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Report

# Estimation of Radiation Field Produced by a Coin-shaped Naturally Radioactive Source and Its Application to School Education

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Naturally radioactive sources were developed using three easily available and familiar substances: potassium chloride, instant coffee, and kelp. The radiation fields that they generated were actual measurements using various instruments to adapt the sources to school radiation education. It was quantitatively found that the potassium chloride source can be used for qualitative experiments on β-rays. The latest national Courses of Study published by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) have been applied since 2020. By the results of our measurements with the Courses of Study, an example of experimental training using naturally radioactive sources: "Absorption training Experiment of β-rays Using Shielding Materials" was developed. We believe that the widespread application of naturally radioactive sources made of familiar materials will make it easier for schoolteachers to carry out radiation experiments in their classes and contribute to establishing the public's literacy on radiation.

*Key words*: radiation education, naturally radioactive source, National Courses of Study, Naturally occurring radioactive materials (NORM)

## 1. Introduction

Radiation is relevant to many fields, including energy, medicine, and industry, and is of interest from a variety of perspectives, not only as a target for active use but also as a potential source of risk. The Japanese Ministry of Education, National Culture, Sports, Science, and Technology (MEXT) was preparing to strengthen radiation education based on the National Courses of Study, which was enforced in 2012, and to provide educational guidelines from kindergarten to high school. At that time, radiation-related topics were mostly covered in science, but in response to the situation after the Fukushima Daiichi Nuclear Power Plant accident in 2011, the policy was changed to cover radiation not only from the scientific perspective but also from the disaster prevention and morality ones. The status of radiation education in schools is revealed in a survey conducted by MEXT covering elementary schools and junior high schools, high schools, and special-needs schools throughout Japan (2019-2020)[1].

There is no doubt that experiments in education generally play a major role in effective learning and deep understanding. The general theory should also be applied to radiation education. However, one of the reported problems relating to radiation experiments in schools

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is that they require a radioactive source[2]. For school teachers who do not have access to radiation facilities, it may not be practical to obtain so-called artificial radiation sources. Even for low-activity sources, which are exempt from the law, the law does not require the control of the total quantity of sources in the establishment, detailed records of storage, use, disposal, and training for users, but some source distributors require these actions, thereby making their use in schools more difficult in Japan[3]. In addition, it is hard to get many of them from the market. As an example of the solution to this problem, the authors considered developing a radiation source made from various materials found around us. Specifically, dried kelp and potassium chloride were powdered and compressed in a doughnut-shaped mold for science experiments[4]. The materials are readily available and can be produced stably without chemical manipulation to increase radioactivity and minimize shape quality[5-9]. In addition, the use of familiar materials makes it possible to use the product regardless of people and places, thereby overcoming the major problems mentioned above. In this study, the fields created by several naturally radioactive sources developed by the authors were evaluated by actual measurements using various measuring instruments; and the possibility of their application to radiation education at school sites was examined. The target audience for this research was junior high school and high school students. By combining these results with the latest Japanese Courses of Study, which will be applied from the 2020-2022 school year, and by proposing specific experimental practices using naturally radioactive sources, we aim to expand the possibilities of implementing radiation education, especially experimental practices, in schools and other educational institutions. From a global perspective, Japan has a good education system, and the same can be said about radiation education. Therefore, we can demonstrate the usefulness of this source by showing the possibility to construct experiments that satisfy this curriculum guideline and provide a high level of radiation education.

## 2. Examination of radiation fields produced by naturally radioactive sources

### *2.1. Nuclides contained in naturally radioactive sources and counting rate*

The materials for sources selected in this study are (a) potassium chloride (purity 99.5% or higher) (YONEYAMA KAGAKU KOGYO KAISHA, LTD.), (b) instant coffee (Ajinomoto AGF, Inc.), and (c) dried kelp (Kitamae Bussan). Other candidates include radon daughter nuclides in air, which are α-emitting nuclides with relatively short half-lives. However, it is difficult to apply our source fabrication method detailed in this study to air as a medium, and we are investigating the possibility of using them in radiation education in a different system.

**Table 1.** Radionuclide and counting rate of each material

| Material | Radionuclide | Counting rate [cpm/g] |
|---|---|---|
| Instant coffee | | 0.048 |
| Kelp | K-40 | 0.088 |
| Potassium chloride | | 0.66 |

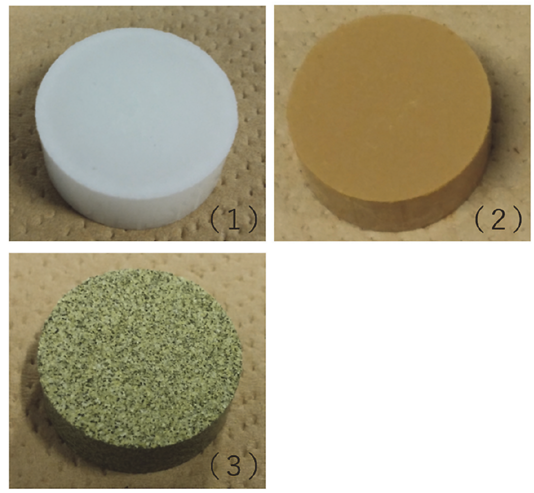


**Fig. 1.** Naturally radioactive sources
(1) Potassium chloride, (2) Instant coffee, (3) Dryed kelp
(Diameter 30 mm, thickness 10 mm)

To identify the nuclides and calculate the specific counting rate per minute, each material was powdered and sealed in a U8 type container of 5 cm in height. The γ-ray energy distribution was measured by a pulse height analyzer calibrated at 0.5 keV/ch using a Ge semiconductor detector (CANBERRA GC2017). The weights of potassium chloride, instant coffee, and dried kelp samples were 107.62 g, 60.43 g, and 85.20 g, respectively. The corresponding measurement times were 21600, 518400, 345600 seconds to obtain 10,000 counts as a peak channel. The measurements were performed following "Gamma-ray Spectrometry using Germanium Detector (5th edition)", the series of environmental radioactivity measuring methods published by Nuclear Regulation Authority in Japan[10]. The obtained results are shown in Table 1. A strong peak of $^{40}K$ was observed at 1461 keV for potassium chloride, instant coffee, and dryed kelp. Each counting rate per 1 g was 0.66 cpm/g, 0.048 cpm/g, and 0.088 cpm/g in that order, and their standard uncertainties were also about 2.5%[10]. Uranium and thorium series nuclides were below the background and not detected. The isotopic abundance ratio of $^{40}K$ in nature is estimated to be about 0.0117%[11], and it is obvious that potassium chloride chemicals commonly found in school science laboratories are good source candidates. It is generally known that kelp contains large amounts of potassium as a mineral and dried and concentrated coffee beans also have a higher potassium concentration.

*2.2. Investigation of radiation field by actual measurement*

The selected naturally radioactive sources are shown in Figure 1. They are fabricated as 1 cm thick flat cylinders of 3 cm diameter and weigh approximately 15 g. For instant coffee and dryed kelp, if there is no hygiene problem, by crushing the source and tasting the coffee after the experiment, or by using the kelp for cooking, we can emphasize the fact that familiar materials emit radiation. We do not expect the dose to be sufficient enough for quantitative consideration as a radiation source. Educational tools which expose students to the fact that radiation exists in nature are important, and we do not completely rule out the use of these sources in the school setting. In this study, the emphasis is on experimentally reproducing and quantitatively discussing radiation-specific phenomena such as the inverse square law of distance and transmission. Therefore, the representative material is potassium chloride, which has the highest counting rate, as a source containing $^{40}K$.

The changes in radiation flux at different distances were evaluated by actual measurements. An end-window GM survey meter (HITACHI TGS-1146) and a 5 mm thick aluminum plate were used for $\gamma$-rays and an end-window GM survey meter for $\beta$-rays. Assuming a realistic measurement time for the practical training, the average value was calculated by setting the measurement time to 1 minute and the number of measurements to 3 times per data set.

This source emits $\beta$-rays of 1.312 MeV (max) from $^{40}K$. In the case of $\beta$-rays, significant counts about six times higher than the background were shown. Distance dependence on the counting rate of the $\gamma$-ray could not be shown in practice due to the competition with background radiation. Emphasizing and recognizing this difference between $\beta$ and $\gamma$ rays can also lead to understanding the competition between background radiation and net radiation from the source, i.e., the lower detection limit in radiation measurements, and the difference in detection efficiency between $\beta$ and $\gamma$ rays with the GM survey meter.

## 3. Effective use of naturally radioactive sources following positioning of "radiation" in school education of Japan

In Japan, school curriculum is based on the Courses of Study, and classes are also taught according to it. Therefore, it is necessary to use this radioactive source in the school setting based on this curriculum, so we organize the treatment of radiation in the Courses of Study and show that a wide range of experiments can be conducted according to the student's level of proficiency.

*3.1. Environment surrounding radiation as an educational theme*

It is well known that educators in elementary, junior high, and high schools may not have received any radiation education as students themselves. Therefore, they do not have sufficient knowledge about radiation or sufficient confidence in their teaching due to the generally sensitive social context of radiation[12]. Under these circumstances, even if education only using textbooks based on the Courses of Study by MEXT is implemented at schools, it is concerning that the content of the textbooks will not be sufficiently retained, as they only provide superficial knowledge and information. This paper proposes the use of naturally radioactive sources as an educational tool to overcome this problem. Our goal is to ensure that both students and educators acquire radiation knowledge appropriate to their level of proficiency and purpose in the process of using this tool in the field. Specifically, the authors intend to clarify the relationship between the various radiation phenomena observed in experiments with sources and the descriptions in the Courses of Study and to make appropriate and effective use of them in schools.

Various studies have been conducted on radiation education in the Courses of Study. Most of them have focused on science, especially physics, chemistry, or social studies[13-15], and comparisons have been made between the old and the new Courses of Study. The descriptions of radiation in the new Courses of Study are not limited to physics, chemistry, and social studies, but can also be found in earth science, health and physical education, and home economics. It should be noted that radiation-related topics are now positioned as a comprehensive educational subject, including disaster prevention and morality, in the current trend toward cross-subject education.

*3.2. Three pillars of the Courses of Study*

The Courses of Study were revised around three pillars related to student qualities and abilities[16, 17]. These three pillars are: first, knowledge and skills to live and work in society and daily life; second, the ability to think, judge, and express to cope with unknown situations; and third, the ability to apply what one has learned to life and society. All subjects emphasize the importance of balancing knowledge acquisition, application, and exploration to develop abilities and qualities that address contemporary issues. In radiation education, it is important to confirm basic phenomena through classroom learning and experiments; to "acquire" knowledge and understand the relationship between familiar technology and radiation; to "utilize" it and experience how the technology can be used in society; and to "explore" it. In other words, the combination of authorized textbooks based on the Courses of Study, the training of teachers on their use, and practical tools such as experiments with naturally radioactive sources as described herein will facilitate a smooth flow and maintain a stable balance between study and practice.

For example, in science and mathematics education, students are required not only to acquire knowledge through classroom lectures, but also to collect data and analyze them by themselves using statistics, to draw graphs by making full use of computers to develop the ability to utilize information, to actively collect information to solve problems and to present to others, and so on. Active learning approaches, such as the use of a computer, or a computer program that uses a computer as a learning tool, are introduced. In addition, the perspective of disaster prevention and safety education was also emphasized in the science curriculum, for example, by enhancing content related to natural disasters. The authors believe that the stakeholders in radiation education should be constantly aware of this kind of trend in school education, which is the core foundation of national literacy. Devising and providing tools and modules that fit the current trends in the educational field will be a steady path to achieving our goals.

### *3.3 Radiation education content by grade level*

The following content is a summary of the experimental practices related to each grade and subject based on the learning items in each subject[18]. We particularly focus on junior high and high school students. In junior high school, there are descriptions of radiation in science, health and physical education, industrial arts, and home economics. In science, radiation is treated from the aspect of science. Health and physical education, industrial arts and home economics deal with radiation in terms of health and hygiene. In high school, there are descriptions of radiation in Basic Chemistry, Basic Physics, Physics, Geology, Home Economics, and Health and Physical Education. The main focus of Basic Chemistry, Basic Physics, and Physics is on the scientific characteristics of radiation and radionuclides themselves. For example, the properties and half-lives of γ-rays and other types of radiation, and the decay of atomic nuclei exist. Geology focuses on age determination while home economics and health and physical education focus on the uses of radiation such as food storage and radiation therapy as well as the risks to life and health. However, the study is always treated as scientific knowledge and principles and its utilization across various subjects. We have the impression that the explanations of each subject should not stop at the knowledge of radiation, but focus on the use of the knowledge and the measures to solve problems. Scientific experiments are important for acquiring knowledge, but the experimental design should be carefully planned so that the content includes the existence of radiation around us.

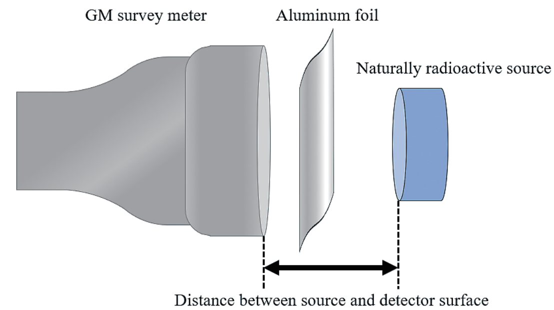


**Fig. 2.** Schematic View of Experiment Proposed for Radiation Education

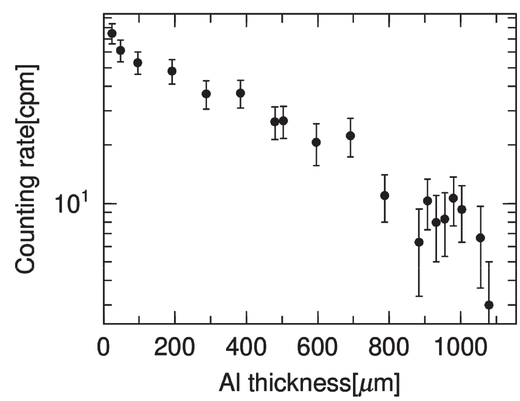


**Fig. 3.** Relationship between Al Thickness and Counting Rate

In this section, we present a β-ray absorption experiment using a shielding material as an example. The experiment plan and discussion points are presented with the descriptions in the Courses of Study, assuming application in junior high and high schools. First, the equipment used and the experimental procedure are shown. These items are common to both middle and high school courses. Figure 2 shows a schematic view of the experiment.

Equipment

- A naturally radioactive source (potassium chloride)
- End-window type GM survey meter or educational instrument for detecting β and γ -rays (GM survey meter is used this time)
- Aluminum foil (12 μm thick)

Experimental Procedure

(1) Turn on the end-window type GM survey meter.
(2) Set the time constant to 30 seconds.
(3) Without placing the source, wait for about 1.5 minutes and measure the background counting rate after it stabilizes.
(4) Place the source and detector such that the distance between the source and the detector surface is 0 cm and then count without aluminum foil.

**Table 2.** Original Data of β-ray Absorption Experiment by Shielding

| Number of aluminum foil | Al thickness[μm] | Net counting rate [cpm] Number of measurements 1 | 2 | 3 | Average | Std.error |
|---|---|---|---|---|---|---|
| 2 | 24 | 69 | 70 | 86 | 75 | 9 |
| 4 | 48 | 64 | 73 | 47 | 61 | 8 |
| 8 | 96 | 55 | 61 | 43 | 53 | 7 |
| 16 | 192 | 49 | 47 | 48 | 48 | 7 |
| 24 | 288 | 36 | 32 | 42 | 37 | 6 |
| 32 | 384 | 39 | 33 | 39 | 37 | 6 |
| 40 | 480 | 19 | 26 | 34 | 26 | 5 |
| 42 | 504 | 26 | 21 | 33 | 27 | 5 |
| 48 | 596 | 16 | 29 | 17 | 21 | 5 |
| 56 | 692 | 32 | 12 | 23 | 22 | 5 |
| 64 | 788 | 17 | 2 | 14 | 11 | 3 |
| 72 | 884 | 12 | 5 | 2 | 6 | 3 |
| 74 | 908 | 6 | 7 | 18 | 10 | 3 |
| 76 | 932 | 10 | 10 | 4 | 8 | 3 |
| 78 | 956 | 13 | 8 | 4 | 8 | 3 |
| 80 | 980 | 8 | 10 | 14 | 11 | 3 |
| 82 | 1004 | 12 | 7 | 9 | 9 | 3 |
| 88 | 1056 | 10 | 4 | 6 | 7 | 3 |
| 90 | 1080 | 6 | 3 | 0 | 3 | 2 |
| Background [cpm] | | 24 | | | | |

(5) Place a piece of aluminum foil between the naturally radioactive source and the measuring plane and count.
(6) Stack several aluminum foils.
(7) Place the stacked aluminum foil between the source and the measuring plane and count.
(8) Repeat steps (6) and (7) for varying distances between source and detector surface

Naturally radioactive sources are less radioactive than artificial sources. Therefore, the time constant was set as long as 30 seconds to minimize the fluctuation of the value and to read the counting rate accurately.

In junior high school, there are units on distance attenuation and naturally occurring radiation and radioactive materials in second and third-grade science; and on food safety and health in industrial arts, home economics, and health and physical education. The Understanding to the principles of radiation and the physical phenomena produced by fields around the source is not necessarily required. Since it is sufficient to recognize the fact that the counting rate decreases as the thickness of the shielding increases, it is not necessary to take detailed measurement points, and about 10 measurement points should be sufficient. In the discussion, the students are made aware that the counting rate decreases as the thickness of the aluminum foil increase, in other words, the phenomenon of shielding in addition to radiation transparency. For this purpose, the students are asked to pay attention to the shape of the graph and note that it is a rightward sloping graph. Using the resulting graph to measure thin aluminum sheets of unknown thickness also contributes to the study of the principles of thickness gauge. The process of recording data is also effective for learning basic experimental data handling through the calculation of uncertainty and averages of radiation measurements and graphing of data.

The content of study in high school is more scientifically and technologically advanced. In physics, for example, one can relate radiation shielding to the interaction of nuclei with the matter, understand the shape of the decay curve, and read its principle. Here, the measurements were taken every 48 μm, which is equivalent to four aluminum foils, after a thickness of several hundred μm, where the effects of bremsstrahlung begin to be seen under this experimental system; and every 96 μm, equivalent to eight aluminum foils, in the other parts of the specimen. Figure 3 and Table 2 show an example of the relationship between the thickness of the aluminum foil and the net counting rate excluding the effect of background counting, as well as the original data. According to this experimental situation, the counting rate decreases almost linearly up until 700 μm, but after 700 μm, it gathers around 9 cpm and does not reach 0 cpm. This is due to the counting of bremsstrahlung from β-rays. Students can calculate the coordinates of the intersection with the x-axis from the slope of the measurement points in the range where the effect of bremsstrahlung is small and can estimate the range of the β-rays. Radionuclides in naturally radioactive sources and their β-ray energies can also be examined, and the information can be used to determine the maximum range within the shielding body. Thus, by appropriately combining classroom lectures using textbooks based on the Courses of Study and experiments such as those proposed in this paper, radiation education of high quality and depth can be developed. Even if the same sources and tools are used, it should be possible to construct an educational module that matches the proficiency level of the students and the purpose of education by devising the experimental procedures and the content of the discussion.

The detailed relationship between the lineup of school experiments organized by proficiency level and the descriptions in the Courses of Study, including the example using these sources presented in this paper, will be published in a separate report shortly.

## 4. Conclusion

Naturally radioactive sources were developed using potassium chloride, instant coffee, and dried kelp. Their characteristics as radiation sources are presented. The materials contained mainly $^{40}K$, but it was quantitatively clear that potassium chloride sources could be used for β -ray experiments.

If naturally radioactive sources made from familiar materials become more widely available, radiation experiments in schools will become easier to conduct, which will contribute to the expansion of radiation education. The results also suggest that the use of this source can provide a high level of radiation education and that it is possible to teach about β radiation in a way that satisfies the Courses of Study in Japan.

In the future, we would like to enhance educational programs, worksheets, and manuals so that school teachers can easily understand and conduct the experiments. We hope that these naturally radioactive sources and their application will increase the number of teachers and students who are interested in radiation.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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