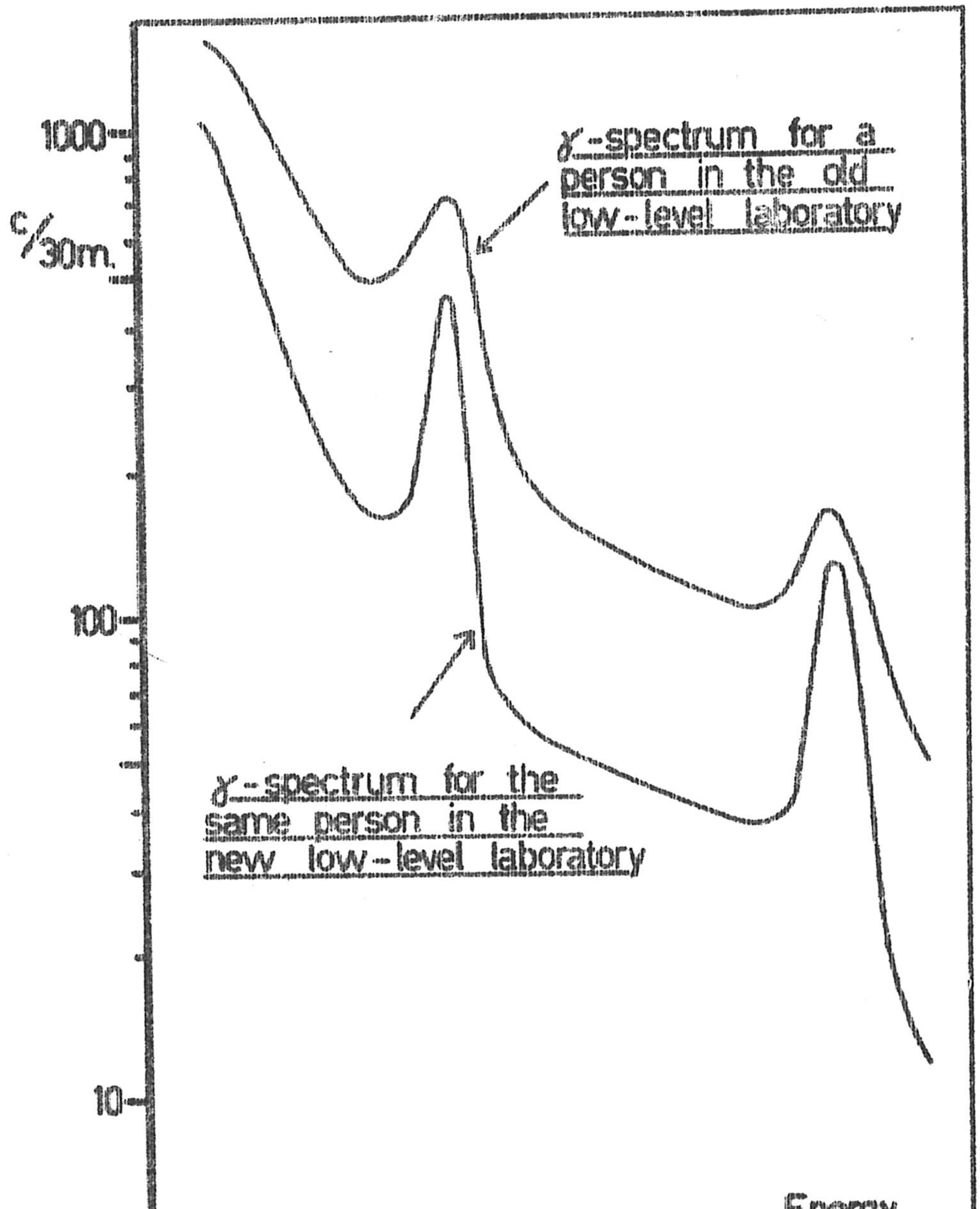

Fig. 3 Improvement of the measuring properties of the "open-booth" counter after changing the crystal and photomultiplier and removal to the "hoforsite" room.

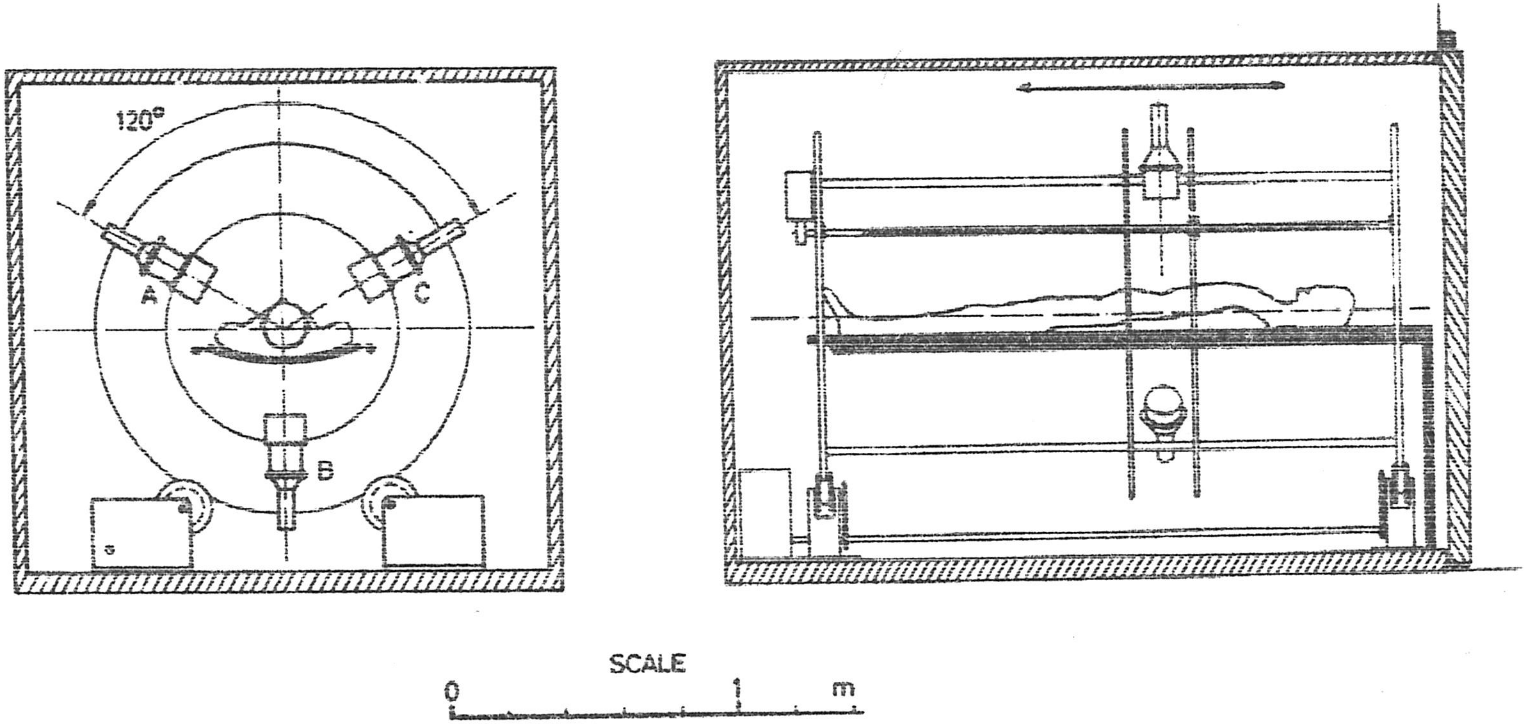

Fig. 4 Whole-body scanner

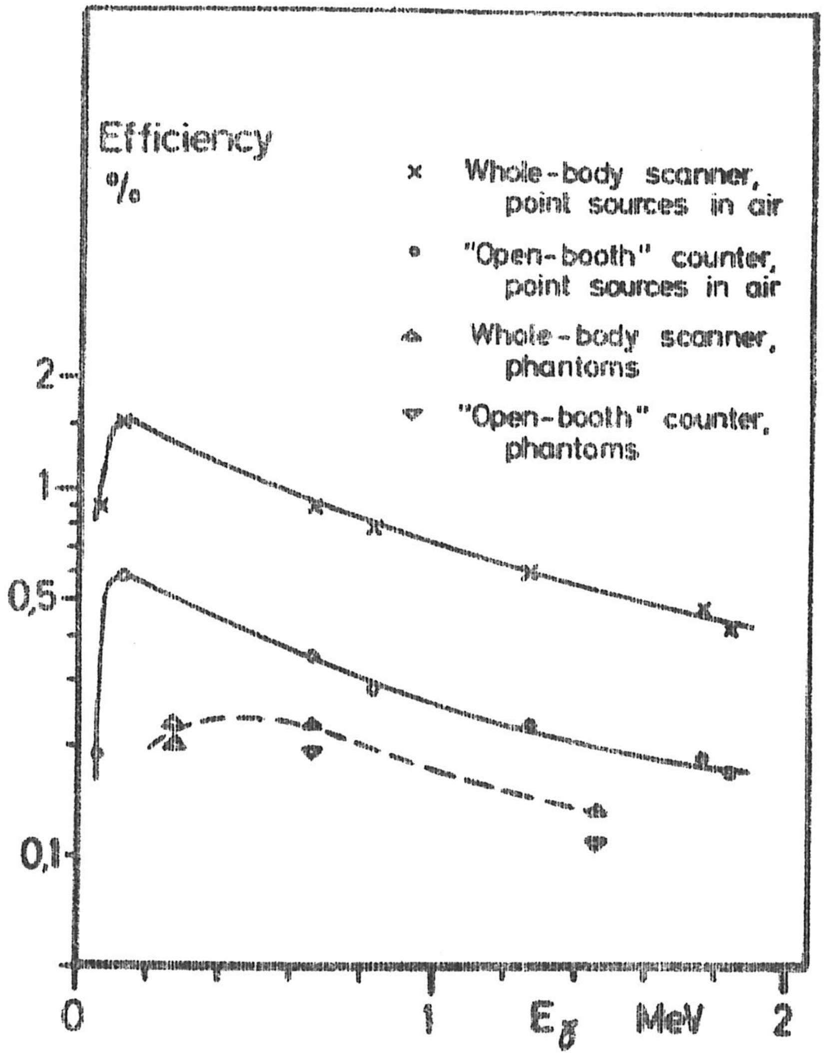

Fig. 5 Peak-efficiency as a function of the peak-energy.

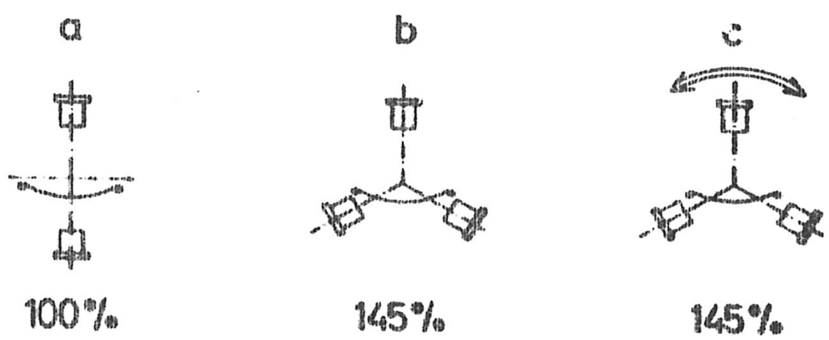

Fig. 6 Relative efficiency for ^{137}Cs point source in air. Energ
0.58 - 0.73 MeV. Measuring arrangements:

a. two fixed crystals

b. three fixed crystals

c. three turning crystals

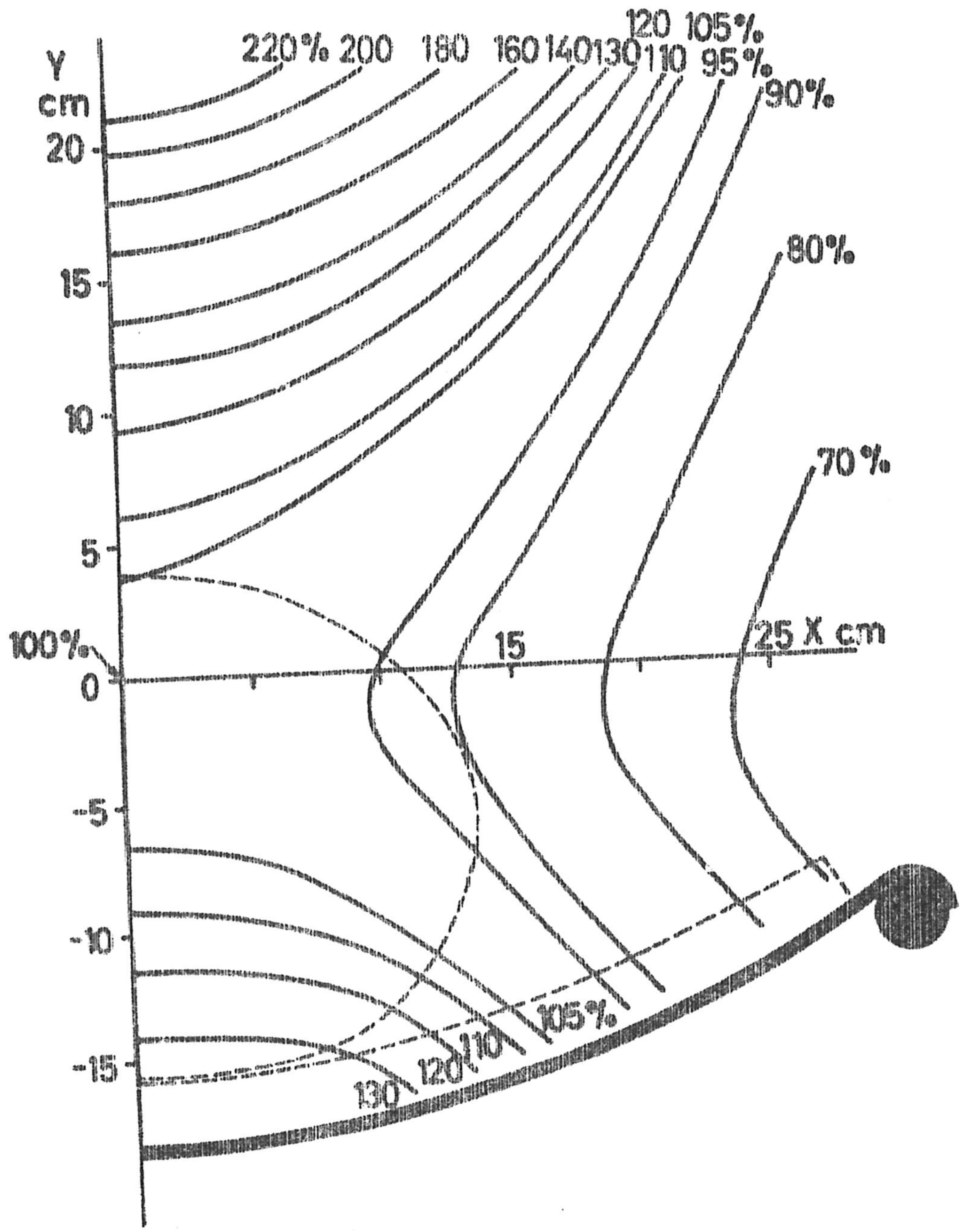

Fig. 7a Isoresponse curves in air for ^{137}Cs point source according to the measuring arrangements shown in Fig. 6. The dashed curves represent location and size of a normal person and a mattress.

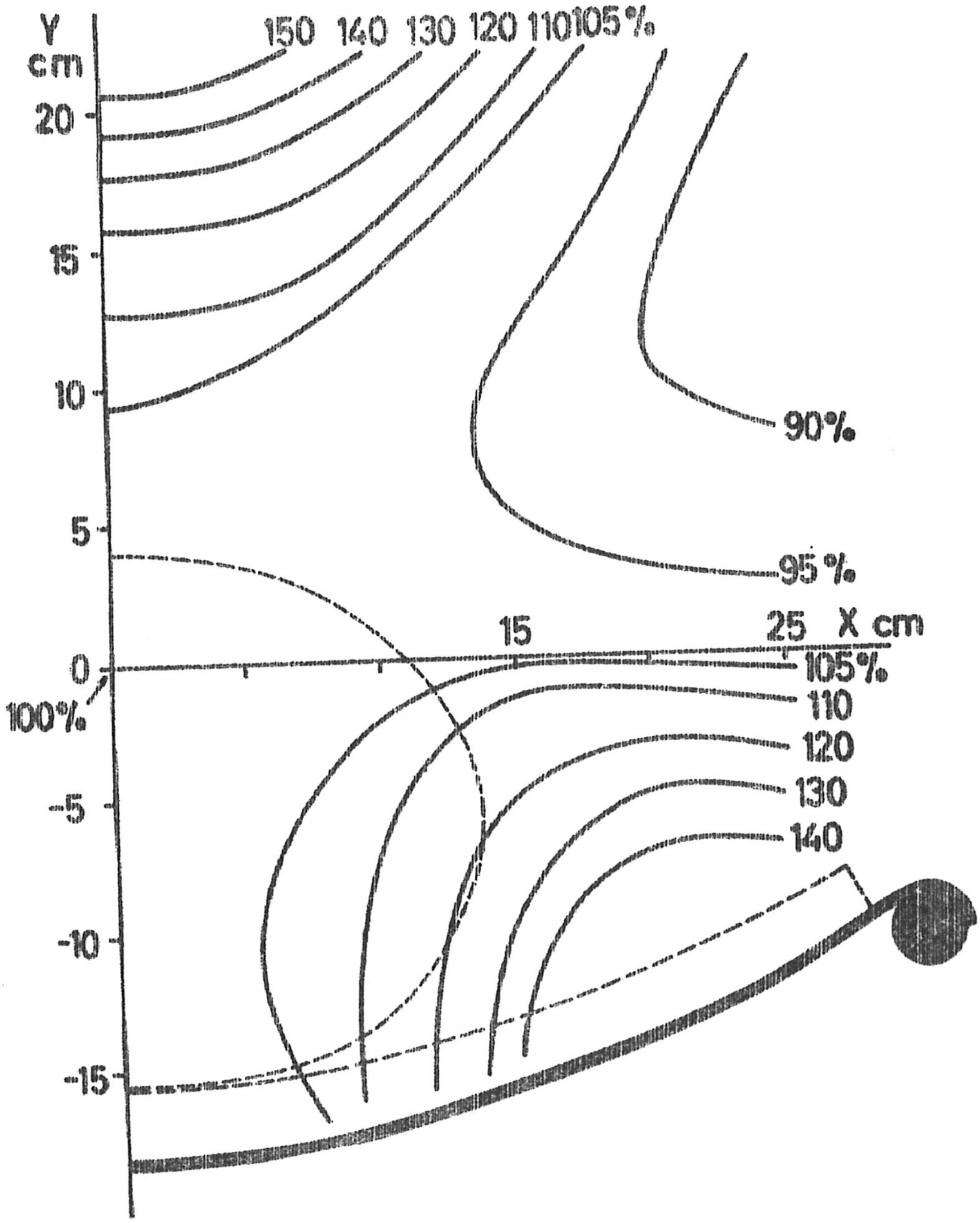

Fig. 7b Isoresponse curves in air for ^{137}Cs point source according to the measuring arrangements shown in Fig. 6. The dashed curves represent location and size of a normal person and a mattress.

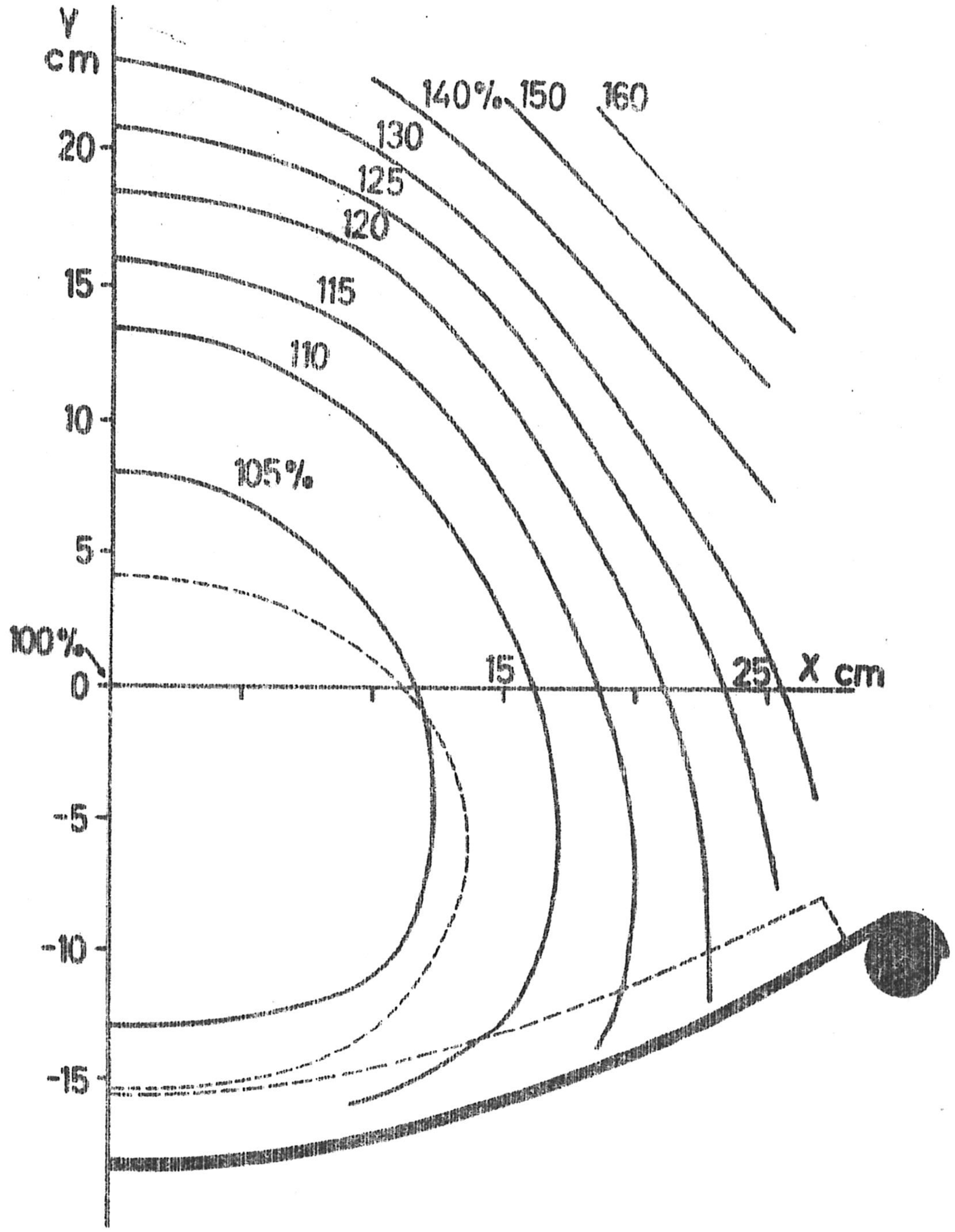

Fig. 7c Isoresponse curves in air for ^{137}Cs point source according to the measuring arrangements shown in Fig. 6. The dashed curves represent location and size of a normal person and a mattress.

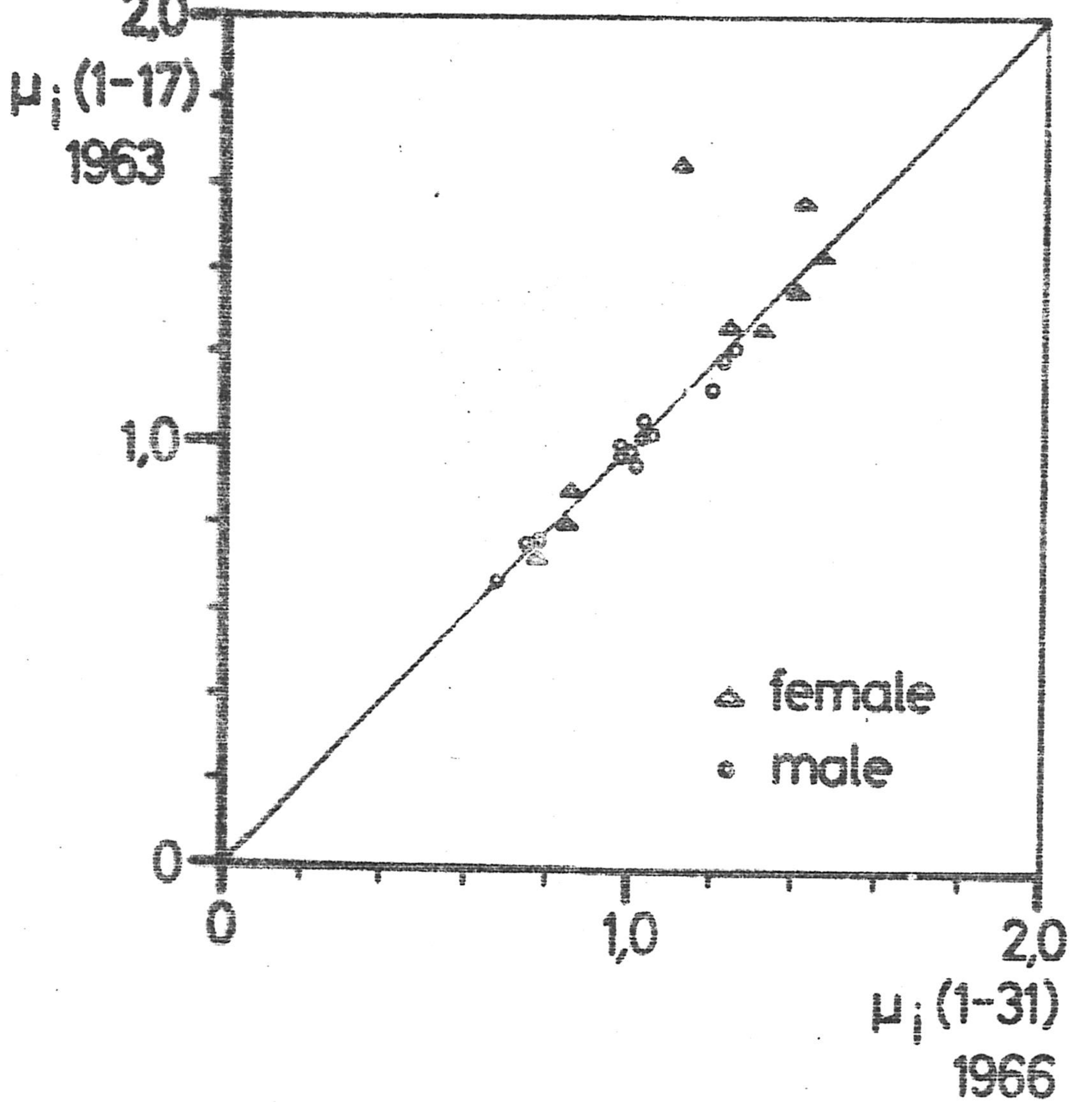

Fig. 8 Comparison of the individual weight factors μ_i obtained in 1963 and 1966.

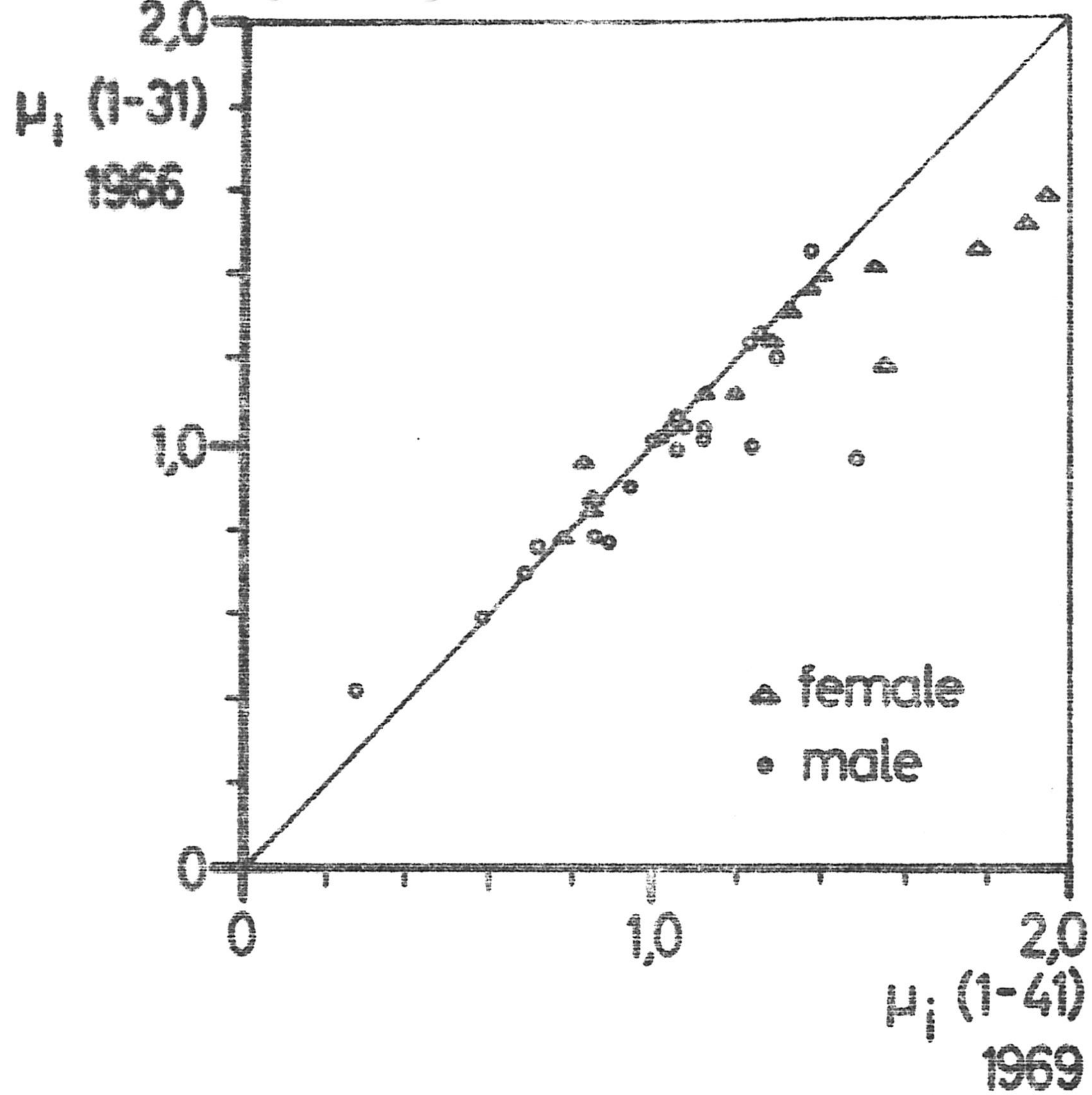

Fig. 9 Comparison of the individual weight factors μ_i obtained in 1966 and 1969.

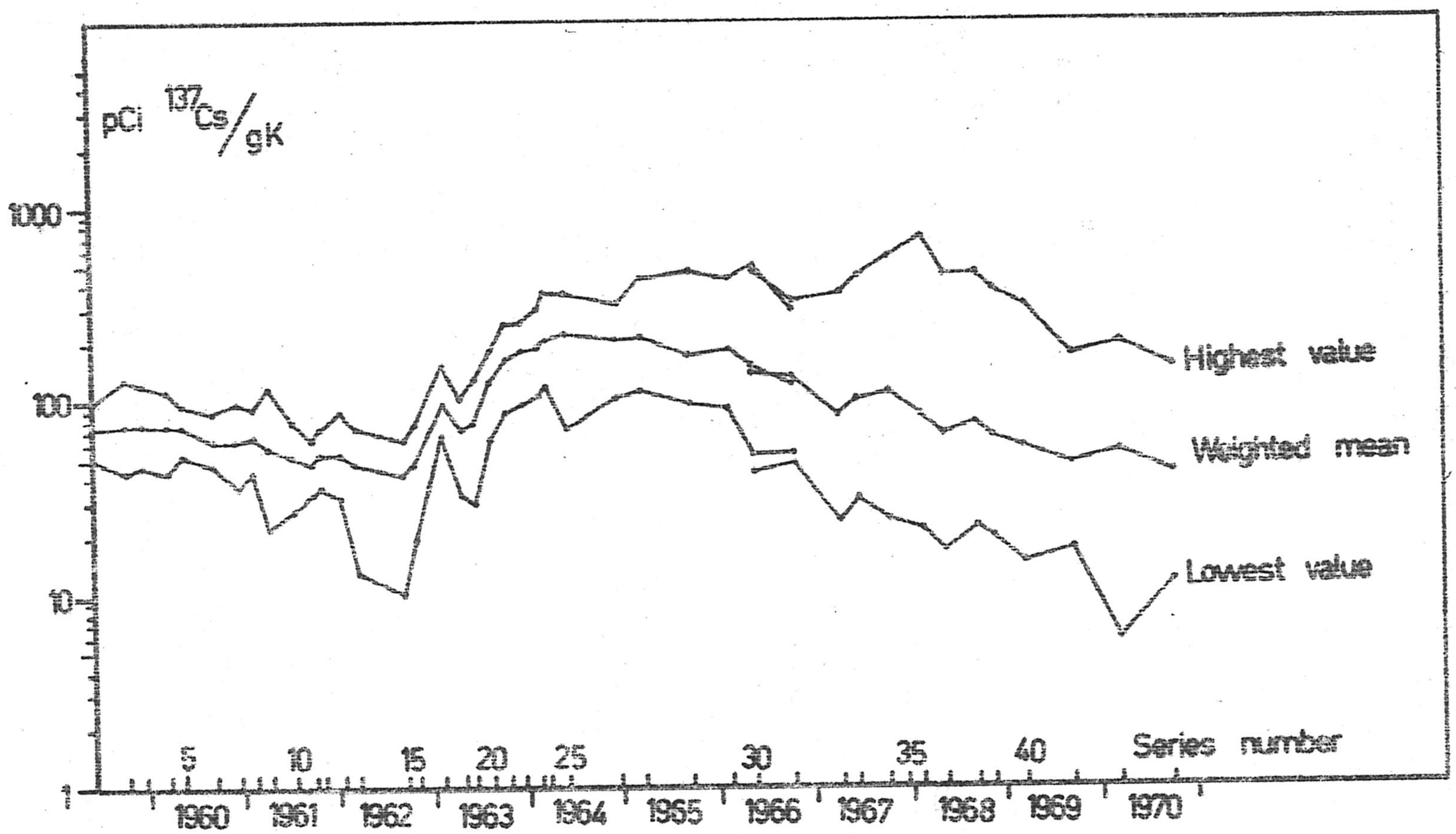

Fig. 10 Variation with time of the cesium level (pCi $^{137}Cs/gK$) in the control group.

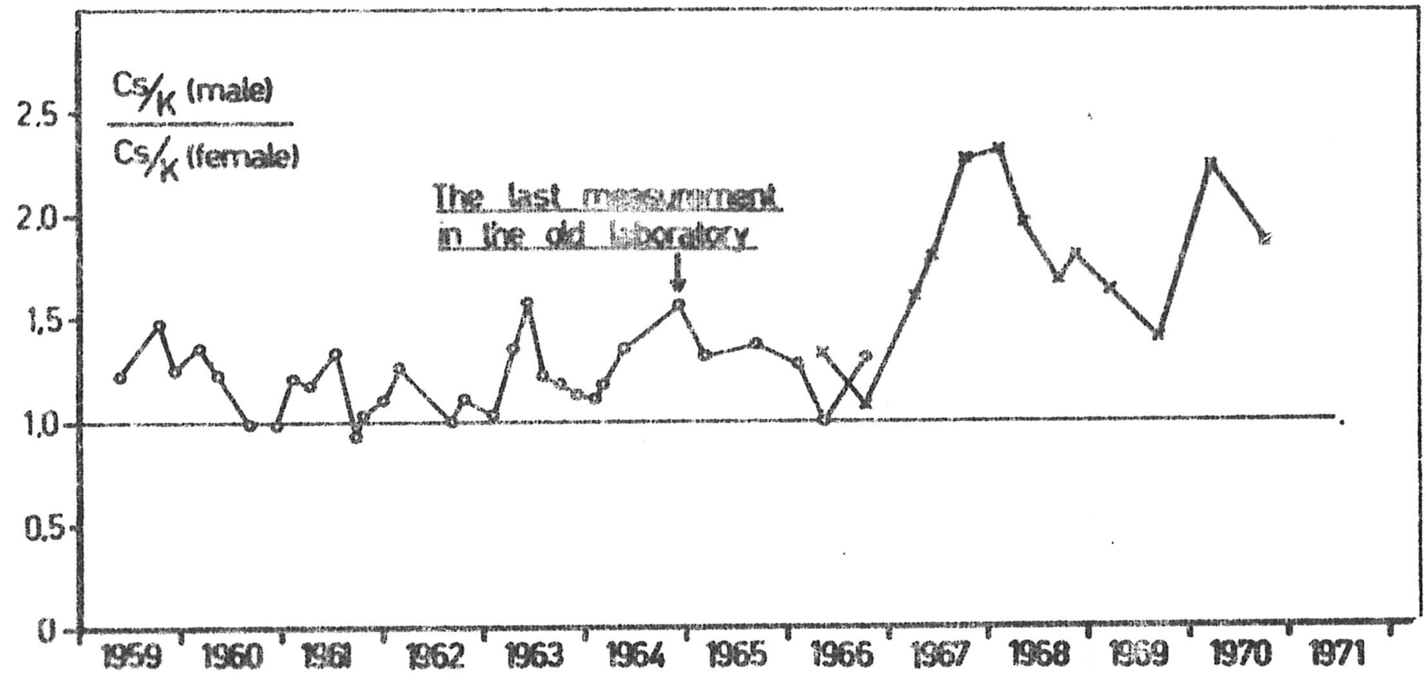

Fig. 11 Variation with time of the $(pCi\,^{137}Cs/gK)_{male}$ / $(pCi\,^{137}Cs/gK)_{female}$ ratio, each group corrected for the selection.

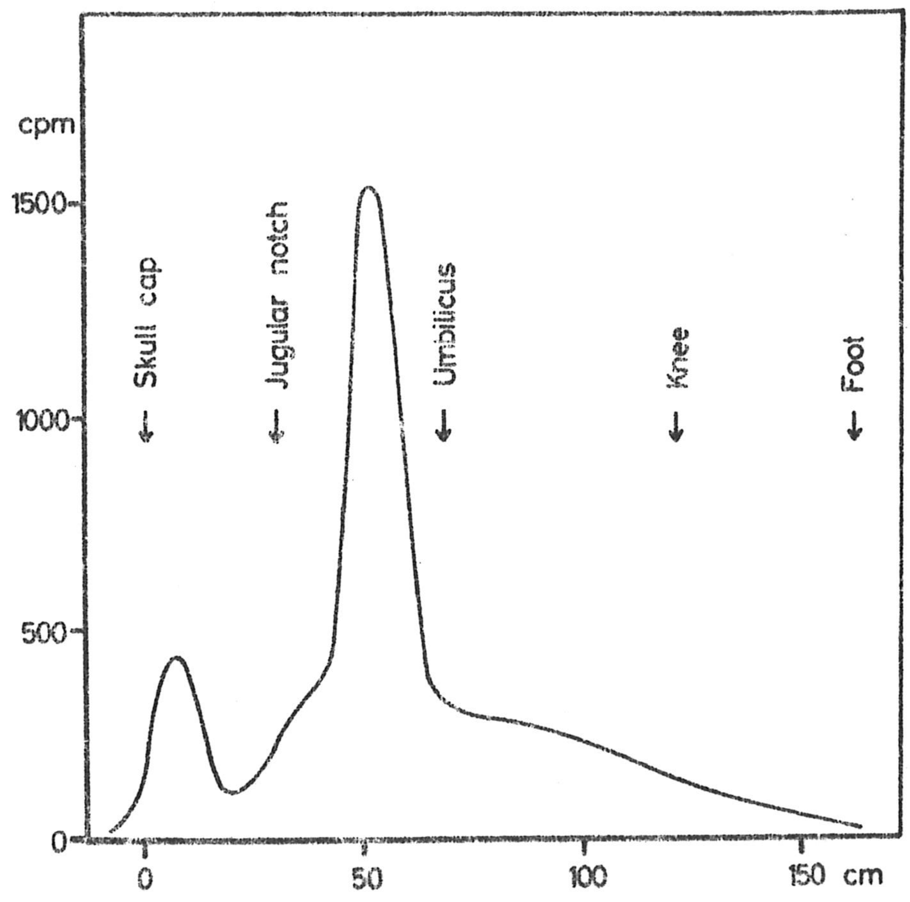

Fig. 12 Profile curve for a volunteer 29 days after intake of methylmercury labelled with ^{203}Hg (ref. 25).