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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

A WIDE RANGE SURVEY METER FOR ESTIMATING γ - AND β-DOSE RATES

Instrument de contrôle des rayonnements permettant d'estimer les débits de dose - γ et - β

A.R. JONES

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Chalk River, Ontario

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Résumé

Un instrument de contrôle des rayonnements a été développé pour mesurer les débits de dose -β dans l'intervalle 0.1 - 100 rad/h (1 mGy/h - 1 Gy/h) et les débits de dose -γ dans l'intervalle 1 mrad/h - 100 rad/h (10 μGy/h - 1 Gy/h). Cet instrument donne un avertissement sonore dans le cas de forts débits de dose -γ et un avertissement à la fois visible et audible lorsqu'il y a dépassement d'une dose -γ déterminée à l'avance.

On décrit dans le rapport la conception de l'instrument et on présente les données obtenues sur la performance d'un prototype technologique. Les facteurs influant sur la performance ayant été étudiés sont les suivants:

- température
- tension des batteries (et type de batterie)
- perte de comptage par compteur GM
- direction des rayonnements incidents
- énergie des rayons -γ

Finalement, on commente l'application et le calibrage de l'instrument de contrôle des rayonnements.

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ABSTRACT

A survey meter has been developed to measure β-dose rates in the range 0.1 - 100 rad/h (1 mGy/h - 1 Gy/h) and γ-dose rates in the range 1 mrad/h - 100 rad/h (10 μGy/h-1 Gy/h). It also provides an audible warning of high γ-dose rates and an audible and visible warning when a predetermined γ-dose is exceeded.

The report describes the design of the survey meter and presents data measured on the performance of an engineering prototype. Factors which affect performance and have been investigated are:

- temperature
- battery voltage (and type of battery)
- GM counter counting loss
- direction of incident radiation
- energy of γ-rays.

Finally, the application and calibration of the survey meter are discussed.

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CONTENTS

1. INTRODUCTION

The general purpose γ-survey meter in use in the laboratories of Atomic Energy of Canada Limited and the power stations of Ontario Hydro was designed in 1962 and has been in service since 1963. While its performance is satisfactory it is becoming increasingly difficult and expensive to obtain components for its continued manufacture and maintenance.

This was one of the reasons for developing a replacement. A second was that innovations in the intervening fifteen years made easier the introduction of the following improvements;

- the measurement of higher dose rates ($\sim$100 rad/h or 1 Gy/h) using GM counters in the pulse mode,
- the measurement of β-dose rates in the same instrument,
- the integration of dose and storage of the information over very long periods ($\sim$ months),
- the presentation of data in numerical form.

2. DESCRIPTION

Figure 1 is a block schematic of the survey meter.

The probe unit, shown in the left of the figure, is mechanically interchangeable from one survey meter to another, having a simple plug-in connection to the main unit.

The probe contains three GM counters, whose positions are indicated by outside markings. One GM counter is used for estimating β-dose rates in the range 0-100 rad/h (0 to 1 Gy/h). It is small to reduce its sensitivity to γ-rays. Its sensitivity to β-rays is determined by a perforated tungsten shield over the thin end window. This shield is thick enough to stop β-particles except for those which pass through the hole in it.

The lowest γ-range, 0-1 rad/h (0-10 mGy/h) is measured using a GM counter whose sensitivity is large enough to give adequate sensitivity at the bottom end of the range and have acceptable counting losses at the top ($\sim$9%).

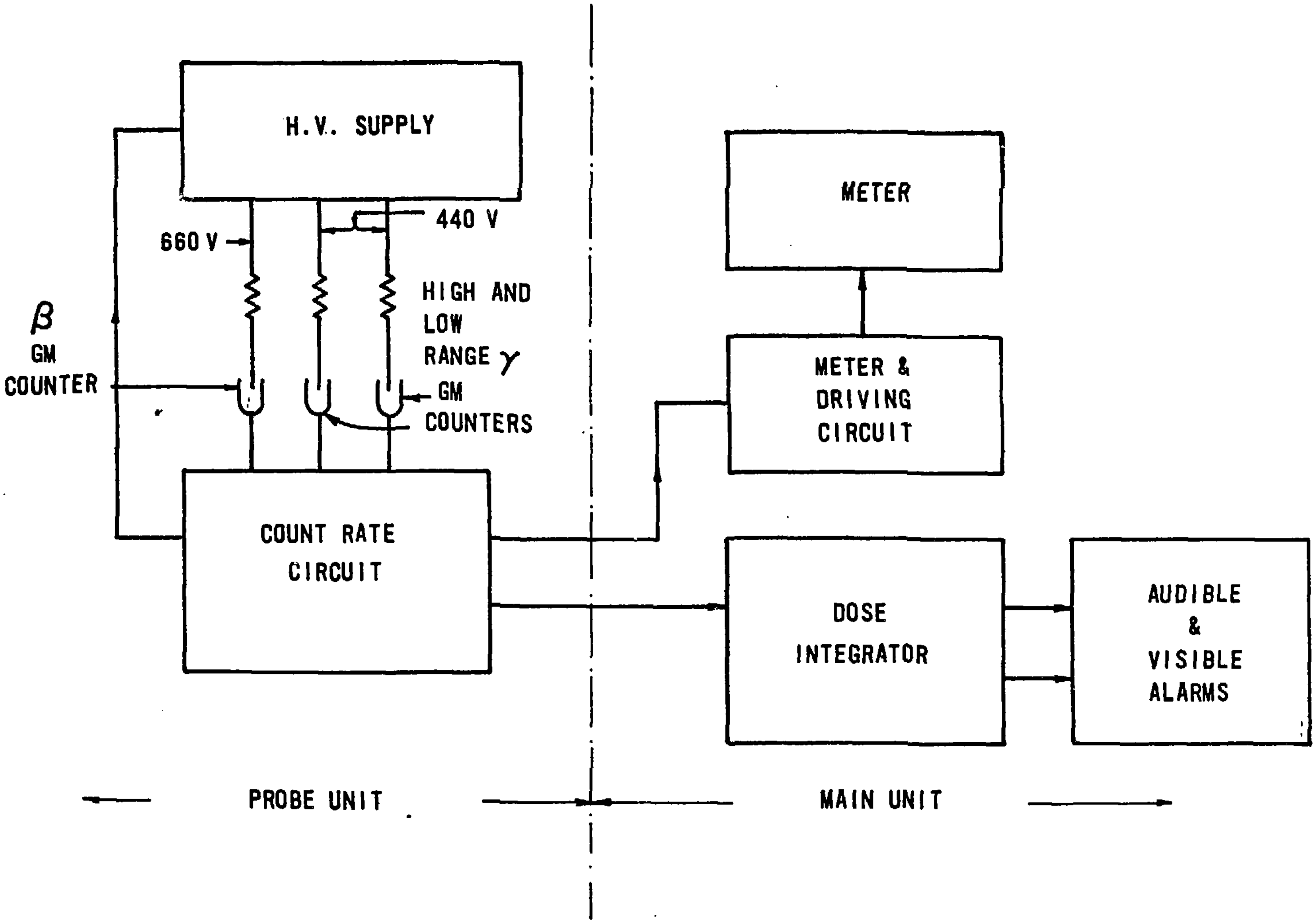


FIGURE 1. Block Schematic of the Survey Meter

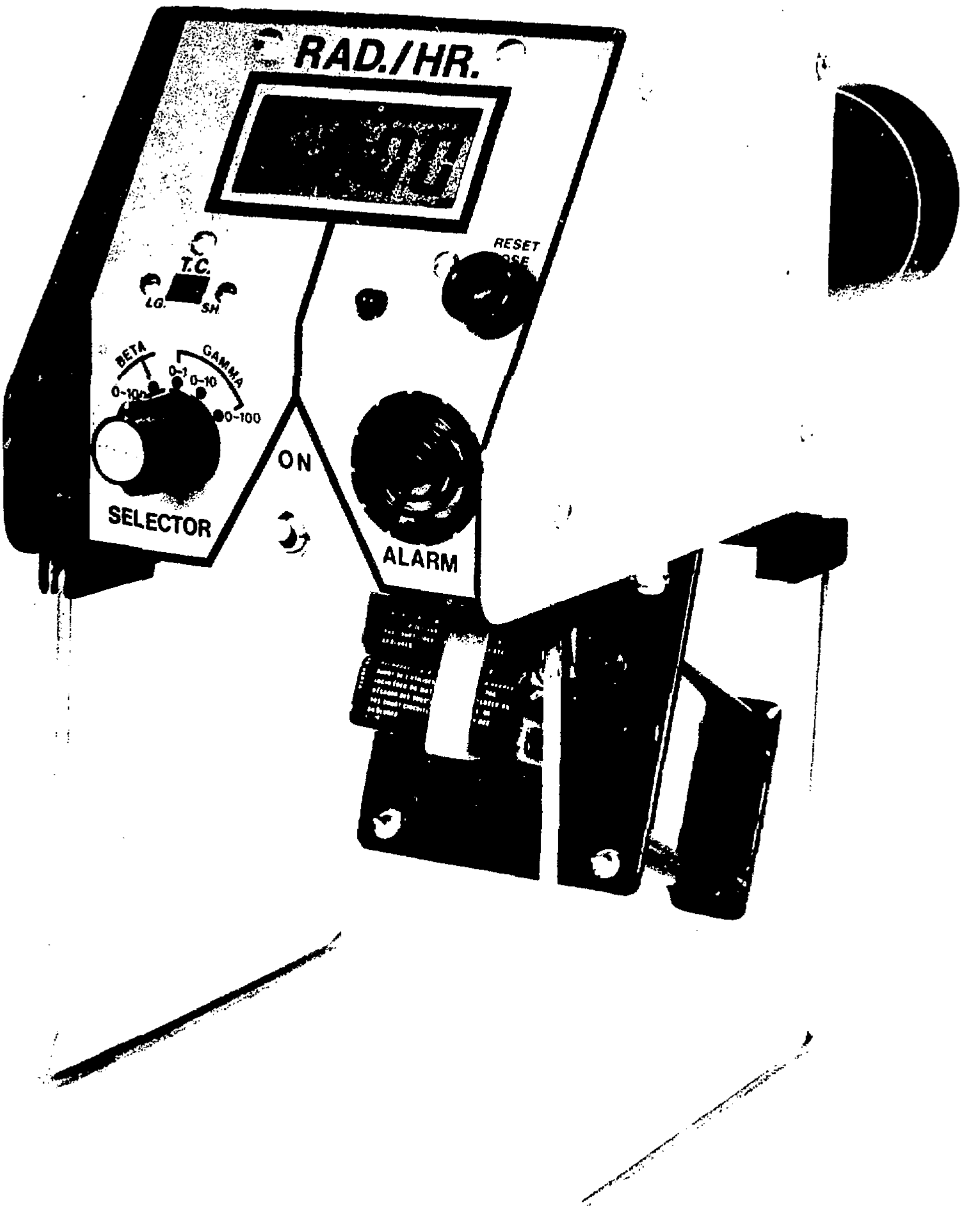


PLATE 1. The Survey Meter Shown with Batteries Accessible.

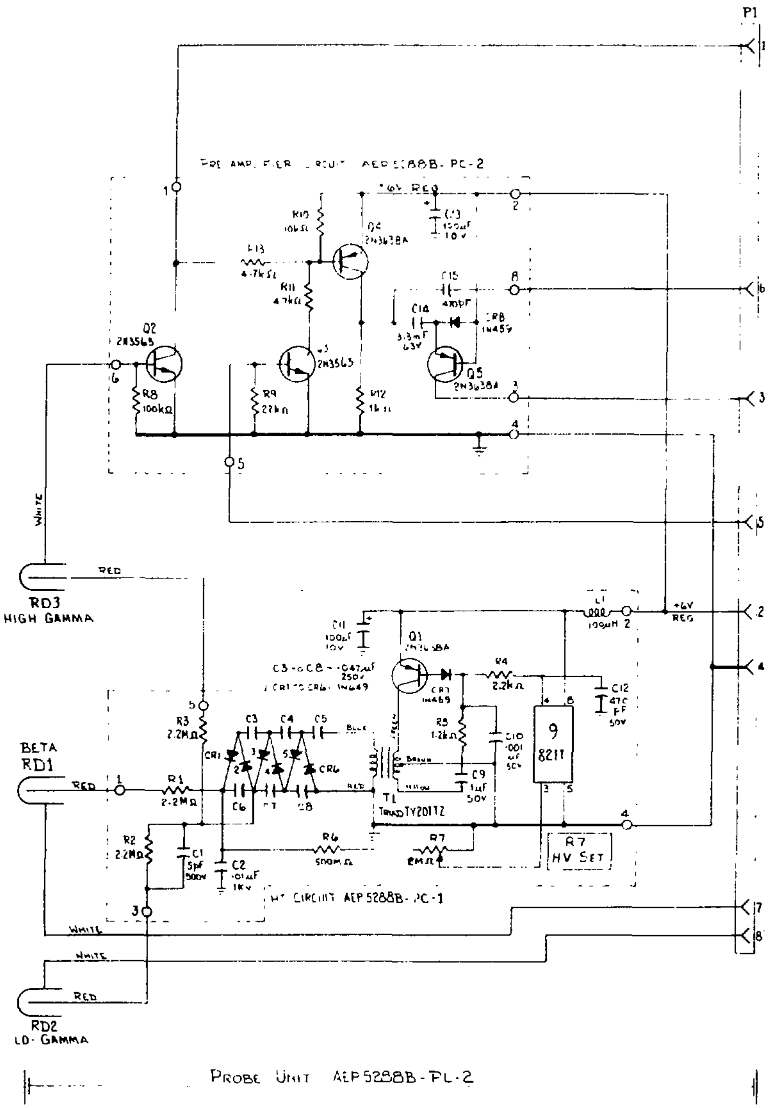
For the middle (0-10 rad/h or 0-0.1 Gy/h) and upper (0-100 rad/h or 0-1 Gy/h) γ-ranges a low sensitivity counter is used. Again it was chosen on account of its appropriate sensitivity and dead time (12% counting losses at 100 rad/h or 1 Gy/h).

The count rate circuit develops a direct current, proportional to the counting rate, which is fed to the meter driving circuit. This circuit converts the current to a voltage, proportional to the current, and smooths it with a short or long time constant which can be chosen using a switch. The display is a digital panel meter and the meter driving circuit provides it with exactly 1 V at full scale.

The count rate circuit also feeds a pulse train to the Dose Integrator. This pulse train is derived from the high range GM counter, regardless of the range in use. Thus the dose integrator operates independently of the other uses of the survey meter. The dose integrator provides one output pulse to the audible alarm whenever about 0.4 mrad (4 μGy) has been accumulated and a continuous output when a pre-selected dose has been accumulated (to both visible and audible alarms).

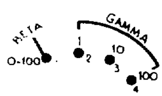
Plate I shows the survey meter set up-right, on its feet. The handle is shown swung forward to reveal the position of the two 'transistor' batteries, accessible for changing when the handle is in this position.

All the operating controls are grouped on the front panel below the liquid crystal numerical display. The power switch, when in its OFF (down) position, cuts the connection to the high and low voltage supplies, display and counting rate circuits. However, the battery voltage is always connected to the dose integrating circuit. Thus, switching the power off does not remove the record of accumulated dose. This is done by pressing the RESET DOSE button just below and to the right of the display.



DETECTORS

RD1 - TGM - N202 (DETECTOR INC)
RD2 GM 27 (APTEC)
RD3 - 3G 70 (ITT)



RANGE

PANEL MARKING FOR S1

FIGURE 2.
Schematic of the Probe Unit.

The range is selected with the SELECTOR switch in the bottom left hand corner and this switch controls the position of the decimal point in the display. Above this switch the T.C. (time constant) switch permits the choice of a slow or fast response.

Behind the main unit is the probe which contains the detectors. This can be removed from the main unit by unscrewing a knurled ring. At the end of the probe is a cap which can be rotated to permit the entry of β-particles into the β-detector.

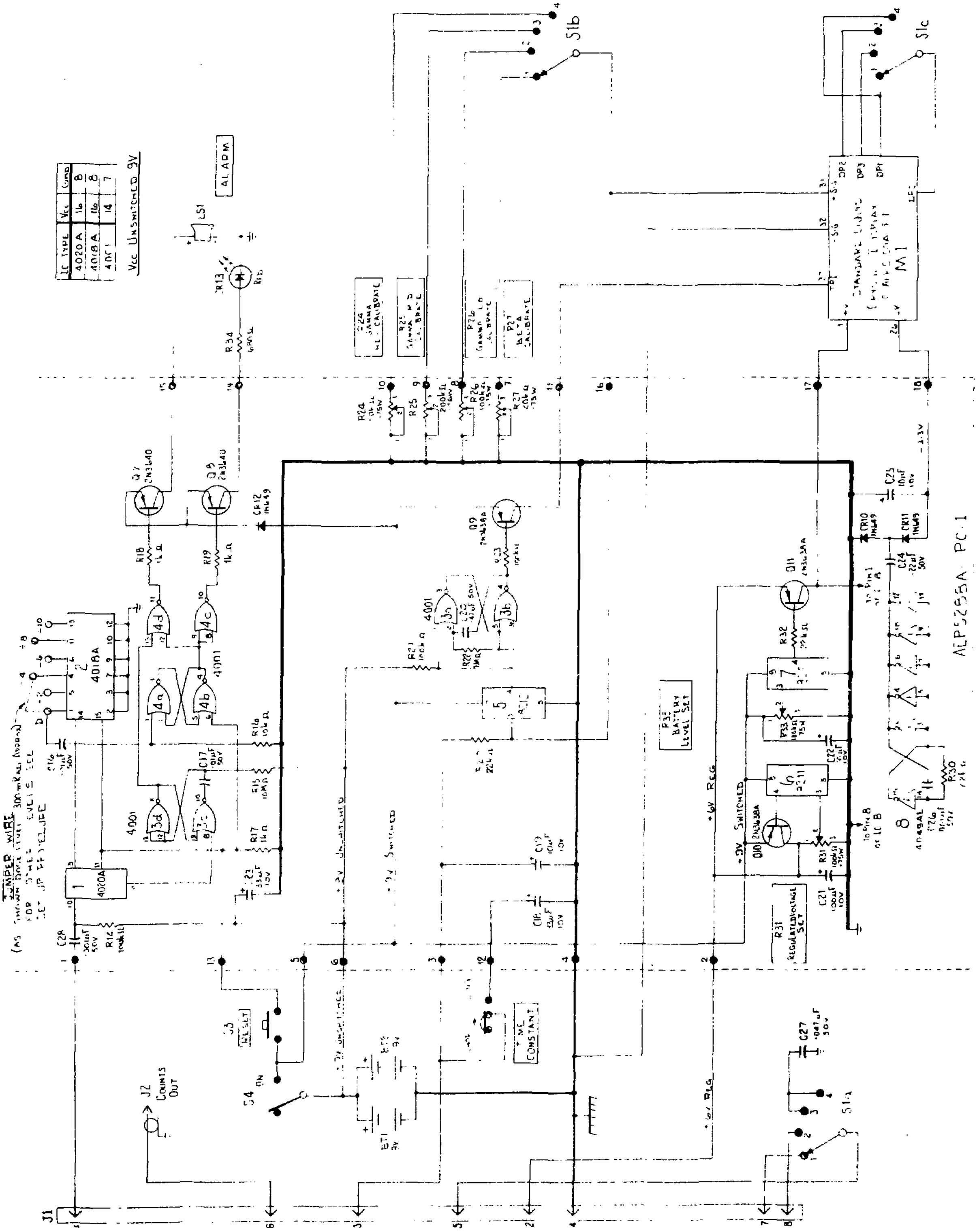
2.1 Description of the Probe Unit

Figure 2 is a schematic of the probe unit.

The high voltage supply provides 440±15 V for the two GM counters (RD2 and RD3) used for γ-measurements and 660±15 V for the β-counter. The high voltage supply is mounted on one printed circuit board (AEP-5288B,PC1). A transistor (Q1) and the input winding of a transformer (T1) forms a blocking oscillator. Power at 6 V is fed via pin 2. The output pulses from the transformer T1 are fed to a Cockcroft-Walton multiplier which produces d.c. voltages twice and three times the pulse voltage at the outputs fed to the three GM counters. The larger d.c. voltage is applied to two resistors (R6 and R7) and a fraction of the voltage is picked off the brush of the trimming resistor (R7). This voltage is applied to terminal 3 of an integrated circuit (IC9) which grounds terminal 4 whenever terminal 3 is below a preset voltage (about 1.1 V) and controls the blocking oscillator via a resistance (R4). The trimming resistor is adjusted so that 660 V is applied to RD1 and 440 V to RD2 and RD3.

The count rate circuit (refer to Figure 1) is located on the second printed circuit board (AEP-5288B,PC2) in the probe unit.

FIGURE 3. Schematic of the Main Unit.



Regardless of the range switch position, the high range GM counter (RD3) is always connected to ground through the base of a transistor (Q2). This transistor is turned on by the GM counter pulses applying a 6 V negative pulse to

- the dose integrator circuit in the main unit,
- the count rate circuit.

The count rate circuit contains a transistor (Q4) that when turned on, produces 6.0 V pulses across a 1 kΩ resistance (R12).

These pulses are applied to a diode pump circuit (C12, Q8 and CR8) which produces a current (I) at pin 3.

$I = 18\ N\cdot nA.$

where $N\cdot s^{-1}$ is the mean pulse rate.

Either the cathode of the β-GM counter (RD1) or of the low range γ-GM counter (RD2) is connected to the base of a transistor (Q3) according to the position of the range switch. This transistor performs the same function as the transistor (Q2) does for the high range γ-GM counter, except that it does not apply pulses to the dose integrator.

2.2 Description of the Main Unit of the Survey Meter

Figure 3 is a schematic of the main unit where most of the components are mounted on one printed circuit board (within the dotted line).

At the top is the dose integrator (IC1-4 and Q7,Q8). Negative pulses from the count rate circuit are applied to pin 10 of a 13 stage binary counter (IC-1). For a typical high range GM counter each rad (10 mGy) produces about 2.5×10^5 pulses which is reduced to about 2,000 pulses/rad at pin 6 and to about 15 pulses/rad (10 mGy) at pin 3. The output from pin 6 is fed to a 0.1s pulse generator (IC3, c and d) whose output is fed to a SONALERT via a gate (IC4d) and transistor (Q7). Thus the SONALERT sounds for 0.1 s whenever about 0.5 mrad (5 Gy) is absorbed. At 1 rad/h (10 μGy/h) there are about 30 sound pulses/minute.

The output at pin 3 is connected to a presettable counter (IC-2) which reduces the sensitivity to about 1.5,1.9,2.6,3.9 or 7.7 pulses/rad (10 mGy) according to the feedback path chosen. The output pulse of this counter (pin 1 of IC-2) sets a flip-flop (IC4, a and b) energizing the SONALERT and light emitting diode (CR13) via two gates (4 c and d) and two transistors (Q7 and Q8). Thus a continuous tone is emitted and the LED is lit after the accumulation of about 0.13,0.26,0.39,0.52 or 0.65 rad.* At the Chalk River Nuclear Laboratories where there is an administrative dose equivalent limit of 0.6 rem (6 mSv) per two week monitoring period the counter is connected to sound the alarm at about 0.39 rad (3.9 mGy). The alarm continues to sound until the reset switch (S3) is pressed when the accumulation of the dose recording begins again.

The output of the count rate circuit, in the probe, is fed into pin 3 of the main printed circuit board. This output is in the form of a pulse train which is smoothed by one or two capacitors (C17 or C16 and C17) according to the position of the time constant switch. The direct-current component of the pulse train is fed via a resistor (R20) to one of four trimmers (R24-27) depending upon the position of the selector switch (S8). Each trimmer is adjusted to obtain 1 V across it at full scale. This voltage is fed to the liquid crystal display (M1) at pin 31.

The smoothing time constant is:

$$C17(R20 + RT) \text{ or } (C17 + C16)(R20 + RT)$$

where RT is the adjusted value of the trimmer resistors and C16 is added for the slower response.

The standard deviation, σ, depends upon the smoothing time constant and the pulse repetition rate n. Expressed as a percentage, the standard deviation is

*1.3,2.6,3.9,5.2 or 6.5 mGy

$$\sigma = \frac{100\%}{\sqrt{(2NC(R35 + RT)}}$$

where C = C17 or C17 + C16.

The repetition rate, n, depends upon the dose rate, D (rad/s or Gy/s), and the GM counter sensitivity S, i.e.,

n = D x S

Using typical GM counter sensitivities the above relations have been used to calculate the response times and standard deviations at various dose rates and ranges. The results of the calculations are shown in Table 1.

The liquid crystal digital panel meter has a 2 V range but the full scale ranges are 1,10 and 100 rad/h (10,100 and 1000 mGy/h) corresponding to a 1 V input to the meter. For this reason an over-range circuit has been designed. When the voltage developed across any of the trimmers (R24-27) reaches about 1 V an integrated circuit (IC5) with an internal reference voltage turns on a pulse generator (IC3a and b) providing a blanking signal to the panel meter through a transistor (Q10) which produces an intermittent supply.

The 9 V (nominal) battery voltage is applied to a regulator (IC6 and Q11) which provides 6 V to all circuits except the dose integrator which is permanently connected to the battery. The panel meter also needs a -3 V supply and this is supplied by a supplementary circuit (IC8 and CR 10,11). The resulting 9 V is applied to the panel meter through a transistor (Q12) as long as the battery voltage remains above 6 V. The battery voltage is monitored by a circuit, a trimmer (R33) and another integrated circuit (IC7) with an internal voltage reference. When the battery voltage falls below 6 V, power is cut off from the display to

- prevent the presentation of false data due to low battery voltage.
- draw attention to the depletion of the battery.

TABLE I. Time Constants and Statistical Fluctuations on Different Ranges

Exposure Rate, rad*/h	Range, rad*/h	Short Time Constant		Long Time Constant	
		Time Constant, S	Standard Deviation, %	Time Constant, S	Standard Deviation, %
.001	0-1	0.51	52	2.21	25
.01	(γ)		16		7.9
.1			5.2		2.5
1.0			1.6		0.79
.01	0-10	1.28	75	5.50	36
.1	(γ)		24		11
1			7.5		3.6
10			2.4		1.1
.1	0-100	0.43	41	1.83	20
1	(γ)		13		6.2
10			4.1		2.0
100			1.3		0.6
.1	0-100	0.38	31	1.62	15
1	(β)		10		4.7
10			3.1		1.5
100			1.0		0.5

*1 rad = 10 mGy

3. PERFORMANCE

The performance of the survey meter is affected by a number of factors

- temperature
- battery voltage
- battery life
- scale linearity
- energy of the incident radiation
- direction of the incident radiation.

The effect of these factors will be discussed in the following sections in the light of measurements made on prototype instruments.

3.1 Temperature Dependence

Measurements made on all four ranges revealed temperature coefficients of 0.2%/°C, or less, measured over the range -20 to +50°C. The display is specified for operation only within the range 0 to 50°C although it operated satisfactorily at -20°C.

3.2 Battery Voltage

The survey meter is provided with a voltage regulator and there is no discernible change in sensitivity over the range 6-9 V. (The battery extinction voltage is 6 V and the maximum battery voltage is 9 V).

3.3 Battery Life

The survey meter only draws power when the display is switched on. However, a variety of different batteries can be used. Based on manufacturers specifications and measured current drains Table II shows battery lives which can be expected under background and high radiation conditions.

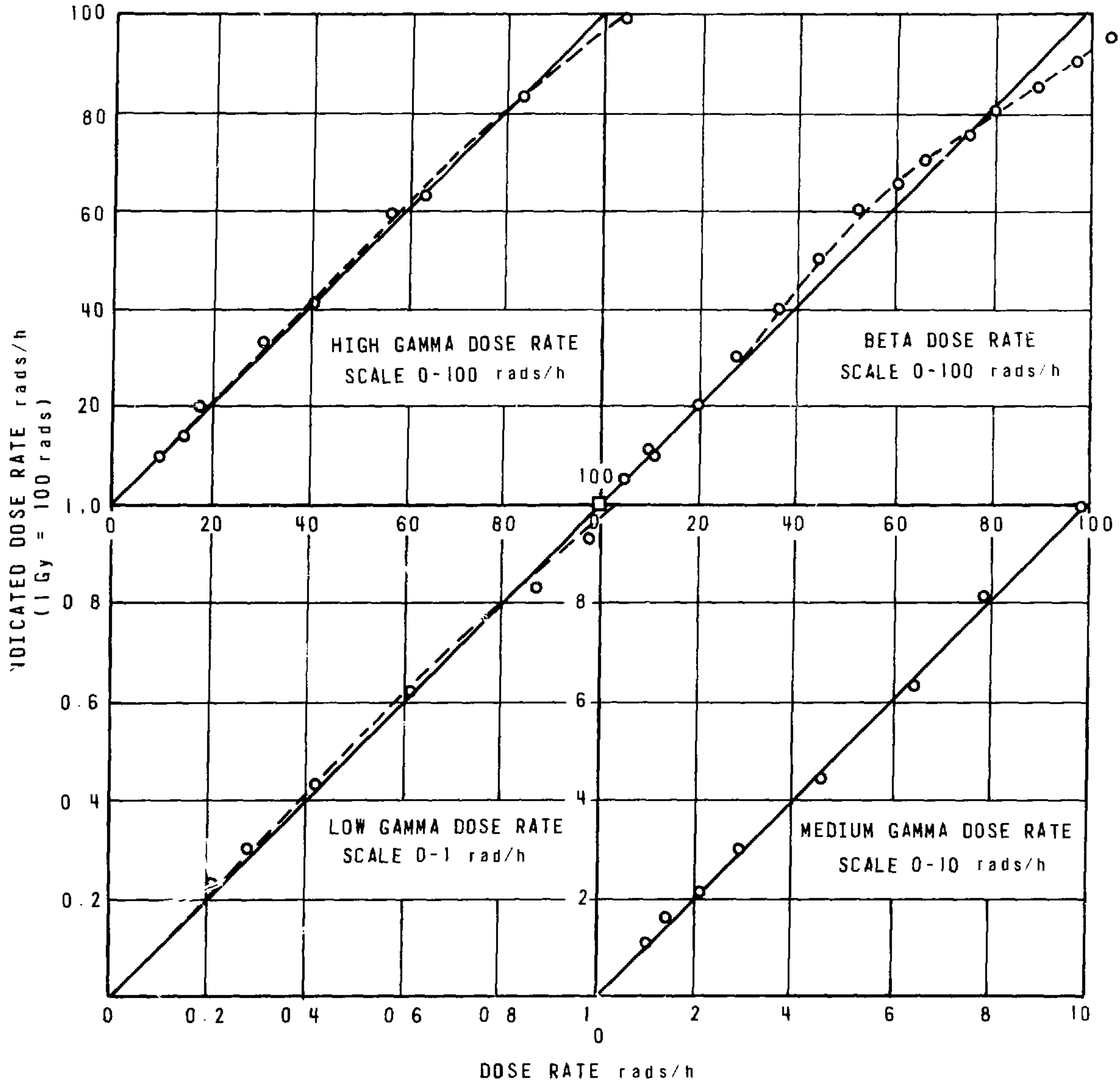


Figure 4. Scale Linearity

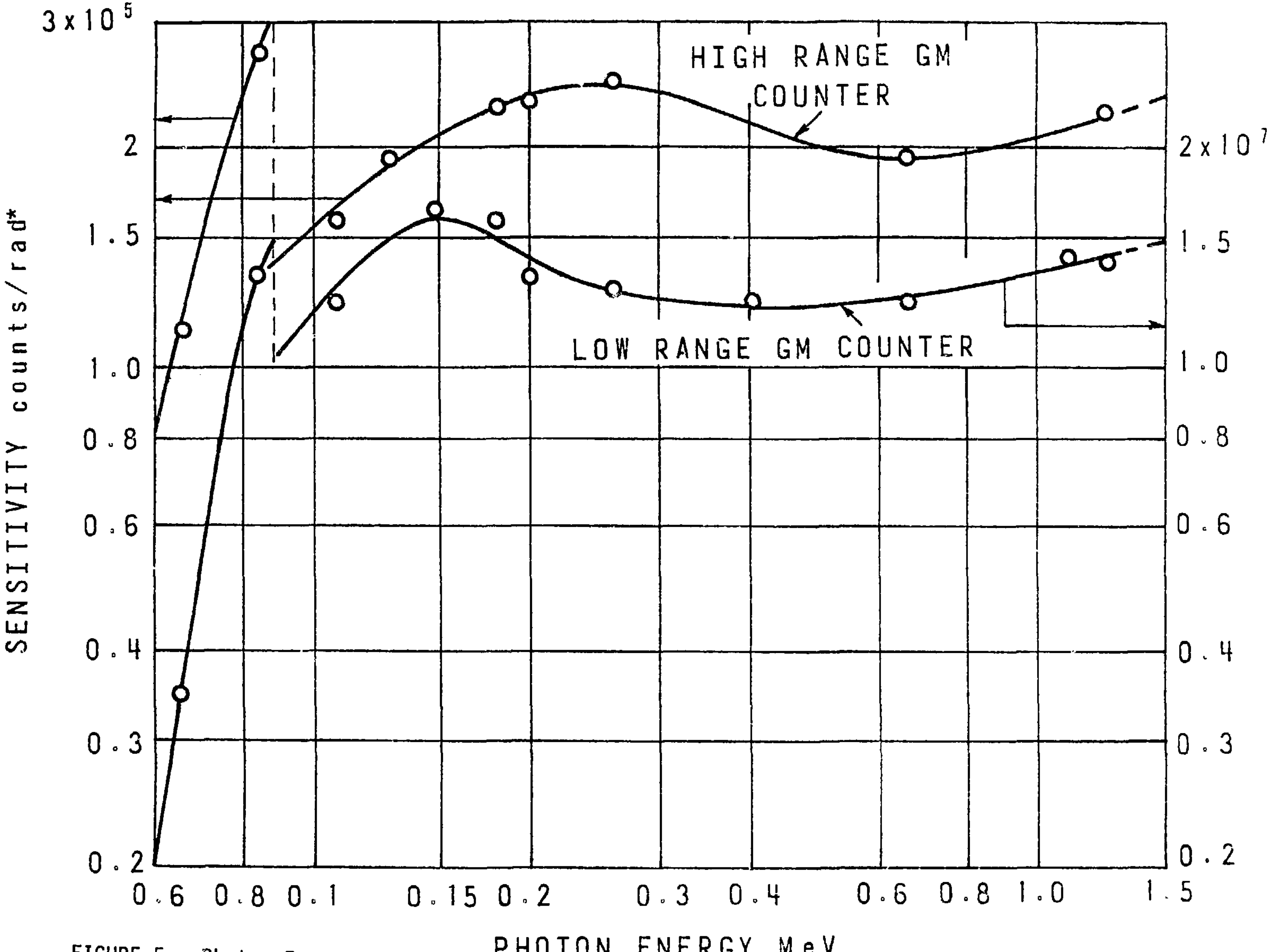


FIGURE 5. Photon Energy Dependence

*1 rad = 10 mGy

Table II. Discharge Lives (hours) of Batteries in the Survey Meter.

Battery Type	Background	100 rad/h; 1 Gy/h
Carbon (4 hours/day)	115	55
Alkaline*	115	60
Mercury	177	88
Nickel Cadmium	14	7

*The advantage of the alkaline battery's longer shelf life is not so important in a regularly used instrument.

3.4 Scale Linearity

Figure 4 shows the relationship between the dose rates measured with a standard ion chamber and those indicated by the survey meter, on all four scales.

The departures from linearity at the upper end of the scale are caused by counting losses in the GM counters. This departure is not detectable in the medium γ-dose-rate scale (0-10 rad/h; 0- 0.1 Gy/h) because the high range GM counter is used and it has relatively low counting losses at 10 rad/h.

To reduce the errors due to counting losses (as well as assuring a quick response during calibration) the survey meter was calibrated at about 80% of full scale.

3.5 Photon Energy Dependence

Figure 5 shows the photon energy dependence for the two GM counters used for the three γ-dose-rate ranges. The sensitivity is plotted in terms of the counts from the GM counter for each unit of dose which would be absorbed by a person at the point occupied by the GM counter. The dose absorbed by the person is defined as that which would be absorbed by the testes of a man facing the source. The dose absorbed in other critical organs, such as the red bone marrow or a woman's ovaries, or by the whole body would be generally lower by an amount depending on the photon energy[2]. The γ-rays were incident at right angles to the GM counter axis.

The discontinuity in the two curves at 88 keV is due to the presence of lead in the filter wrapped around the GM counters, the lead attenuating more strongly just above the K-edge energy.

The following table summarizes the data presented by the two curves shown in Figure 5 .

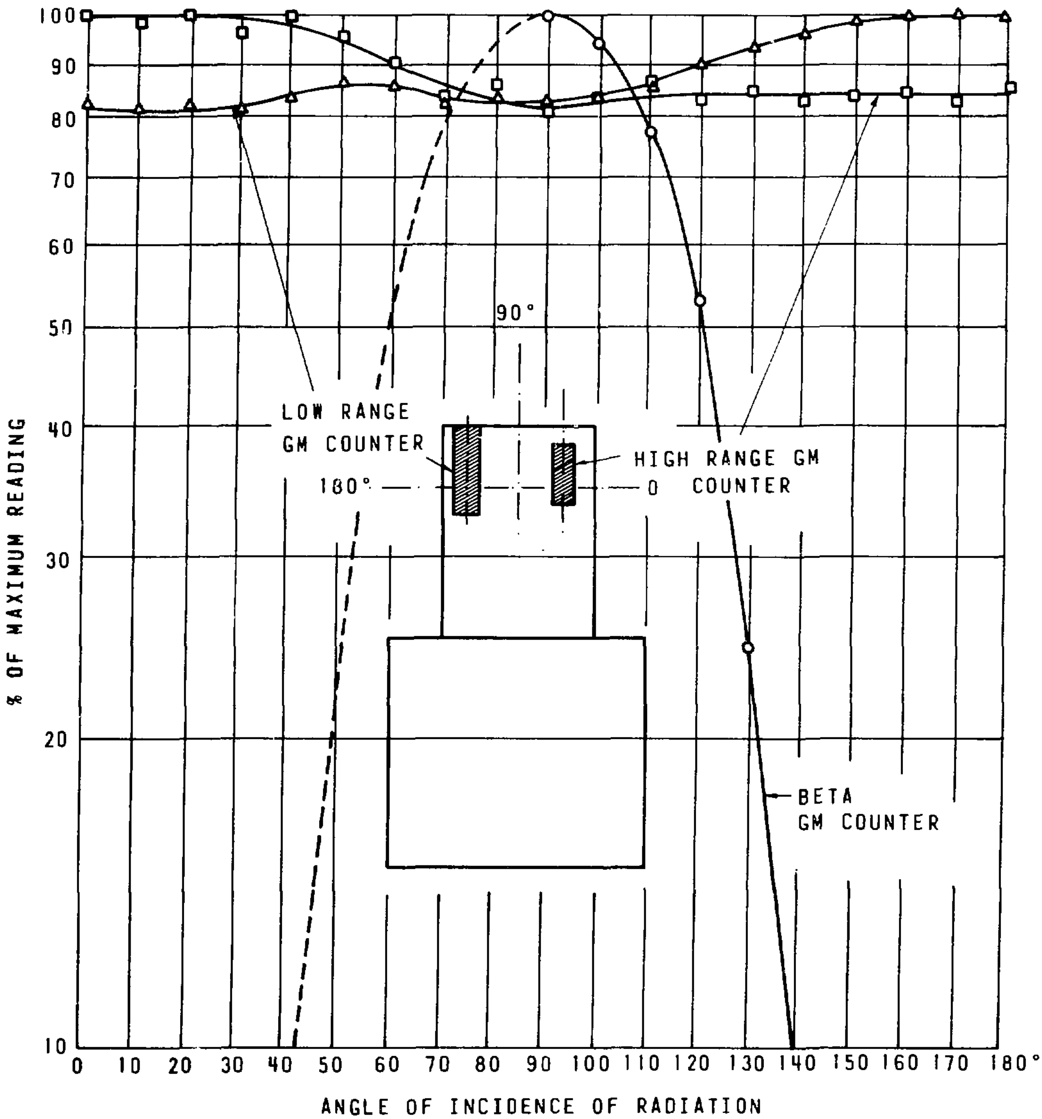


Figure 6. Directional Response of Detectors.

Table III

	Low Range GM Counter	Medium and High Range GM Counter
Mean sensitivity in counts/rad (counts/Gy)	$1.33 \times 10^7 (\times 10^8)$	$2.13 \times 10^5 (\times 10^7)$
% standard deviation of sensitivity	7	8
over the energy range	0.1 - 1.5 MeV	0.15 - 1.5 MeV
Max. positive deviation (%)	21 at 0.15 MeV	15 at 0.25 MeV
Max. negative deviation (%)	-10 at 0.1 MeV	-14 at 0.12 MeV

The standard and maximum deviations give an idea of the probable and worst errors caused by photon energy dependence.

It should be noticed that below about 0.08 MeV the sensitivities of both detectors drop quite rapidly.

3.6 Directional Dependence

Figure 6 shows the directional dependence of the β-GM counter for β-rays and that of the other two counters for γ-rays.

The β-GM counter is sharply directional in its response because of the collimating effect of the perforated shield over the thin end window. The data shown are for a $^{90}Sr/^{90}Y$ source.

The directional dependence of the γ-GM-counters was measured to determine the shielding effect which they exert on each other. This was done by irradiating the detectors with radium γ-rays and rotating the survey meter in the horizontal plane which contains the axes of the two GM counters. It should be noted that for rotation in other planes, e.g. the vertical one, this shielding effect, of one tube by the other, would not occur.

4. APPLICATION OF THE SURVEY METERS

The survey meters have three basic functions

- to delineate areas where hazardous γ- and β-dose rates exist,
- to estimate the hazard to a person occupying the area,

- to warn the user of hazardous γ-dose rates when he is inadvertently exposed to them and to draw his attention to the absorption of a predetermined dose (whether the exposure is inadvertent or intended).

4.1 Delineation of Areas of Hazardous γ-and β-Dose Rates

For this task the short time constant should be chosen since the survey meter will be moved fairly rapidly in the radiation field.

For β-dose-rate surveying, the detector should be exposed by rotating the disc at the end of the probe. Since the meter is very directional in response it should be pointed in various directions in the radiation field unless the direction from which the radiation comes is known.

At high-gamma dose rates (>1 rad/h or 10 mGy/h) increases in dose rate will also be indicated by increases in the frequency of sound and light pulses from the alarm unit. Increases in β-dose rate will not have this effect.

4.2 Dose-Rate Estimation

For the estimation of dose rates rather than simple surveying of a work place, it is generally better to use the longer time constant, for better statistics, and to leave the meter in one position until the reading has stopped rising or falling. For γ-dose rates below 1 rad/h (10 mGy/h) faster responses are obtained by using the lowest range.

For estimation of γ-dose rates more accurate estimates will be obtained by irradiating the probe at right angles to its axis. However, the shielding effects of the GM counters should be avoided (refer to Figure 6) by irradiating the probe from the left for the low range scale and the right for the middle and upper dose-rate ranges. If the source is very close, attention should be paid to the location of the detectors which is indicated by the white ring around the probe and the white crosses on its end.

For estimation of β-dose rates a reading must be made with the detector exposed and the window pointed towards the source and a second reading with the detector covered (by rotating the disc at the end of the probe). The β-dose rate is estimated from the difference between the two readings.

Because the displays are quite large and can be read at up to 3 m distance the dose to the user may be reduced by setting the survey meter down on its supports and retiring from the region of higher dose rates.

For greater protection of the user or to gain access to small spaces the probe can be separated from the main unit by a cable up to 6 m in length.

4.3 Warning of Hazardous Dose Rates and of the Absorption of a Predetermined Dose

When the survey meter is switched off, power is still supplied to the memory circuit so that a record of the accumulated dose since the last resetting of the memory is preserved. Accumulation of total exposure and the operation of the alarm circuits only occurs while power is switched on.

The dose is integrated from zero from the time the RESET DOSE button is pressed and released. The dose at which the survey meter alarms varies a little from one survey meter to another depending upon the sensitivity of the high range GM counter. The actual value is inscribed upon the top of the survey meter. Dose accumulation is accurate from background up to 100 rad/h (1 Gy/h). Above this rate the estimation is increasingly in error due to counting losses.

When the preset dose is reached the SONALERT sounds continuously and the single LED, next to it, is lighted. The RESET DOSE button should be pressed immediately to permit re-accumulation. If the preset dose has not been reached the accumulated dose can be found by exposing the survey meter to a test source of known output until the alarm sounds.

Whenever about 0.4 mrad (4 μGy) is absorbed a short sound tone is emitted but the LED is not lighted. Thus, the dose rate is proportional to the rate at which sound pulses are emitted.

5. CALIBRATION

Calibration of all four ranges and the dose alarm level should be performed at the time of manufacture and whenever certain components are changed. The components concerned are listed in the following sections.

The survey meter reading is the dose rate that would be received by someone in the same place. The beta-ray dose rate is that which would be received at a depth of 7 mg/cm^2 in the skin. In the case of γ-radiation exposure the dose rate is that which would be received by the testes of a man facing the γ-source.

The dose rate in rad/h (10 mGy/h) so defined is roughly numerically equal to the exposure rate in R/h. However, the two quantities differ somewhat depending on the γ-source used. The conversion from exposure to dose is given in the following table.

Table IV. Exposure Rate (R/h) to Give a Dose Rate of 1 rad/h (10 mGy/h)

Isotope	High & Middle Range*	Low Range
^{60}Co	0.99	1.02
^{226}Ra	1.01	1.01
^{137}Cs	1.16	1.16

* and dose alarm circuit.

Slightly different factors are given for the different ranges because the energy dependences of the two GM counters used for measuring γ-dose rates differ slightly.

It is not recommended to use x-rays for calibration.

Since the survey meter measures dose rates up to 100 rad/h (1 Gy/h) it is prudent to use quite high radiation fields during calibration and therefore care must be taken to limit the exposure of the person calibrating to an acceptably low level. There are several approaches which can be used to reduce exposure:

- collimated beams can be used so that the radiation detectors are irradiated without any part of the person calibrating being in the direct beam,

- the probe unit can be remotely connected to the main unit using a cable ,
- the survey meter can be adjusted using remote controls.

Unless the third approach is taken the dose to the whole body and the fingers should be monitored.

5.1 Calibration of the Dose Alarm

The setting of the dose alarm cannot be adjusted except by changing connections on the printed circuit board and the changes so produced are large (refer to section 2.2). However, there are variations in sensitivity between different high range GM counters and for a given feedback connection the dose required to set the alarm should be measured. (The measured value is then inscribed on the top of the survey meter on the label provided.)

The high range GM counter should be irradiated at right angles to its axis. The exposure rate should be measured at the location of the GM counter itself which is indicated by markings on the probe. The location of the high range GM counter is at the intersection of the plane containing the white circle and a line, at right angles to this plane, which passes through the cross labelled HI-GAMMA. The direction of irradiation should not place the high range GM counters in the shadow of the other two counters. To avoid errors due to counting losses the exposure rate should be less than 100 R/h but large enough to allow a setting in the range of 0.1 - 0.7 R to be made in a reasonable period of time.

Table IV, Column 1, should be consulted to convert exposure rate to dose rate.

The dose to alarm is measured by timing the interval between the release of the reset button to the lighting of the LED and multiplying this time by the measured exposure rate.

This calibration must be done whenever

- the high range GM counter (RD1) is replaced
- the probe unit is changed.

5.2 Calibration of 0-100 rad/h (1 Gy/h) Range (γ)

The high range detector should be exposed to the test source in the same way as described in section 5.1.

To perform the calibration the cover of the main unit should be removed. The power switch is set to ON, the time constant switch to LG and the range switch to GAMMA 0-100.

The high range GM counter should be exposed to 50 to 100 R/h and the trimmer (R24) adjusted until the meter reading agrees with the known dose rate (refer to section 5.0). Six seconds should elapse between separate adjustments.

This calibration must be done whenever any one of the following is changed:

- the high range GM counter (RD1)
- the trimmer (R24)
- the capacitor (C12)
- the probe unit.

5.3 Calibration of 0-10 rad/h (0.1 Gy/h) Range (γ)

This is carried out the same as for the 0-100 rad/h range but with the range switch set to GAMMA 0-100.

The high range GM counter should be exposed to 5 to 10 R/h and the trimmer (R25) adjusted until the meter reading agrees with the known dose rate (refer to section 5.0). At least seventeen seconds should elapse between separate adjustments.

This calibration must be done whenever :

- the high range GM counter (RD1) is replaced
- the trimmer (R25) is replaced
- the capacitor (C12) is replaced
- the probe is changed.

5.4 Calibration of 0-1 rad/h (10 mGy/h) Range (γ)

For this range the GM counter location is marked on the probe with a cross labelled GAMMA-LO.

With the range switch set to GAMMA 0-1, the low range GM counter should be exposed to 0.5 to 1 R/h and the trimmer R26 adjusted until the meter reading agrees with the known dose rate (refer to section 5.0). At least seven seconds should elapse between separate adjustments.

This calibration should be performed whenever

- the low range GM counter (RD2) is replaced
- the trimmer (R26) is replaced
- the capacitor (C12) is replaced
- the probe unit is interchanged.

5.5 Calibration of 0-100 rad/h (1 Gy/h) Range (β)

To calibrate on this range a $^{90}Sr/^{90}Y$ source should be located on the axis of the Beta Sensitive tube at least 100 mm away from the perforated shield which is now exposed by rotating the end cap. The dose rate at the perforated shield should be about 80 rad/h (0.8 Gy/h) so that the full scale operation can be checked.

This calibration requires a strong source which must be handled with great care by the operator.

Alternatively, or if a suitably strong β-source is unavailable, a combination of γ-ray source and a weak $^{90}Sr/^{90}Y$ β-source may be used. First the $^{90}Sr/^{90}Y$ source is positioned and the pulse counting rate is measured (at pin 1 on the printed circuit board). The counter is then exposed to a variable exposure rate of γ-radiation which is then adjusted until the same counting rate is attained. Let this exposure rate be R and the dose rate from the small $^{90}Sr/^{90}Y$ source be D. Then the γ-radiation exposure rate should be increased to $80\frac{R}{D}$ and the trimmer (R27) adjusted until a reading of 80 rads/h (0.8 Gy/h) is obtained. At least five seconds should elapse between each adjustment.

For this calibration the time constant switch should be set to LG and the range switch to BETA 0-100.

This calibration should be performed whenever

- the beta GM counter (RD1) is replaced
- the trimmer (R27) is replaced
- the capacitor (C12) is replaced
- the probe unit is interchanged.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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