A PORTABLE CALORIMETER FOR ABSORBED DOSE DETERMINATION FROM HIGH ENERGY RADIATION

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INTRODUCTION

In the past the physical quantity exposure and its unit "Röntgen" were most widely used in radiation dosimetry. However, this quantity is only defined for photons up to several MeV and therefore not applicable for high energy radiation increasingly used today in radiation therapy. A further inherent problem is that the unit "Röntgen" is not compatible with the SI units. In order to overcome this difficulties the physical quantity "absorbed dose" (D) has widely replaced exposure and a new special name for the unit of absorbed dose the "gray" (Gy) has been introduced internationally[1].

This unit is used almost exclusively already in radiation therapy. In radiation protection the physical quantity dose equivalent with the new special name Sievert (Sv) is applied which is also based on the measurement of absorbed dose.

The portable graphite calorimeter described in this paper is a primary standard for the determination of absorbed dose. The energy from radiation absorbed is heating the graphite and rises its temperature. This temperature rise is compared to that produced by a well known amount of electrical energy released by an internal heater. The basic problem with the construction and use of an absorbed dose calorimeter lies in the fact that a temperature rise of 14 µK has to be measured to determine a dose of 1 cGy (1 rad).

CALORIMETER CONSTRUCTION

The construction of the calorimeter is based on the design by DOMEN at the NBS Washington[2]. It consists of the following cylindrical graphite bodies:

1. The "phantom", the outermost part of the calorimeter (300 mm diameter, 100 mm thick), is supported by a wooden frame and not thermoregulated. Additional graphite plates can be mounted in front to determine depth dose distribution. All the other bodies are situated in a lucite vacuum chamber.

2. The "medium" is a high precision thermoregulated graphite cylinder enclosed in the vacuum chamber. The front of the medium is covered by an aluminized mylar window of 0,13 mm thickness. The working temperature of the medium is approximately 27°C. The short-term stability of the temperature is about 5.10^{-4}K, the long-term stability about 5.10^{-3}K.

3. The "shield" is mounted in the central hole of the medium. It is thermally isolated against the medium by vacuum gaps and coatings of aluminized mylar, 10 µm thick. It acts as a thermal buffer between the medium and the graphite bodies described below.

4. The "jacket" is thermally isolated against the shield by gaps and coatings as well. It has the shape of a cylindrical box and encloses the "core". It further reduces the temperature gradients.

5. The "core" is the actual point of measurement for the determination of absorbed dose. Although it is isolated against the jacket by vacuum gaps of 0,5 mm, it is not coated in order to minimize the presence of materials other than graphite. Fig. 1 is a photograph of the complete calorimter, Fig.2 shows a cross section of the basic calorimeter components. The short term temperature stability of the core is within $\pm$ 1 µK.

A spiral heater is embedded in the back of the medium. It is controlled automatically by a precision thermoregulator. The shield, jacket and core are equipped with electrical heaters which are operated manually.

The temperature in all graphite bodies except the phantom is measured by microthermistors with 0,3 mm diameter. Their nominal resistance at 25°C is 10 kΩ. The thermistors are switched into the arms of a Wheatstone bride (Fig. 3). Each thermistor is balanced by a variable resistor (R_M, R_S, R_J, R_{C1}, R_{C2}). The first arm in the bride (1) consists of two fixed 10 kΩ resistors and is used as a reference. The bridge is powered by an AC source (0,2 - 1 Vrms, 2 - 10 Hz) which also controls the sensitivity of a lock-in amplifier with respect to frequency and phase. The lock-in amplifier can be switched between each two points (1-6) in the bride circuitry as desired. By this way the temperature can be observed in each body.

The core contains two measuring thermistors (C_1, C_2) in order to double the sensitivity for low dose rate measurements. In this case the amplifier is switched between point 5 and 6. In order to obtain a heat-loss compensated calibration[2] it's also possible to measure the temperature rise in the core plus jacket (amplifier between 4 and 6). The amplifier output voltage is recorded on a strip chart recorder.

MEASUREMENTS AND RESULTS

The basic state of the calorimeter for any measurement is a temporary temperature equilibrium. In this state the power input by the measuring thermistors equals the heat-loss rate of each body. In practice precisely defined energy inputs into the bodies by the different heaters can shorten the time to reach temporary equilibrium considerably. The temperature drift rate of each body is a measure for the deviation of its temperature from the equilibrium.

The calibration of the instrument can be performed either in the heat-loss compensated mode or in a quasi-adiabatic mode achieved by input of an exactly measured amount of energy in the core heater. Radiation measurements are usually made quasi-adiabatically. The calorimeter response for a calibration- or irradiation-run is evaluated by determining the relative resistance change of the core thermistors. In order to be independent on the amplifier gain the bridge circuit is balanced before and after electrical heating or irradiation to zero bridge output. This can be obtained by changing balancing resistors by a well known amount.

The calibration of the instrument was performed at an electrical power level equivalent to about 60 $mGy.s^{-1}$. The calorimeter calibration factor has be determined as - 140 mJ per percent resistance change (nominal) with a standard deviation of a single run of less than 0,1 %. The long-term stability of this calibration factor is better than 10^{-3}.

The quasi-adiabatic radiation measurements were made at a doserate of about 5 $mGy.s^{-1}$ in a ^{60}Co beam. The irradiation time was 4 min and the absorbed dose of each run (≈1,2 Gy) could be determined with the standard deviation of a single run better than 0,3 %. On the chart recorder plot of a typical radiation run one scale division is corresponding to a temperature rise of 14 µK equivalent to a bridge output voltage of 100 nV and a dose of 10mGy.

CONCLUSION

The portable graphite calorimeter described proved to be a suitable primary standard for the determination of absorbed dose. The range of measurement extends from about 1 $mGy.s^{-1}$ up to the very high doserates produced by betatrons and linear accelerator applied in radiation therapy. Due to the application of a new high precision thermoregulator, an improved electronic measuring circuitry with AC-Wheatstone bridge and lock-in-amplifier a significant improvement in the limit of detection down to the range of protection level doses could be achieved.

REFERENCES

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(2) DOMEN, St.R., LAMPERTI, P.J.: A heat loss compensated calorimeter: theory, design and performance. J.Res.Nat.Bur.Stand. (US) - A Vol. 78 A No. 5, 595-610, 1974 (Sept. - Oct.)

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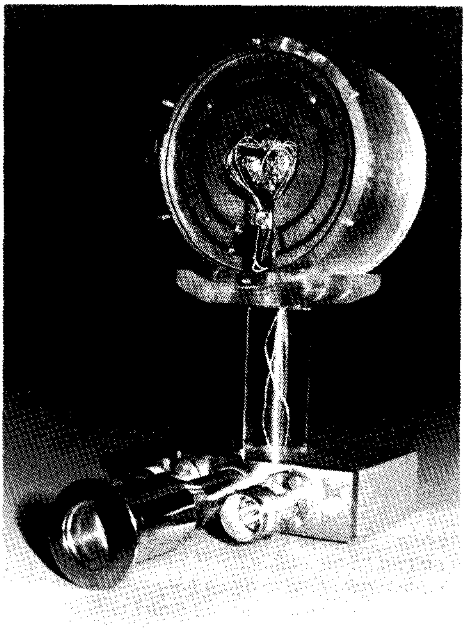

Fig. 1: View of Calorimeter Assembly

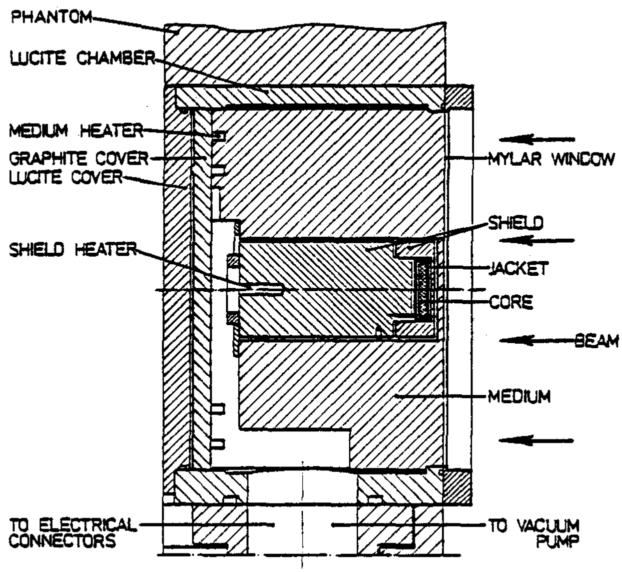

Fig. 2: Cross Section

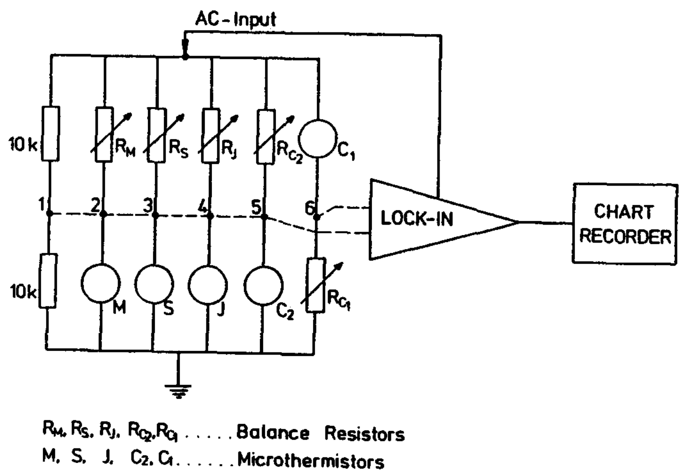

Fig. 3: Schematic Circuitry of Wheatstone-Bridge