Radiation Sources Fabricated from Tea Leaf and Educational Trial

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Abstract. Various radioisotopes are as ubiquitous as air and water around us. Everything on Earth contains naturally occurring radioisotopes and inevitably emits radiation. Typical examples include potassium chloride, chemical fertilizers, and kelps. In our previous studies, a compression and formation method was developed to form these materials into solid disks. Solid disks that emit sufficient radiation detectable by radiation measuring devices such as Geiger-Mueller (GM) survey meters can then be used as radiation sources for educational purposes. In the present study, five brands of black tea were purchased at supermarkets in Japan and the compression and formation method was applied to the tea leaves. The resulting solid tea disks were found to contain potassium-40 with 50–60 Bq/100 g, which was determined using a gamma-ray spectrometer. To evaluate their potential as radiation sources for educational purposes, measurements relating to the three principles of radiation protection were carried out using GM survey meters. The solid tea disks were then used in measurements for investigating the existence of natural radioisotopes and the randomness of radiation counts.

Keywords: radiation education, educational radiation source, black tea

1 INTRODUCTION

Everything on Earth inevitably contains naturally occurring radioisotopes [1, 2] and emits radiation. Typical examples include potassium chloride, chemical fertilizers, and kelps. These materials contain the natural radioisotope potassium-40 (^{40}K). In our previous studies, a compression and formation method [3] was developed to form those materials into solid disks that emit radiation. Thus fabricated disks were used in various educational courses on radiation [3-8]. Upon completing these courses, a number of students would accept the existence of natural radioisotopes. However, other students had difficulty accepting it as they felt the materials were very rare or special. It was concluded that the solid disks should be made of a material familiar to most people. Black tea [9-10] can be potentially used because it is commonly consumed all over the world and considered a daily commodity. Thus, more people may be able to understand the existence of natural radioisotopes when they can measure the radiation emitted from solid disks fabricated from black tea. In the present study, five brands of black tea were purchased at supermarkets in Japan and the compression and formation method was applied to the tea leaves. The weight, diameter, thickness, and gamma-ray spectra of the fabricated disks were examined. Three dependence tests of radiation counts on time, distance, and shielding were then carried out with Geiger-Mueller (GM) survey meters to evaluate the potential of the solid tea disks to be used as radiation sources for educational purposes. Subsequently, two trials were conducted on the solid tea disks – the first to verify the existence of natural radioisotopes, and the second to investigate the randomness of radiation counts represented by a Gaussian distribution curve.

2 METHOD OF EXAMINATION AND MEASUREMENT

2.1 Black Tea Brands

Tea is the most commonly consumed drink in the world after water and includes varieties such as black, green, and oolong [9-10]. These teas are manufactured from the same leaves but undergo different processing. Nowadays, there is a large variety of commercially available teas. In the present study, five brands of black tea were purchased at supermarkets in Japan and used as the raw materials for the solid tea disks.

2.2 Fabrication of Solid Tea Disks

The previously developed compression and formation method was applied to the five black tea brands. About 15 g of each brand was placed into a cylindrical stainless steel mold (inner diameter: 35 mm, height: 30 mm) and then compressed. A compression pressure of around 150 kN was applied for about 3 minutes to fabricate the disks. In the present study, seven disks were fabricated from each brand. A total of 35 solid tea disks were created and their weight, diameter, and thickness were examined.

2.3 Gamma-ray Spectrum Measurement

One of the seven solid tea disks fabricated from each of the five brands was selected as a representative, and the gamma-ray spectra of the five representative disks were obtained by 50000-second measurement using a CsI gamma-ray spectrometer (Monster II, Sanwa Corporation). Then the spectrum was also measured under background radiation in the same manner after the solid tea disk was removed. The obtained spectra was analyzed and the radionuclide and radioactivity contained in the five representative disks were determined.

2.4 Evaluation of Solid Tea Disks as Educational Radiation Sources

To evaluate the solid tea disks as educational radiation sources, one of the 35 disks was selected as the representative and its radiation was measured with a GM survey meter (Aloka TGS-146). The measurements included three dependence tests of radiation counts on time, distance, and shielding [6-8]. The measurement setup, shown in Fig. 1, consisted of the solid tea disk, a disk stand, and a GM survey meter (body and GM probe).

2.4.1 Distance dependence test

In the first test, the solid tea disk was placed in the disk stand and the GM survey meter was placed at several distances (0, 1, 2, 4, 7, 15, and 30 cm) from the surface of the solid tea disk (Fig. 1). Then the radiation was counted for one minute at each distance. Afterwards, the disk was removed, and the 1-minute counts were measured under background radiation. The measurements with and without the disk were repeated ten times at the respective distances.

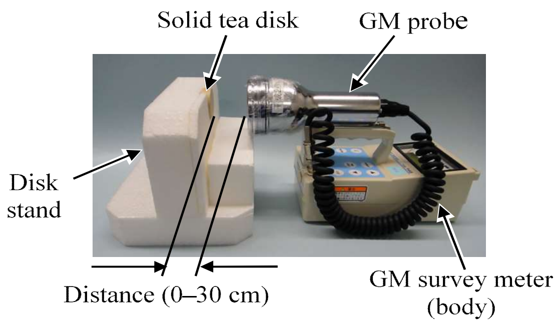

Figure 1: Measurement setup of solid tea disk using GM survey meter.

2.4.2 Shield dependence test

In this test, the solid tea disk was placed in the disk stand and the GM probe was placed at a fixed distance of 10 mm. Then Kent papers were inserted into the space between the GM probe and the disk (ref., Fig. 1). The Kent paper (thickness: 0.25 mm, mass density: 0.93 g/cm^3) was used as the shielding material. Various thicknesses from 0 to 8 mm were attained by stacking suitable numbers of the Kent papers. The measurements of the 1-minute counts were repeated ten times for the respective thicknesses. The solid tea disk was detached and a 4 mm-paper shield was inserted, and then ten 1-minute counts were measured under background radiation. It was assumed that the 4 mm-paper shield yielded the average of the effect of paper shields 0 to 8 mm thick for background radiation measurement.

2.4.3 Time dependence test

In the third test, the solid tea disk was set in the disk stand by directly attaching it to the head surface of the GM probe, making the distance zero, as shown in Fig. 1. In this measurement, the radiation counts accumulated by the GM probe were checked and recorded every minute for a period of 10 minutes. Then, the solid tea disk was removed and the same measurement was carried out. The measurements with and without the solid tea disk were repeated ten times for elapsed times of 1, 2, . ….9, and 10 minutes.

2.5 Utilization of Solid Tea Disks

On the basis of the results obtained from the three dependence tests, two trials were conducted utilizing the solid tea disks. In the first trial, an additional time dependence test was carried out in a 7-cm thick lead-equivalent shielding box. The second trial was carried out to investigate the randomness of radiation counts. In this trial, the solid tea disk was placed directly on the surface of the GM probe (ref., Fig. 1) and the 1-minute counts were measured fifty times. Then the frequency distribution of the fifty 1-minute counts was examined.

3 RESULTS AND DISCUSSION

3.1 Characteristics of Black Tea Brands

Table 1 summarizes the characteristics of the five black tea brands used in the present study. The first and second columns list the brand numbers and abbreviated brand names, respectively. The names were determined from the characteristic flavor and fragrance of each tea. The third column lists the primary origins of the products. The five brands were found to be mixtures of tea leaves harvested in more than two regions. The vendors or manufacturers are listed in the last column.

Table 1: Characteristics of five black tea brands.

Brand number	Abbreviated brand name	Product origin	Vendor or manufacturer
1	Rich flavor	Assam(>70%), Sri Lanka	Nittoh
2	Less bitter	Sri Lanka(>55%), India	Nittoh
3	Plain flavor	Kenya, Sri Lanka	Lipton
4	Mild aroma	India, Kenya	Nittoh
5	Light flavor	India, Sri Lanka	Seiyu

3.2 Features of Solid Tea Disks

Figure 2 shows a typical solid tea disk fabricated in this study. The disk was fabricated with the black tea from brand 1. All fabricated solid tea disks retained their smell, and remnants of tea leaves were observed on the surface. These remnants were effective for visualizing the raw material used.

Figure 2: Solid disk fabricated from black tea by compression and formation method.

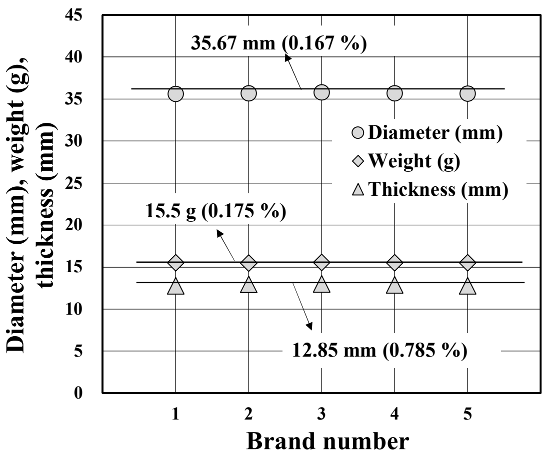

Figure 3: Average weight, diameter, and thickness of seven solid tea disks fabricated from five black tea brands.

The features of the solid tea disks are summarized in Fig. 3. The X-axis shows the brand numbers, and the circle, rhombus, and triangular symbols denote the diameter, weight, and thickness of the disks, respectively. Each symbol represents the average of seven disks fabricated from each brand. The relative standard deviations (RSDs) are less than 1%. The three horizontal lines in Fig. 3 represent the averages of five circles, five rhombuses, and five triangles. Their values were 35.67 mm, 15.50 g, and 12.85 mm, and their RSDs were 0.167, 0.175 and 0.785%, respectively. Figure 3 demonstrates that the 35 solid disks did not significantly vary in dimension and weight regardless of individual fabrications and brands used as raw materials.

3.3 Identification of Radionuclide ^{40}K and Radioactivity

Figure 4 shows the obtained gamma-ray spectra of the five representative solid tea disks (circles, rhombuses, squares, triangles, and crosses) and the background radiation (black circles). In each spectrum, the main peak was observed at 1461 keV. These peaks correspond to gamma rays emitted from ^{40}K contained in the disks and the surrounding environment (background). Natural potassium contains three isotopes, ^{39}K, ^{40}K, and ^{41}K, and ^{40}K emits a beta particle (1312 keV, 89.3 %) and a gamma ray (1461 keV, 10.7 %). In Fig. 4, the peak in the spectrum of the solid tea disks is noticeably higher than that of the background. From these spectra, the radioactivity of ^{40}K contained in the solid tea disks were determined to be about 58.0, 55.2, 55.5, 58.8, and 54.0 Bq/100 g in order of brand numbers (1 to 5), respectively. These results demonstrate that radioactivity of ^{40}K contained in the five brands of black tea is almost the same. Consequently, the 35 solid tea disks may contain approximately the same radioactivity of ^{40}K because their weights are nearly the same (ref., Fig. 3).

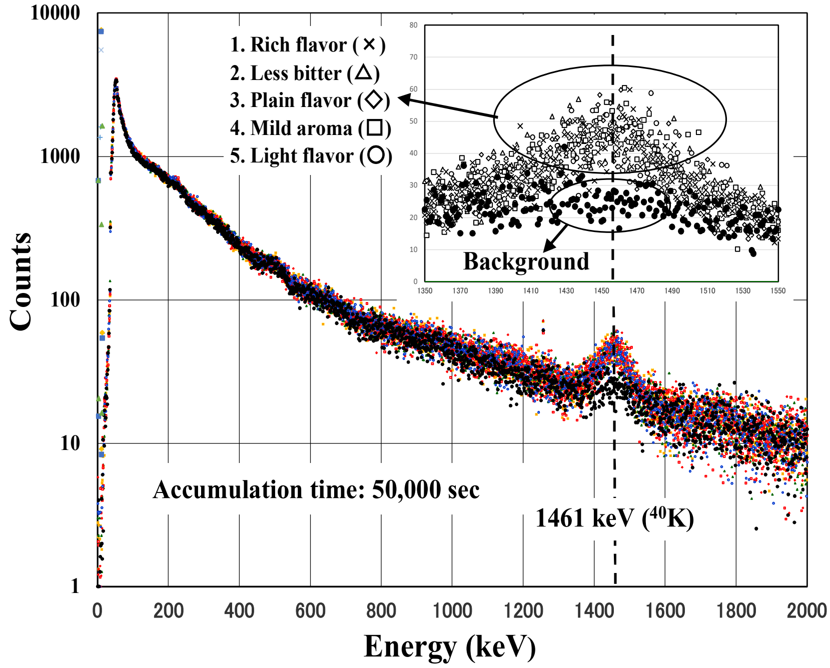

Figure 4: Typical gamma-ray spectra of five black tea brands and background radiations.

3.4 Evaluation of Solid Tea Disks as Radiation Sources for Educational Purposes

In the three dependence tests, beta rays emitted from ^{40}K were mainly measured by the GM probe. The obtained results are shown in Fig. 5 (A), (B), and (C). The X- and Y-axes correspond to the distance and 1-minute counts in (A), the thickness of paper shield and 1-minute counts in (B), and elapsed time and accumulated counts in (C). The accumulated counts are radiation counts accumulated within elapsed times.

3.4.1 Distance dependence test

In Fig. 5 (A), the circles and error bars represent the average and standard deviation (σ) of 1-minute counts obtained from the ten measurements of the solid tea disks at respective distances. The solid horizontal and dashed lines are the average and the upper limit of 2σ of 1-minute counts of the background radiation obtained by the ten measurements without the solid tea disks. In Fig. 5 (A), the lower limit of 2σ is not shown. Where, 2σ was derived by doubling the standard deviation of the ten 1-minute counts of the background radiation. The confidence interval of 2σ was approximately 95%, i.e., about 95% of the background radiation counts are contained in this fluctuation range. The circle and error bar exceeding the upper limit is only that obtained for zero distance. Other circles and/or error bars fall partly or fully under the upper limit. This means the 1-minute counts clearly distinguishable from background radiation are obtained only when the solid tea disk is directly attached to the surface of the GM probe (distance = 0). Consequently, the results shown in Fig. 5 (A) cannot demonstrate the distance dependence of radiation counts (the inverse-square law).

3.4.2 Shield dependence test

In Fig. 5 (B), the circles and error bars are the average and σ of 1-minute counts obtained by the ten measurements for respective thicknesses. The horizontal solid and dashed lines are the average and the upper limit of 2σ of background radiation counts obtained by the ten times measurements without the solid tea disks for the 4-mm paper shield. As with the previous figure (A), the lower limit is not shown here. All the circles fall under the upper limit of 2σ of the background radiation counts. Therefore, this result does not demonstrate decreasing radiation counts with respect to shielding thickness.

3.4.3 Time dependence test

In Fig. 5 (C), the circles and error bars are the average and σ of the accumulated counts obtained from the ten measurements of the solid tea disks. Line-1 and the dashed line are regressed from the averages and the upper limits of 2σ derived from accumulated counts of background radiation obtained by the ten measurements repeated at the respective elapsed times. All the circles exceed the upper limit of 2σ, although the error bar for the 1-minute elapsed time slightly crosses over the dashed line. This explains the linear relationship between accumulated count and elapsed time and shows that the solid tea disks can be used to demonstrate the time dependence of radiation counts.

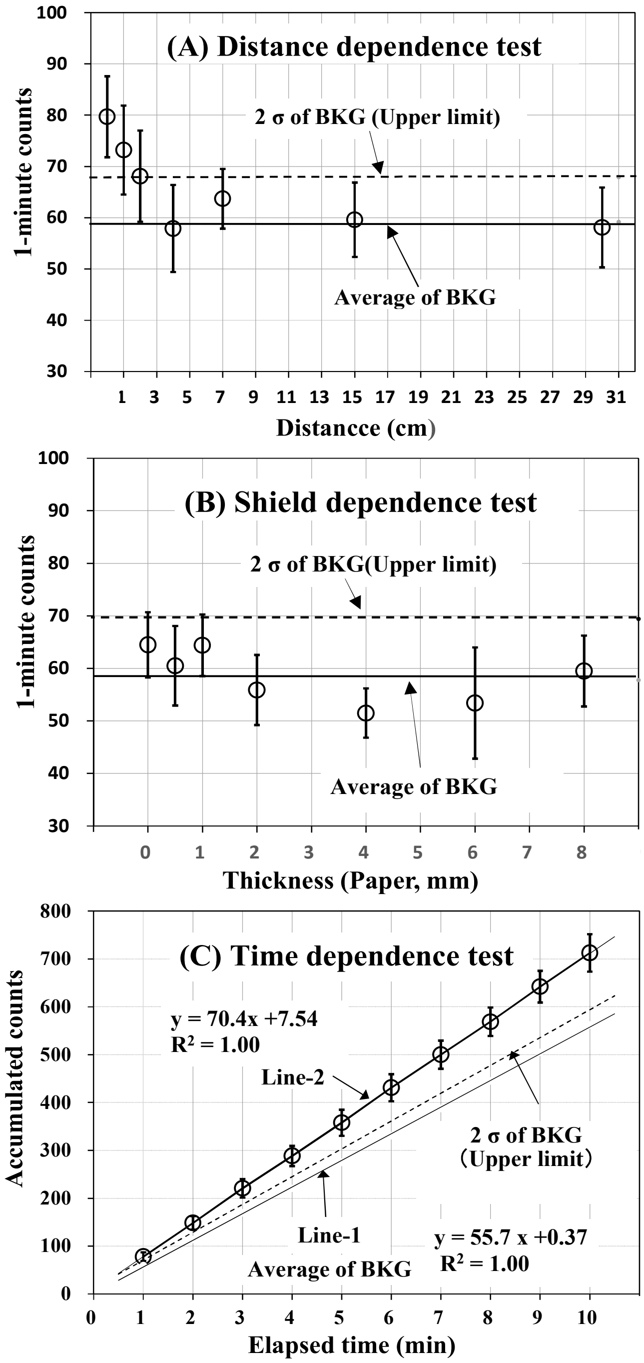

Figure 5: Results of three dependence tests of radiation intensity on distance, shielding, and time.

3.5 Utilization of Solid Tea Disks

From the results of the three dependence tests, it was determined that the solid tea disks must be used by directly attaching them to the surface of the GM probe. In this measurement condition, the measured radiation counts could be distinguished from background radiation counts. Considering these results, two trials were conducted as realistic applications by measuring the radiation from the solid tea disks using GM survey meters.

3.5.1 Uncovering existence of natural radioisotopes

In the first trial, the results of the time dependence test were used to find the existence of natural radioisotopes. In Fig. 5 (C), the relationships between radiation counts and elapsed time are represented by straight lines 1 and 2 with inclinations of 70.4 and 55.7, respectively. The inclination of line-2 with the solid tea disk was slightly larger than line-1 of the background radiation, and the inclination ratio of the former to the latter was 1.26 (= 70.4/55.7). Line-2 reflects both the radiation emitted from the solid tea disks and background, whereas line-1 only represents the background radiation. The difference in inclinations may be because the black tea contains a small amount of natural radioisotopes and emits radiation, although the radionuclide and radioactivity were unknown.

To further clarify the existence of natural radioisotopes, the additional time dependence test was tried in a 7-cm thick lead-equivalent shielding box. The results are shown in Fig. 6, in which all notations are the same as Fig. 5 (C), and likewise, two straight lines 1 and 2 with different inclinations. The inclination of line-2 is noticeably larger (40.3) than that of line-1 (26.0). The inclination ratio of the former to the latter is 1.43 (= 40.3 / 26.0), which is 1.13 times larger than that without the shielding box. This ratio shows that the use of a shielding box make the existence of natural radioisotopes in the tea slightly more distinguishable.

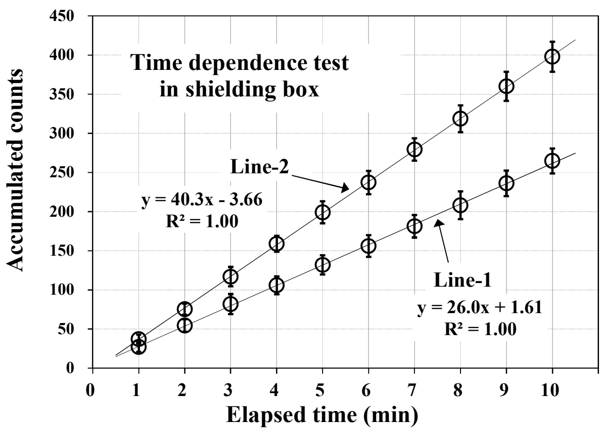

Figure 6: Results of time dependence test carried out in shielding box.

3.5.2 Randomness of radiation counts

It is well known that radiation counts are random and their frequency of occurrence follow a Gaussian distribution function. In the second trial, the solid tea disks were used to demonstrate this randomness. A disk was placed directly on the surface of the GM probe and fifty 1-minute counts were measured. The obtained result is shown as a frequency distribution in Fig. 7. The X- and Y-axes are the counting interval (8 counts) and frequency of occurrence of radiation counts, respectively. The circles represent the frequencies obtained from 1-minute counts within the respective counting intervals, and the solid bell-shaped line was derived using Eq. (1).

$$G(x) = \frac{1}{\sqrt{2\pi} \cdot \sigma} \exp\left(-\frac{(x-m)^2}{2\sigma^2} \right) \quad (1)$$

G(x): Gaussian distribution function
x: 1-minute count including background radiation (cpm),
m: average of fifty 1-minute counts (73.8 cpm), and
σ: standard deviation of fifty 1-minute counts (10.3 cpm).

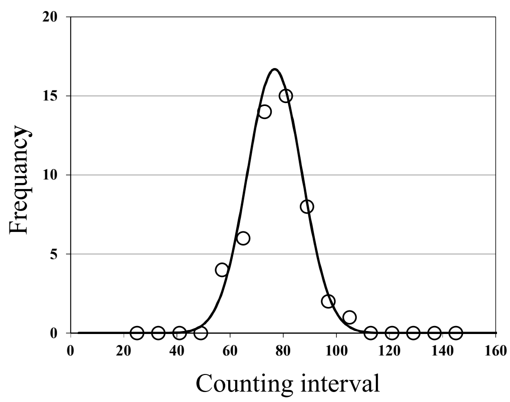

Figure 7: Histogram (frequency graph) and Gaussian curve determined from 1-minute radiation counts for solid tea disk.

In Eq. (1), the average (m) and standard deviation (σ) were calculated from the fifty 1-minute counts. All the circles plotted in Fig. 7 were around the solid bell-shaped line. This line is the Gaussian distribution curve. Consequently, it was concluded that the solid tea disks could be used as educational radiation sources to demonstrate that radiation counts statistically fluctuate and the frequency distribution can be represented by a Gaussian distribution curve.

4 SUMMARY AND CONCLUSION

In this study, five brands of black tea were investigated as potential sources of radiation to be used for educational purposes. A compression and formation method was applied and seven solid disks were fabricated for each brand. The obtained 35 solid disks were almost identical in weight, diameter, and thickness regardless of individual fabrications and brands. Then the solid disks were measured using a CsI gamma-ray spectrometer and were found to contain the natural ^{40}K radioisotope with a radioactivity of 50–60 Bq/100 g.

To evaluate the solid tea disks as educational radiation sources, three dependence tests of radiation counts on time, distance, and shielding were carried out using Geiger-Mueller (GM) survey meters. The radiation counts were found to be distinguishable from background radiations when the disk was directly placed on the surface of the GM probe. On the basis of these results, two trials utilizing the disk were conducted to determine the existence of natural radioisotopes and to investigate the randomness of radiation counts represented by a Gaussian distribution curve. The trials verified that solid tea disks could be used as radiation sources for educational purposes.

Since tea is a drink familiar to most, solid tea disks may be effective radiation sources for use in educational settings. These sources fabricated from black tea are not legally defined radioisotopes and are not governed by radiation laws because they are fabricated from commonly available tea leaves, so they may become widely used as an educational tool for studying radiation. In addition to black tea, green and oolong tea may also be feasible educational tools because they are manufactured from the same tea leaves but processed differently.

5 REFERENCES

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