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Original Article

Building a Graphite Calorimetry System for the Dosimetry of Therapeutic X-ray Beams

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ABSTRACT

A graphite calorimetry system was built and tested under irradiation. The noise level of the temperature measurement system was approximately 0.08 mK (peak to peak). The temperature of the core part rose by approximately 8.6 mK at 800 MU (monitor unit) for 6-MV X-ray beams, and it increased as X-ray energy increased. The temperature rise showed less spread when it was normalized to the accumulated charge, as measured by an external monitoring chamber. The radiation energy absorbed by the core part was determined to have values of 0.798 J/μC, 0.389 J/μC, and 0.352 J/μC at 6 MV, 10 MV, and 18 MV, respectively. These values were so consistent among repeated runs that their coefficient of variance was less than 0.15%.

1. Introduction

Radiation therapy using high energy X-rays generated by medical linear accelerators has already been a major tool for cancer treatment. Approximately 30% of patients with cancer are undergoing radiation treatment [1], and 197 medical linear accelerators are currently operating in Korea [1–3]. Thus, radiation therapy quality control and assurance is very important for cancer treatment.

Radiation dosimetry is the most important indicator for quality control and assurance. When the irradiation is accurately performed at the prescribed dose, cancer cell death is maximized, whereas normal cell death is minimized. For this purpose, the International Commission on Radiation Units & Measurement recommends that the radiation dose measurement uncertainty should not exceed 5% [4].

The radiation therapy dose is calibrated in terms of the water absorbed dose (unit: Gy) [4–6]. The water absorbed dose is a physical quantity that is defined as the amount of radiation energy absorbed by water of a unit mass [4–6]. Water absorbed dose measurement can be realized with water calorimetry or by graphite calorimetry. Primary standard dosimetry laboratories use these types of calorimetry for primary dosimetry standards.

The world's first graphite calorimetry system was developed by S.R. Domen at the National Bureau of Standards in the 1970s [7]. Compared to water calorimetry, graphite introduces additional uncertainty owing to the necessity of converting the graphite absorbed dose to the water absorbed dose. However, the graphite method still has advantages over water calorimetry. One is that graphite has a specific heat capacity lower than that of water, which leads to a greater rise in

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temperature than is the case for water at the same absorbed dose. Another is that graphite has no thermal [8,9].

The sensitive volume or sensitive medium of a graphite calorimeter is called a core. Thermal isolation of the core from the environment is very important because the temperature at the core increases by only a few milliKelvins when a graphite calorimeter is irradiated by therapeutic X-rays. Thus, the core is usually covered with many layers of jackets in vacuum. In the core, there are one or more thermometers and heaters. The thermometer(s) is needed to measure the temperature rise of the core at irradiation. The heater(s) is needed for the calibration of the temperature rise to the energy absorbed in the core. The calibration is performed by comparing the temperature rise at irradiation to the temperature rise caused by known amounts of electric heat or energy. Thermistors, or resistive thermometers, are used for temperature measurements at the core as well as for heating. Thermistors have poor linearity and poor stability; however, they have sensitivity to temperature and are not affected by irradiation up to megaGrays [10]. In addition, thermistors are available in very small sizes, which is helpful for minimizing impurities in the core.

To ensure the repeatable measurement of the core temperature, the calorimeter must run under a quasi-adiabatic condition [11,12]. Under this condition, thermal transfer from the core to the inner jacket is kept nearly constant, and the temperature rise at the core is always proportional to the energy absorbed during its runs. A French group recently achieved this condition by introducing thermal feedback [13,14] to the inner jacket. In this study, a similar type of thermal feedback was developed and applied to achieve this quasi-adiabatic condition.

In this study, a graphite calorimetry system was built to measure the high energy X-ray absorbed dose. Experiments were performed to investigate system properties, and the results are discussed. In Section 4, the uncertainties of some values are given, but details are not provided as to how they were evaluated, because that is outside the scope of this article.

2. Materials and methods

2.1. Apparatus

2.1.1. Building graphite calorimeter

The graphite calorimeter (C1505-4) adopted a pan-shaped vacuum housing and double-layered jackets as in the design of the GR9 of the French group [13]. The core was covered with two layers of jackets and graphite mediums, and then placed in a vacuum housing and a graphite phantom. All of the graphite parts were composed of a batch product of high-density pyrolytic graphite (M507; Morgan Korea, Daegu, South Korea), whose density was separately determined to be (1.8154 ± 0.0014) g/cm^3.

The core was 16 mm in diameter and was 3 mm thick, with three sensing thermistors, one heating thermistor and three supports, as shown in Fig. 1. NTC-type thermistors with micro glass beads (diam.: 0.3 mm) were used (AB6B4-BR11KA103; GE Measurement & Control, U.S.A.). The thermistors had

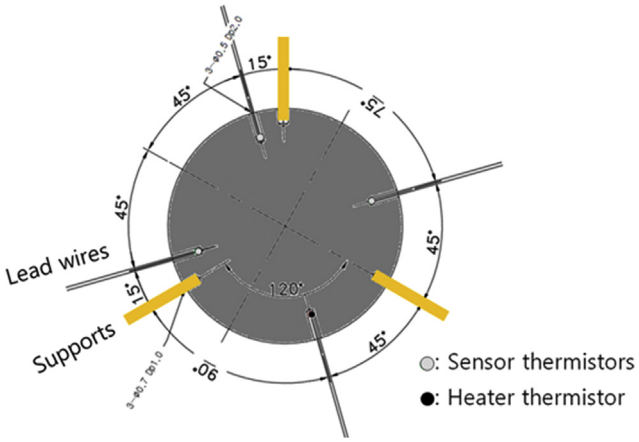

Fig. 1 – Schematic layout of the graphite calorimeter core (C1505-4).

resistances of 20 kΩ at room temperature; they contained nickel alloy lead wires (0.101 mm thick). Hollow Kapton tubes were used to support the core. Epoxy resin was used to glue all of the components of the core together. During the integration of the core, the core was weighed at each step to detect impurities (nongraphite ingredients). The jackets were prepared in the same manner as the core, but they were not weighed. The inner surfaces of the jackets were lined with thin aluminized Mylar foils to reduce radiative heat transfer. The outer jacket used a Manganin wire (LakeShore, OH, U.S.A.) (diam.: 0.202 mm) as a heater, instead of using thermistors.

After all parts were built, the thermistors were calibrated for temperature in a high precision water bath (7008, Fluke). The parts were separately placed in thin and watertight polyethylene bags (100 μm thick) and placed in the water bath. The temperature of the bath was measured using an SPRT (Standard Platinum Resistor Thermometer, 5187SA, Tinsley). The resistance of the thermistors and the SPRT was read using a high precision half-bridge (1595A, Fluke). Calibration was performed within a range of 20–30°C at each degree Celsius.

2.1.2. Electronics and external monitoring chambers

Wheatstone bridges were built to measure the temperature of the core and of the inner jacket. High precision standard resistors and decade resistors were used to build the bridges. A high precision voltage calibration source (3350A, Transmille) was used to supply the excitation voltage to the bridges. Nanovoltmeters (34420A; Agilent, CA, U.S.A.) were used to read the voltage difference across gaps in the bridges.

An electric heating and power measurement circuit was built, as shown in Fig. 2. In the figure, V_x represents the voltage drop across the heating thermistor of the core. R_s and V_s represent the resistance of a standard resistor and the voltage drop across the resistor, respectively. Then, the electric power dissipated at the heating thermistor, P_x, is given as $P_x = V_x V_s / R_s$. Electric power was fed by a multichannel dc power supply (2230-30-1, Keithley) to the heating thermistor. A precision resistor (SRL-10k; IET Labs., MA, U.S.A.) was used as the R_s; its

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