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TECHNICAL MATERIAL

Experience-Based Radiation Education Using Chemical Fertilizer Radiation Sources

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Many materials contain naturally occurring radioisotopes such as ^{40}K, ^{232}Th, and ^{238}U and are often used to demonstrate natural radiation and the radioisotopes existing around us. One of those materials is chemical fertilizer, which contains naturally occurring potassium-40 radioisotopes. In the present study, chemical fertilizers containing potassium sulfates were used to fabricate radiation sources for educational use. The fabricated radiation sources were applied to experience-based radiation education courses held in the home for the first time. In the course, four radiation measurements were conducted. One measurement was performed to evaluate background radiation and the other three were performed to assess the dependence of radiation counts on time, distance, and shielding thickness. The courses were held three times, and three couples participated. As a result, it was confirmed that the experience-based radiation education course using the radiation sources fabricated from chemical fertilizer could be safely and easily practiced, and the chemical fertilizer radiation sources were very useful not only for finding out the existence of natural radiation and radioisotopes but also for understanding the characteristics of radiation, whose intensity depends on time, distance, and shielding (radiation protection principles).

KEYWORDS: ***chemical fertilizers, potassium-40, naturally occurring radioisotope, experience-based radiation course, radiation education in the home***

I. Introduction

There are various natural materials containing naturally occurring radioisotopes such as ^{40}K, ^{232}Th, and ^{238}U[1,2]. These materials are often used in work-study courses on radiation. Chemical fertilizer is one of the most well known of such materials, and it contains potassium-40 radioisotopes. A method for fabricating radiation sources with materials containing natural radioisotopes has recently been developed[3-6]. This method was applied to chemical fertilizers containing potassium sulfate to fabricate radiation sources for educational use[5,7]. Thus, fabricated radiation sources are referred to as chemical fertilizer radiation sources in this paper. The sources were not legal radioisotopes and not regulated by the radiation regulation laws[8] because they were simply pressed and formed from usual chemical fertilizers. Consequently, chemical fertilizer radiation sources can be used anywhere although legal radiation sources must be handled at radiation facilities in accordance with radiation regulation laws. In the present study, the chemical fertilizer radiation sources were applied to an experience-based radiation education in the home. This education is termed “radiation education in the home.”

For radiation education in the home, four measurements to evaluate background radiation and three to assess dependence on time, distance, and shielding effects were performed. Three couples (six participants) took this education. Through the education, they could clearly understand the existence of natural radiation and radioisotopes around us and understand that the intensity of radiation depends on time, distance, and shielding (radiation protection principles). It was concluded that chemical fertilizer radiation sources can be a useful teaching aid even for radiation education in the home and will make it possible to do experience-based radiation education not just in the home but also in classrooms, houses with children, and community halls.

II. General description

1. Chemical fertilizer

In the present study, chemical fertilizer containing potassium sulfate (Asahi Industries Co., Ltd.) was purchased to fabricate chemical fertilizer radiation sources. This chemical fertilizer is sold for use in the family garden. The amount of potassium was 50% according to the ingredient table on the package. To confirm this amount and the radioactivity of the potassium-40[9-11] it contained, chemical analysis with an atomic absorption/flame emission spectrometer (Shimadzu AA-6200) and nuclide analysis with a germanium semiconductor detector (ORTEC : GMX20-S) were carried out. The results showed that the weight percentage of potassium was 52% and that the radioactivity of ^{40}K was 14 Bq/g. The radioisotope ^{40}K

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emits beta particles with a maximum energy of 1.33 MeV (89%) and gamma-rays of 1.46 MeV (11%). The half-life of ^{40}K is 1.28×10^9 years.

2. Chemical fertilizer radiation sources

To fabricate chemical fertilizer radiation sources, 20 g of chemical fertilizer containing potassium sulfate were micronized with a triturator and then placed into a cylindrical stainless-steel formwork with an inner diameter of 35 mm and a height of 30 mm. A hydraulic hand pump (Osaka Jack Co. Ltd., Model: TW-0.7) was used to press the fertilizer powder in the formwork into a disk-shaped solid cake with a force of approximately 160 kN. The disk cake fabricated was a chemical fertilizer radiation source with a diameter of 35 mm. Thus fabricated radiation sources had radiation emitting strength about five times as large as background radiation as estimated from two 1-min integrated counts, 57.1 cpm and 295 cpm, as described in III. 1 and 2.

3. Setup of radiation measurement

The setup for measuring radiations emitted from the chemical fertilizer radiation sources is shown in a photo and illustration diagram in **Figure 1**, which shows a radiation source, a source stand, and a Geiger-Mueller (GM) survey meter (Aloka TGS-146). The GM survey meter consisted of a GM probe connected to a counting and display unit with a counting mode as well as rate meter mode. In the present measurements with the GM survey meter, the counting mode was selected. The chemical fertilizer radiation source was placed in a fixed position on the source stand. The GM probe was mounted on the meter unit in the opposite direction for convenience. The diameter of the GM probe was about 50 mm, sufficiently larger than the diameter of the chemical fertilizer radiation sources (35 mm).

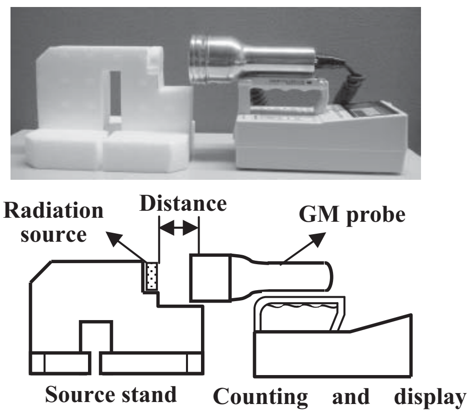

Fig. 1 Setup for radiation source and GM survey meter.

4. Participants in the radiation education

Radiation education in the home was held for three couples by using chemical fertilizer radiation sources in an ordinary house. The ages of the husbands and wives were respectively 32 and 22, 40 and 26, and 61 and 56 at the time of the education. Three wives and two husbands had no experience with radiation education at all. Only one husband, 61 years old, had the experience of handling legal radioisotopes and radiation. The six participants took the present radiation education in the home by using chemical fertilizer radiation sources.

III. Practicing radiation education in the home

Individual participants were provided with a GM survey meter, a chemical fertilizer radiation source, and a data sheet at the beginning of the education. The GM survey meter was used as an integrating radiation counter (counting mode). The education involved four radiation measurements to evaluate the strength of background radiation and to find that the intensity of radiation depends on time, distance, and shielding.

1. Evaluating background radiation

The first measurement was conducted to evaluate the strength of background (BKG) radiation and to accustom the participants to using the GM survey meter. The total amount of BKG radiation was counted for counting intervals of 1, 2, 3, 4, and 5 min without the radiation source.

The results are summarized in **Table 1**, in which the values of average and relative standard deviation (RSD) were derived for the respective counting intervals by using the count data measured by the six participants. The values listed under the heading of "cpm" are the average count rates of 1-min integrated BKG radiation and its RSD derived on the basis of the 5-min BKG counts detected. These results show that the BKG counts scattered among individual participants, and the extent of data scattering decreased from 14.2 to 7.2% RSD as the counting intervals increased from 1 to 5 min. The results mean that their BKG data for each counting interval were consistent with each other within 15% RSD, and the BKG level was concluded to be 57.1 ± 7.2 cpm as a whole. The results in Table 1 were derived using all data measured by the six participants, while the participants did not know one another's data during the education. Consequently, in the next and subsequent measurements, the participants used their own measured BKG data instead of the data shown in Table 1 when they calculated the net counts of radiation. Through the first measurement, participants could learn basic skills for using the GM survey meter and directly get a sense of the existence of natural radiation and radioisotopes.

Table 1 Estimation of background radiation counts for the GM survey meter.

Counting interval(min)	1	2	3	4	5	cpm
BKG (counts)	59.8	117.3	175.3	230.8	285.7	57.1
RSD.(%)	14.2	12.9	12.5	10.0	7.2	7.2

RSD: Relative standard deviation

2. Linearity with time

In the second measurement, the chemical fertilizer radiation source was placed on the fixed position of the source stand in Fig. 1. The position of the GM survey meter was adjusted so that the chemical fertilizer radiation source was directly attached to the center of the surface of the GM probe. Then, the integrated counts of the radiation sources were measured every minute with the GM survey meter from the start up to the end of the 5-min period. The radiation counts measured were the sum of both counts due to natural radiation and the radiation emitted from the chemical fertilizer radiation sources. Consequently, integrated net counts due to only the chemical fertilizer radiation source were derived by subtracting the background counts measured in the previous BKG measurement from the counts measured in this measurement.

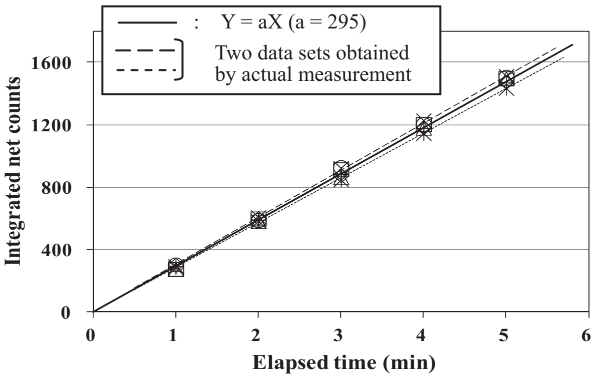

Fig. 2 Dependence of radiation counts on elapsed time.

The results obtained by all six participants are plotted using six different signs in **Figure 2**. The horizontal and vertical axes correspond to the elapsed time and integrated net counts, respectively. The elapsed time corresponds to the cumulative counting time. This graph shows that the integrated count increased linearly with counting interval and that the data obtained somewhat varied among individual participants. The extent of scattering was smaller than 10% RSD.

Three lines are drawn in **Figure 2**. The solid line from the origin represents a linear function $Y = aX$ $(a = 295)$ for reference, and two dashed lines represent the data obtained by arbitrary chosen two participants. This shows that participants could draw accurate linear lines similar to the solid line by themselves although both of the dashed lines do not exactly coincide with each other. This result indicates that all the participants' data scattered somewhat, but yet they possibly understood the linearity between integrated counts of radiation and counting intervals by examining only their own data.

3. Distance dependence

The third measurement was done to enable the participants to understand that the dependence of radiation count on distance could be explained by the inverse-square law. The chemical fertilizer radiation source was placed again at a fixed position on the source stand in **Figure 1**, and the GM survey meter was moved to locations at various distances (0 to 30 cm) from the chemical fertilizer radiation source, and the 1-min integrated counts (counting interval: 1min) were measured at the respective locations. Then, the 1-min integrated net counts were obtained by subtracting the background count (cpm) from the 1-min integrated counts measured in the same way as the previous background measurement.

The results are plotted in **Figure 3**, where the horizontal and vertical axes show respectively the distances and 1-min integrated net counts. Six signs are used to represent data measured by the six participants and vary depending on the participant. The extent of scattering was about 15% or less in the relative standard deviation for distances shorter than 3 cm. This increased for longer distances. On the whole, the 1-min integrated net counts decreased more steeply as the distance increased when the source was located closer to the detector. This initial steep decrease was followed by a slow decrease with distance.

Three curves are also drawn in **Figure 3**. The solid curve represents an inverse square function $Y = A/(a+X)^2$ (A = 3000, a = 3) as a reference for approximation. Here, X and Y correspond to the distance and the 1-min integrated net counts, respectively. The physical meaning of constant "a" is the effective depth from the detector surface to the point where radiation is detected. The 1-min integrated net counts obtained by the six participants are around the curve of the inverse square function. Two dashed curves are drawn by connecting and smoothing the data obtained by arbitrary chosen two participants. The two curves show that participants could draw curves similar to the solid curve by connecting their own data.

Consequently, both curves are semi-quantitatively explained by the inverse-square law. With the results, individual participants could understand that the intensity of radiation decreased according to the inverse-square law on the basis of their own data.

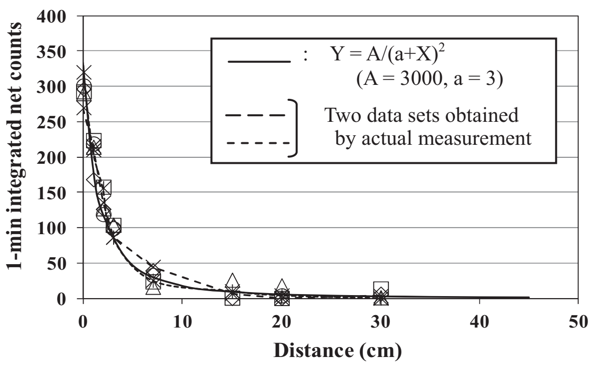

Fig. 3 Dependence of radiation count rates on distance.

4. Shielding thickness dependence

In the fourth measurement, the GM probe was placed at a fixed distance of 15 mm from the radiation source in **Figure 1**. Then, shielding materials were inserted into the space between the probe and the source, and the 1-min integrated counts were measured with the GM survey meter. A Kent paper (thickness: 0.25 mm and mass density: 0.93 g/cm^3) was used as a shielding material. Various thicknesses from 0 to 8 mm were achieved by folding proper numbers of paper. The 1-min integrated counts were measured at all thicknesses. Similar to the previous measurements, the 1-min integrated net counts were obtained by subtracting the background counts from the 1-min integrated counts measured. The results are plotted in **Figure 4**, where the horizontal and vertical axes of the graphs show the thickness of the paper and the 1-min integrated net counts.

The data obtained by the six participants are plotted using six different signs again. The extent of scattering was about 25% or less in the relative standard deviation for shielding thinner than 4 mm, and this increased as thickness became thicker. The graph reveals that the 1-min integrated net counts decreased rapidly as the thickness of the shielding paper increased within a small range of 4 cm and decreased weakly after that.

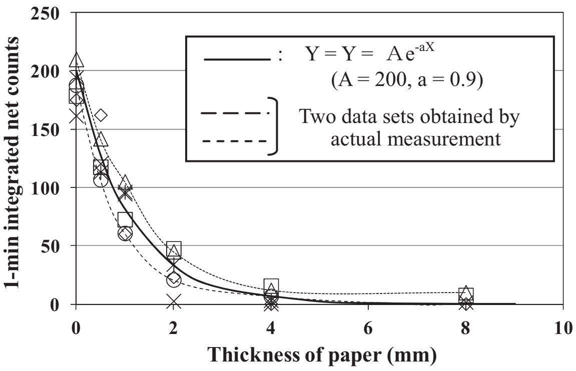

Fig. 4 Dependence of radiation count rates on shielding thickness.

Three curves are drawn in **Figure 4**. The solid curve represents an exponential function $Y = Ae^{-aX}$ as a reference for approximation. Here, X and Y are, respectively, the thickness and the 1-min integrated net counts of radiation. The values of "A" and "a" are 200 (cpm) and 0.9. All 1-min integrated net counts lie along the exponential curve. In the same way as that in Fig. 3, two dashed curves are drawn by connecting and smoothing respective data obtained by arbitrary chosen two participants. This shows that all the participants could draw curves similar to the solid exponential curve by using their own data. These curves can explain semi-quantitatively that the intensity of radiation decreased along the exponential curve of shielding thickness.

IV. Summary

Radiation sources were fabricated for educational use by using formation and compression methods with commercially available chemical fertilizers that anyone can purchase. The fabricated radiation sources were applied to an experience–based radiation education in the home for the first time. Three couples (six participants) took the radiation education in the home, which included four measurements to evaluate background radiation and the dependences of radiation intensity on time, distance, and shielding thickness. Measurement of radiation was carried out with a GM survey meter (counting mode). The participants could safely and easily perform the radiation measurements and clearly understood existence of natural radiation and radioisotopes around us. Although data obtained varied somewhat depending on the participants, they could understand the characteristics of radiation on the basis of their own measured data. The characteristics were the linearity between the radiation count and the counting interval, the inverse-square law between radiation intensity and distance, and the exponential relationship between the effectiveness of radiation shielding and its thickness.

It was concluded that chemical fertilizer radiation sources could be fabricated from conventional chemical fertilizers that anyone could easily purchase and are convenient educational tools for the teaching of radiation. By using chemical fertilizer radiation sources, radiation education in the home could be conducted without need to worry about radiation related laws, and this experience-based radiation education can be conducted at all common places not only in the home but also in school classrooms, houses with children, and community halls where legal radiation sources cannot be handled. This made it possible for us to enjoy radiation measurement together with participants.

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