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Analysis of transient and thermostatic behavior of water calorimeter for radiation dosimetry

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1. Introduction

An institutional measure which can be used to protect the patient from over-exposure during radiation therapy, still domestic technology has a higher uncertainty than the international standards. In order to maintain the therapeutic accuracy recommended by the WHO, the American Medical Physics Association has published research results that uncertainty of absorbed dose measurement should be given to less than 3% and many countries are developing the absorbed dose evaluation technique using a calorimeter. Therefore development of water calorimeter and standard measurement method of absorbed dose through the evaluation and ongoing measurement is required in Korea.

As an initial step in the development of the water calorimeter by domestic technology, we designed geometry of the phantom and carried out the simulation of the thermal behavior according to the radiation transport and energy deposition by 145TBq KRISS ^{60}Co beam. By using the EGSnrc; γ-rays and electron transport simulation code, we calculated the absorbed dose distribution. We developed a program that automatically converts to fillable form from the output data of EGSnrc to ANSYS-CFX code. By using the ANSYS-CFX code, we calculated the thermal behavior and the temperature distribution in water phantom. As a result of research we can simulate the new structure and material of the water calorimeter and secured the design methodology of the optimum geometry.

2. Methods

2.1. Simulation input information and geometry.

The study of standard water calorimeter has been continuously carried out internationally. We refer to the water calorimeter model of NIST, which has been introduced in other standard researchers as reference [1]. The geometry of water calorimeter is shown in Figure 1. The internal volume of water phantom is 30 × 30 × 30 cm^3 and the air layer is included top end of the outer wall which is maintained at 4 ℃. Sealed water core and a thermistor are located in the direction of the γ-ray beam entrance window. X-axis is parallel to thermistor, y-axis is parallel to gravity and z-axis is parallel to direction of ^{60}Co beam. The materials and dimensions of water calorimeter are given in table 1.

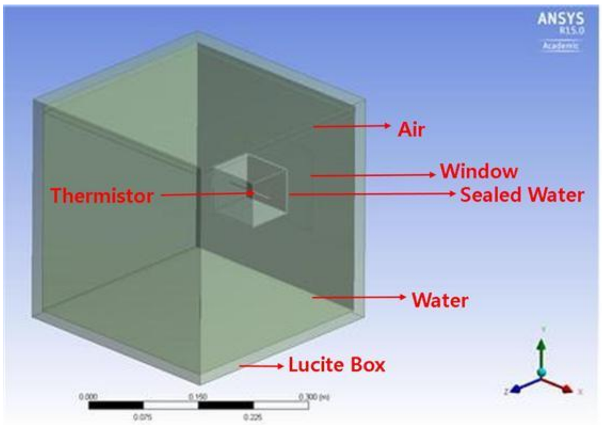

Fig. 1. 3D modeling of water calorimeter

Table 1. Material data

		Geometry	Material
Water Phantom	Wall	Thickness 1 cm	Lucite
	Window	Thickness 0.3 cm	Lucite
		Area 12 × 12 cm^2	
	Air	Thickness 1 cm	Air
	Water	Volume 30 × 30 × 30 cm^3	Water
Sealed water core	Glass tube	Thickness 0.1 cm	Glass
		Inside volume 6.5 × 6.5 × 7.5 cm^3	
Thermistor	Thermistor	Volume 0.03 × 0.03 × 0.03 cm^3	Glass
		Distance between Window and Thermistor : 5 cm	
	Pyrex tube	Thickness 0.01 cm	Glass
	Adhesion space		Epoxy

2.2. Simulation of absorbed dose distribution in the water phantom by KRISS ^{60}Co beam irradiation.

Using the γ-ray and electron transport simulation computer code EGSnrc, we calculated energy distribution in the water phantom by KRISS *^{60}Co* beam. The number of simulation history was 8 × 10^9 and sealed water core was applied to overcome the heat defect which inhibits the measurement accuracy of the water calorimeter [2]. Γ-rays are emitted from the point source which is 100 cm away from the thermistor and it was simulated as a pyramid form. The area of γ-ray beam reaching the z-plane is 10 × 10 cm^2. A number of γ-rays that enter into the window area were 2.210883 × 10^{11} per second. Cutoff energy of electrons and photons were used from default settings of EGSnrc 0.521, 0.01 MeV (including the rest mass energy). The output unit calculated in EGSnrc is [Gy/particle].

2.3. Development of visualization and data conversion program of simulation results

We developed the visualization and data conversion program using MATLAB and GUI (Graphic User Interface) guide. EGSnrc output data (absorbed dose per particle) is converted as an input data of ANSYS-CFX (thermal energy generation per unit volume) and visually identifiable by this code. Conversion from the output data of the EGSnrc to input data of the ANSYS-CFX is performed as follows:

$$\text{Absorbed Dose Rate}\left[\frac{\text{Gy}}{\text{s}}\right] = \text{EGS output}\left[\frac{\text{Gy}\times cm^2}{\#}\right]\text{Source Intensity}\left[\frac{\#}{cm^2 s}\right] \quad (1)$$

$$\text{Thermal Generation Rate}\left[\frac{\text{W}}{\text{m}^3}\right] = \text{Absorbed Dose Rate}\left[\frac{\text{Gy}}{\text{s}}\right]\times\text{Density}\left[\frac{\text{kg}}{\text{m}^3}\right] \quad (2)$$

2.4. Calculation of thermal behavior and temperature distribution in the water phantom by KRISS ^{60}Co beam irradiation.

When the radiation absorbed by the water and the surrounding material the energy is mostly converted into kinetic energy and the vibration of molecules, which appear to increase in temperature. Although some of the absorbed energy is not contributing to the temperature rise due to the generation of secondary radiation or heat defect, we assume that all of the absorbed dose is converted into thermal energy in this study. ANSYS-CFX can receive input from the heat generation amount of the specific position and be input to the coordinate value of the specified grid. Unit of the input data were set to the heat generation amount per unit volume [W / m3].

3. Result

Using EGSnrc we calculated the energy deposition distribution of water phantom.

A sealed water core is being used as a way to overcome the heat defect, which inhibit the uncertainty. An absorbed dose per second at a 5 cm distance of water phantom to window is 9 mGy/s and uncertainty is 1 %. These results are shown in figure 2~4. The Window of the developed data conversion and plotting program is given in figure 5.

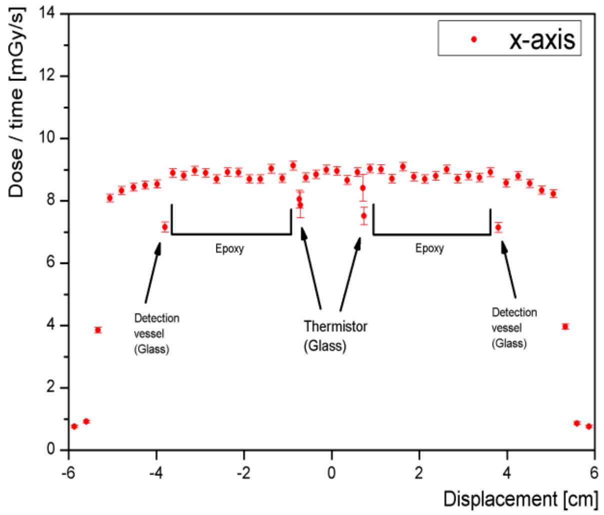

Fig. 2. Dose along the x-axis of water calorimeter including thermistor.

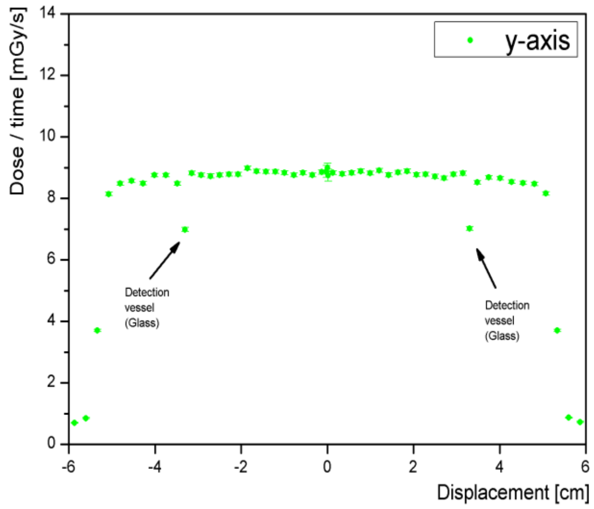

Fig. 3. Dose along the y-axis of water calorimeter including thermistor.

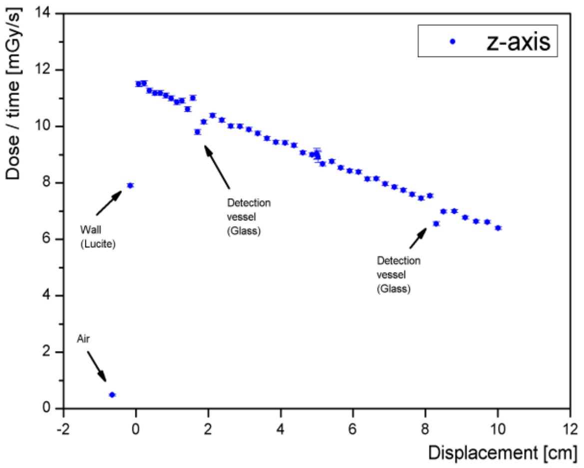

Fig. 4. Dose along the z-axis of water calorimeter including thermistor.

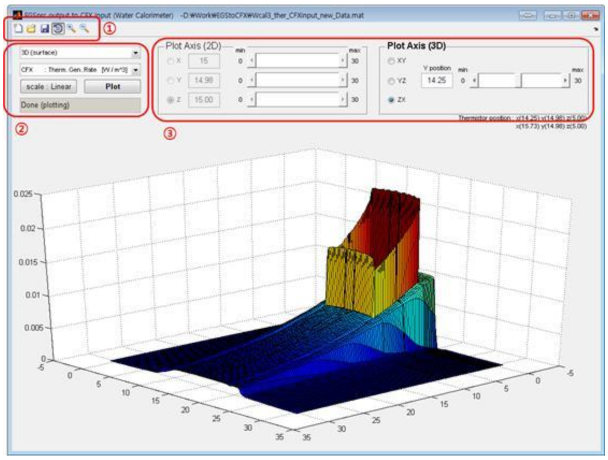

Fig. 5. Window of the developed data conversion and plotting program.

Simulation of thermal behavior and temperature distribution in the water phantom was performed using the finite element analysis code, ANSYS-CFX. We evaluated the self-heating impact of thermistor, high-performance temperature measurement sensor, which influence on the thermal behavior of water phantom. Temperature variation ΔT at thermistor position when the 5 minutes has elapsed since the ^{60}Co beam irradiation start without self-heating of thermistor was 0.7 mK. And when it is calculated by taking into account the self-heating of the thermistor, ΔT was 24 mK. These results are shown in figure 6~7.

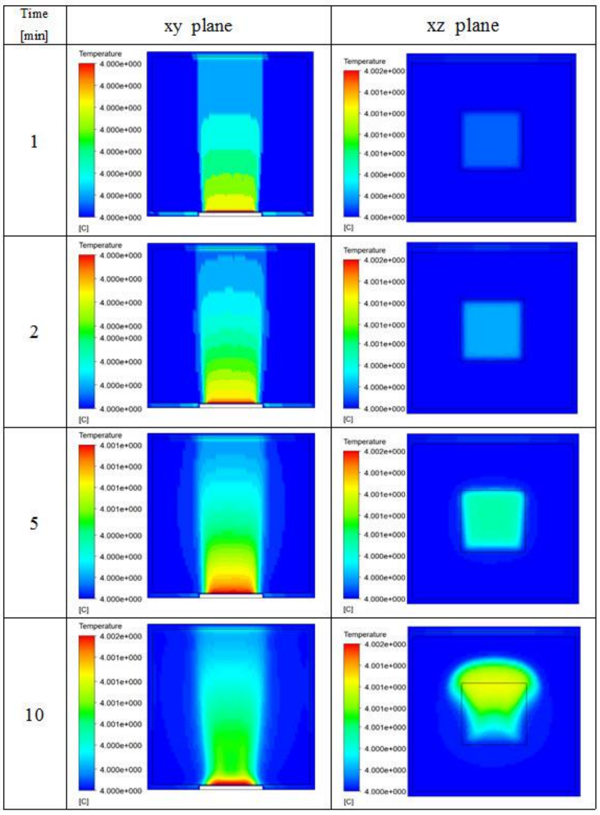

Fig. 6. Temperature distribution in the water phantom without sealed water.

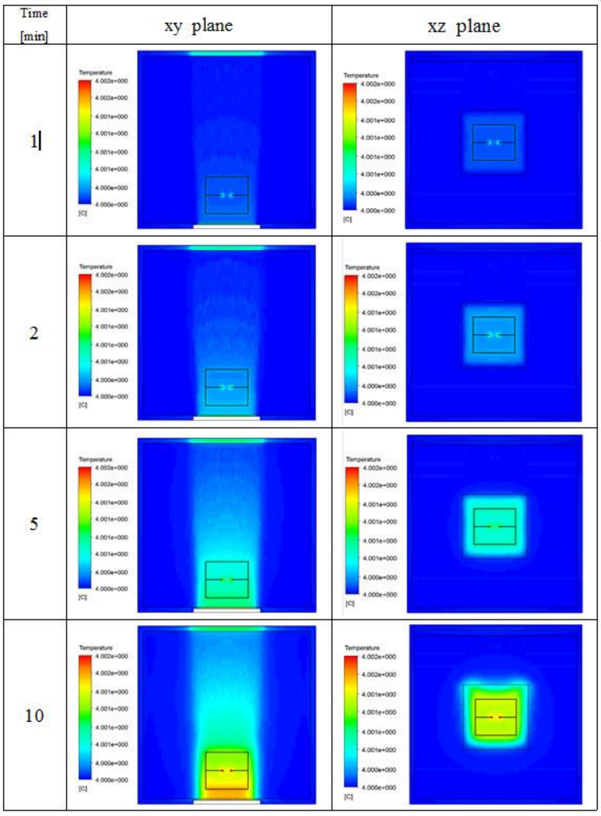

Fig. 7. Temperature distribution in the water phantom with sealed water.

4. Conclusion and Further Work

The results of this study will be used as the basic data for development of the standard water calorimeter in Korea Research Institute of Standards and Science. Through a parallel development and comparison with the graphite calorimeter, this result is expected to be utilized to improve the standard dosimetry.

Acknowledgements

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REFERENCES

[1] http://www.nist.gov/pml/data/star/index.cfm (15 Oct 2014, date last accessed).
[2] S.R. Domen, "A sealed water calorimeter for measuring absorbed dose", Journal of Research of National Institute of Standards and Technology, 99 (1994) 121.