Training Given in Radiation Measurements Using Radiation Sources Fabricated from Potassium Chloride Chemicals

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Radiation sources were fabricated from potassium chloride chemicals that contained naturally occurring potassium-40 radioisotopes, and applied to training new workers in laboratory measurements in courses on protection against exposure to radiation at the National Institute for Fusion Science. The training involved four measurements of radiation, that to evaluate background radiation and three to assess the dependence on time, distance, and shielding effects. The counts of radiation emitted by the potassium chloride radiation sources were measured with a Geiger-Muller (GM) survey meter. Although data obtained in the training varied somewhat depending on the students, they could evaluate the level of natural radiation and understand the principles of protection against exposure to radiation. It was concluded that radiation sources fabricated from potassium chloride chemicals are convenient educational tools for illustrating naturally existing radiation and radioisotopes, and they enabled better comprehension of the principles of protection against exposure to radiation.

Key words: potassium chloride, K-40 natural radioisotope, educational radiation source, training in laboratory measurements

1. Introduction

Various radioisotopes such as ^{40}K , ^{232}Th , and ^{238}U occur naturally in various materials^{1,2)}. These are natural materials containing radioisotopes and are often used in vocational-study courses on radiation because easily comprehensible specimens contain natural radioisotopes^{3–7)}. Potassium chloride⁸⁾ is one of the most well known of these materials, which contains potassium-40 radioisotopes^{9,10)} in small quantities. A method of fabricating radiation sources with materials containing natural radioisotopes has recently been developed called compression and formation method^{11–15)}. This method was applied to commercially available potassium chloride chemicals to fabricate radiation sources for educational use. The fabricated sources were actually used in training students in a course on laboratory measurements for protection against exposure to radiation aimed at enabling a better understanding of natural radiation and radioisotopes, and the principles underlying protection against radiation at the National Institute for Fusion Science. The training in laboratory measurements consisted of four measurements,

i.e., evaluation of background radiation, dependence on time, dependence on distance, and dependence on shielding effects. To investigate the educational effect of training in laboratory measurements using radiation sources fabricated from potassium chloride, data were obtained by 25 students and their free descriptions in measurement reports were examined.

2. General description of training in laboratory measurements

2.1 Radiation sources

2.1.1. Potassium and potassium chloride

The potassium chloride chemicals used were in the form of white powder. As the potassium in the chemicals reacts strongly with water and generates hydrogen gas, it requires careful treatment. Nevertheless, potassium chloride is very stable and safe when handled. It was employed as the raw material to fabricate the educational radiation sources for this reason. Potassium chloride obviously contains potassium. Naturally occurring potassium exists as three isotopes of ^{39}K , ^{40}K , and ^{41}K and their

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abundance ratios correspond to 93.258%, 0.0117%, and 6.730%. The ^{40}K of three isotopes emits beta particles with a maximum energy of 1.33 MeV as a result of beta decay (89%) and gamma radiation at 1.46 MeV due to electron capture (11%). The half-life of ^{40}K is 1.28×10^9 years, which means that its change in radioactivity over time is negligible over a human lifetime. Thus, radiation sources using potassium chloride could be used indefinitely. Commercially available potassium chloride chemicals (Yoneyama Yakuhinn Kogyo Co., Ltd., Special Grade) were purchased for the present study and used as the raw materials to fabricate the educational radiation sources.

2.1.2 Fabrication of potassium chloride radiation sources

To fabricate a radiation source, 20 g of potassium chloride was weighed with a direct-reading balance (Sartorius, Model: BP121S), micronized with a triturator, and placed into a cylindrical stainless-steel formwork with an inner diameter of 35 mm and a height of 30 mm. It was then compressed with a force of approximately 160 kN with a hydraulic hand pump (Osaka Jack Co. Ltd., TW-0.7) and a jack (Osaka Jack Co. Ltd., NT20S12.5) into a disk-shaped solid cake. This was an educational radiation source with a diameter of 35 mm, equal to the inner diameter of the cylindrical stainless formwork. The radiation source that was thus fabricated from potassium chloride chemicals was termed a source.

By consistently repeating this method, twenty sources were fabricated and their radioactivity was assessed through count rates. The count rates were obtained by 30-min integration in which a source was appressed to the center of the head surface of the probe of a Geiger–Mueller (GM) survey meter (Aloka, TGS-146). This measurement setup was the same as that in Fig. 1 (A), which will be explained in detail later. The average count rate obtained was 438.2 cpm with a relative standard deviations

(RSD) of approximately 0.94%. The sources fabricated had almost the same amounts of radioactivity. However, the average background count rate based on measurements by 25 students was 47.2 cpm with an RSD of 6.8%. The students used one of these sources in their training.

2.2 Overview of training in laboratory measurements

2.2.1 Training in laboratory measurements

Individual students were given a GM survey meter, a source, and a data sheet for their training in laboratory measurements. The GM survey meter was composed of a probe attached to a body (Fig.1). The diameter of the probe was about 50 mm, which was significantly larger than the diameter of the sources (35 mm). The GM survey meter was used as a counter for radiation integration throughout the training. The training in laboratory measurements involved four measurements to evaluate background radiation, dependence on time, dependence on distance, and dependence on shielding effects. Students recognized naturally existing radiation in their measurements to evaluate the background. The last three measurements of dependencies enabled students to better comprehend the principles underlying protection against exposure to radiation based on time, distance, and shielding. Students also recognized naturally occurring radioisotopes through measurements because they used sources fabricated from commercially available potassium chloride chemicals that could easily be purchased as common chemicals, and not radioisotopes.

2.2.2 Data sheets

The data sheets in Fig. 2 were prepared to tabulate the measured radiation counts and draw graphs. The left side of the data sheet contains four tables that were used to write down radiation counts that students measured. The column “Discussion and

Fig. 1 Setup for radiation sources and GM survey meters for training in laboratory measurements.

Measurement data sheet

Date	Year: 2010	Month:	day:
Affiliation			
Name			

(1) Evaluation of background radiation

Elapsed time (minute)	1	2	3	4	5	Count rate (cpm)
Counts						

(2) Dependence on time

Elapsed time (minute)	1	2	3	4	5	Counts
Counts						
Net counts						

(3) Dependence on distance (Inverse-square law)

Distance (cm)	count/m	Net counts (cpm)
0		
1		
2		
3		
7		
15		
20		
30		

(4) Dependence on Shielding effects
(Kent paper, $^{233}\text{g}/\text{m}^2$, 0.25mm, Distance : 15mm)

Number of Paper	Thickness (mm)	count/m	Net counts (cpm)
0	0.0		
2	0.5		
4	1.0		
8	2.0		
16	4.0		
32	8.0		

(1) Background evaluation

(2) Time dependence

(3) Distance dependence (Inverse-square law)

(4) Shield effect

Discussion and Impression (write freely)

Summary

Name _____

(1、2) BKG-counts, Source counts, Net counts

(3) Inverse-square law

(4) Shielding effect

Fig. 2 Measurement data sheets prepared for training in laboratory measurements.

Impressions (write freely)” is at the bottom of the data sheet where students could describe any terms they wanted to write down. There are three blank graphs at the right of the sheet with scaled horizontal and vertical axes that could be used to plot the data they obtained, and the finished graphs were used to assess and discuss radiation and protection against exposure to it based on students’ own measured data. The laboratory measurements in the training could be done sequentially and smoothly by students filling in the blanks on the sheet with radiation counts they measured with their GM survey meter. The data sheet was a helpful aid to students in their training on laboratory measurements. Below are four brief explanations of these tables.

(1) Evaluation of background radiation

The table titled “Evaluation of background radiation” was used to record the counts of natural radiation measured in the background. These measurements were included in the training to evaluate the count levels of background radiation and the time

to integrate the radiation counts was set to 5 min. After measurements had started, the counts integrated from the start to the end of the 5-min period were read out at one minute intervals from the GM survey meter and written down in this table. The counts read out were the total amounts of background radiation detected by the GM survey meter for 1, 2, 3, 4, and up to 5 min. The count rate (cpm) in the rightmost column is the average count integrated for a minute (cpm), which was calculated by dividing the 5-min integrated counts by the elapsed time of 5 min.

(2) Dependence on time

The second table was used to measure the dependence on time and was aimed at making students understand that the integrated radiation count was linearly proportional to the integration time, which was the period from the start to the end of measurements. There are schematics and photographs of the measurement setup in Fig. 1(A). The measurement setup con-

tained a source, a source stand, and the body of the GM survey meter. The source was used by placing it on the source stand. The GM probe was placed on the body of the GM survey meter in the opposite direction for convenience. The GM survey meter was also positioned so that the source was directly attached at the center of the surface of the GM probe as seen in Fig. 1 (A). The time to integrate the radiation counts was 5 min, and these were read out from the start up to the end of the 5-min period every minute and written down in the second table on the data sheet. The net counts in the table were derived by subtracting the background counts obtained from the background evaluation in (1) from the radiation counts obtained from these measurements.

(3) Dependence on distance (inverse-square law)

The third measurements were done to enable students to understand that the dependence of radiation count on distance could be explained by the inverse-square law. The integration time for radiation counts was changed from 5 to 1 min here and the GM survey meter was placed at locations with various distances, and the 1-min integration counts were measured for these locations. The measurement setup is presented in Fig. 1 (B), and the distance is defined as the inner dimension distance between both the inner surfaces of the probe and the source. The distance was adjusted from 0 to 30 cm, being zero when the source was placed directly on the surface of the GM probe. The 1-min integration counts of radiation were measured for all distances and the 1-min integration net counts were derived by subtracting the 1-min integration counts of background radiation from the 1-min integration counts obtained from these measurements. The 1-min integration counts of background radiation are those in the rightmost column of the first table in the data sheet.

(4) Dependence on shielding effects

As shown in Fig. 1 (C), the GM probe was placed at a fixed distance of 15 mm from the source. Shielding materials were inserted into the space between the probe and the source and the 1-min integration counts were measured with the GM survey meter. Kent paper (thickness: 0.25 mm and mass density: 0.93 g/cm^3) was used in these measurements as the shielding material. The paper was cut into 50×50 -mm sheets and given numbers of papers were stacked to produce shielding of five thicknesses (0.5, 1, 2, 4, and 8 mm). The integration net count per minute was also derived by subtracting the background count from that of the source, in the same way as in the previous measurements described in (3).

3. Results obtained by students in training on laboratory measurements

The courses on protection against exposure to radiation were held nine times and 25 new workers took them in the past year in laboratory measurements using sources. Some of these have been staff, researchers, and graduate students. They returned data sheets on which they had written down measurement data after the course. All the data in the present study reported by students were plotted on the same graphs to find whether they could obtain satisfactory results as was expected. The terms in the column "Discussion and Impressions (write freely)" were also checked to find what students had discussed with one another and were impressed about from their own data that they had obtained through training.

3.1 Measurements to evaluate background radiation

The measurements to evaluate background radiation were the first training given to students. The students obtained basic skills throughout measurements using the GM survey meter. The data obtained by the 25 students are plotted in Fig. 3, which contains a main graph (A) and the two small sub-graphs in (B) and (C) at the right of the main graph. The horizontal and vertical axes in these graphs are the elapsed time and integrated counts. The integrated counts are radiation counts detected with the GM survey meter for the elapsed time. The elapsed time corresponds to the integration time. The horizontal and vertical axes have only been titled on the main graph (A). Sub-graphs (B) and (C) have the same titles for their axes. The numerous open circles plotted in Fig. 3 (A) correspond to all data measured by all students, and the crosses are the average integrated counts based on all data circles at elapsed times of 1, 2, 3, 4, and 5 min. This means that the data that were obtained varied among individual students. The extent of scattering was about 10 percent in RSD. The average data prove that integrated counts increased linearly as time elapsed, i.e., integration time. An accurate line could be drawn as seen in Fig. 3 (A) by using average data. The line visually corroborates the linearity between elapsed time and integrated counts. However, the average values are not those that students could obtain in their training because they only knew their own data from actual measurements, and they did not know one another's data. Consequently, no student could derive the average integrated count. Therefore, they had to consider the relationship between the integration time and the integrated counts they obtained themselves data. Typical data obtained by two students are plotted in Figs. 3 (B) and (C), where the crosses

Fig. 3 Dependence of background radiation counts on elapsed time.
 (A) All data measured by all students,
 (B) Data, which are larger than the average values, measured by the first student, and
 (C) Data, which are smaller than the average values, measured by the second student.

represent the averages. Data in (B) obtained by the first student are much larger than the average values, and in (C), data obtained by the second student are smaller than the average values. In Fig. 3 (A), all the students' data are scattered somewhat widely around data marked with crosses. Despite this, Figs. 3 (B) and (C) indicate that it is possible to gain same understanding from only individual student data. This is because they can also draw accurate lines by themselves, and find the data are around the lines as seen in Figs. 3 (B) and (C), although the lines in sub-graphs (B) and (C) do not coincide with the line in (A). Students can directly feel the existence of natural radiation through these measurements and understand the linearity between integrated counts of background radiation and integration time from their own data.

3.2 Integration time and integrated counts

Students in the second measurements used the sources first. They started measurements after they had been given a brief explanation of the radiation emitted from the sources. The measurement set up is shown in Fig. 1 (A). The integration time was set to 5 min in these measurements. The students found that the measured counts contained the counts of background radiation in these measurements. The results obtained by the 25 students are plotted in Fig. 4, which has the same (A), (B), and (C) as those in Fig. 3. The horizontal and vertical axes are the elapsed time and integrated net counts. The elapsed time corresponds to

the integration time of radiation counts. The radiation counts measured with the GM survey meter are the sum of both counts due to natural radiation and radiation emitted from the source. Consequently, the integrated net counts in Fig. 4 were derived by subtracting the background counts measured in the previous section from the radiation counts measured while placing the source on the source stand. The open circles in Fig. 4 (A) are all the integrated net counts measured by all students and the crosses are the values averaged from 25 data circles at elapsed times of 1, 2, 3, 4, and 5 min. The integrated net counts vary depending on individual students and the extent of scattering is a few percent in the standard deviation. A linear plot could again be drawn using average data denoted by the crosses, which explains the linearity between the elapsed time and the integrated net counts. However, no average data could be obtained by students for the same reason as that given in the previous section. Therefore, they had to examine the relationship between the integrated net counts and the elapsed time by only using their own data. Figs. 4 (B) and (C) have representative results for two students obtained in the same way as those in Fig. 3. The data in (B) and (C) are larger and smaller than the average values. Figs. 4 (B) and (C) demonstrate that individual student data can provide the relationship between integrated net counts and the elapsed time in the same way as using average values. This is because they can draw linear plots by themselves and find that the data are around the lines in Figs. 4 (B) and (C). Figures 4 (B)

Fig. 4 Dependence of radiation net counts on elapsed time.
 (A) All data measured by all students,
 (B) Data, which are larger than the average values, measured by the first student, and
 (C) Data, which are smaller than the average values, measured by the second student.

Fig. 5 Dependence of 1-min radiation net counts on distance.
 (A) All data measured by all students,
 (B) Data, which are larger than the average values, measured by the first student, and
 (C) Data, which are smaller than the average values, measured by the second student.

and (C) indicate that individual students can understand the relationship by only using their own data.

3.3 Measurements of dependence on distance

The next measurements were done using the setup in Fig. 1 (B). The source was placed on a specific position on the source stand and the inside distance between the source and the GM

probe ranged from 0 to 30 cm. The integration time of radiation was set to 1-min and it was measured at these distances. The 1-min integrated net counts in Fig. 5 were obtained by subtracting the background count (cpm) obtained in 3.1 from the 1-min integrated counts measured at respective positions. The 1-minute integrated net counts were obtained at eight distances in the range from 0 to 30 cm.

The results are plotted in Fig. 5 (A), where the open circles indicate the 1-minute integrated net counts obtained by 25 students and the crosses are the values averaged from 25 data circles. The data obtained by students vary depending on individual students and the extent of scattering is about 10 percent or less in the relative standard deviation for distances shorter than 3 cm. This increases for longer distances because the radiation counts reduce and deviation increases. Examining all data including the average, the initial steep decrease in the 1-min integrated net counts was drastic as the distance from the source ranged closer. This steep decrease was followed by a slow decrease as the distance increased. These changes in distance could be explained according to the inverse-square law. A curve represented by function $Y = A/(a + X)^2$ has been plotted in Fig. 5 for reference, X and Y corresponding to the distance and the 1-min integrated net counts, and A and a being constants with values of 9×10^3 (cpm · cm²) and 5 (cm), respectively. The plotted data lie along the curve. These values were determined by fitting the curve to the data points by trial and error. The physical meaning of the constant “ a ” is the effective depth from the detector surface to the point where radiation is detected. The average values are semi-quantitatively explained by the inverse-square law, which is an important principle underlying protection against radiation. Representative results for two students are plotted in Figs. 5 (B) and (C). The data in (B) and (C) are larger and smaller than the average values. The small figures in (B) and

(C) indicate that data from individual students can demonstrate the relationship between the 1-min integrated net counts and the distances are the same as average values. Students can actually understand that the intensity of radiation decreases according to the inverse-square law by only using their own data.

3.4 Measurement of dependence on shielding thickness

The last measurements were done using shielding made of Kent paper that had various thicknesses. Various thicknesses from 0 to 8 mm were achieved by folding the paper a number of times. The measurement setup is shown in Fig. 1 (C). The source was placed at a specific position on the source stand and the GM probe was placed at a fixed location 15 mm from the surface of the source. The integration time of radiation was then set to 1-min and paper shielding with various thicknesses was inserted between the source and the GM probe. The 1-min integrated net 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 at all shielding thicknesses. The results are plotted in Fig. 6(A), where the open circles indicate the 1-min integrated net counts measured by 25 students and the crosses are the averages from 25 data circles. The data obtained by students varied among individuals and the extent of scattering was about 25 percent or less in the relative standard deviation for shielding thinner than 2 mm, and this increased as shielding be-

Fig. 6 Dependence of 1-min radiation counts on shielding thickness.

(A) All data measured by all students,

(B) Data, which are larger than the average values, measured by the first student, and

(C) Data, which are smaller than the average values, measured by the second student.

came thicker, because the 1-min integrated net counts decreased and fluctuations increased. There were various other reasons that caused larger deviations than those in the other measurements. The first was difficulty in placing the source exactly 15 mm from the surface of the GM probe. As the distance of 15 mm was very short, small differences in fixing the source position would create somewhat larger differences in the 1-min integrated net counts. One data set in Fig. 6 (A) deviates a great deal more from the average and the other data. The larger deviation may be because students with deviating data might have pressed the source and shielding papers against each other. If this occurred, the distance between the source and the GM probe would always have been shorter than 15 mm, and resulted in larger 1-min integrated net counts.

Even if the data with large fluctuations in Fig. 6(A) are included, the results reveal that the 1-min integrated counts decreased as the thickness of the shielding paper increased. The initial steep decrease indicates shielding was effective within a small range. This steep decrease shifted to a weak decrease as the range of thicknesses increased. This change means that the intensity of radiation emitted from the source decreased exponentially as shielding thickness increased. The curve in Fig. 6(A) representing exponential function $Y = Ae^{-X}$ has also been drawn for reference. X and Y are the thickness and the 1-min integrated net counts that correspond to radiation intensity. The “ A ” is a constant with a value of 250 (cpm). The 1-min integrated net counts lie along the exponential curve with some deviations. This semi-quantitatively explains that the effectiveness of shielding varies exponentially with the thickness of shielding. Figure 6(A) also shows the maximum range of radiation for paper is about 6 mm¹⁴⁾, and this short maximum range demonstrates that the count rate measured by the GM survey meter must mainly be attributed to beta rays, although ⁴⁰K contained in the sources emits beta particles and gamma rays. Figures 6 (B) and (C) are representative results for two students. The Data in (B) and (C) are both cases with data that are larger and smaller than the average values, and they indicate that a respective data set of two students can demonstrate the relationship between 1-min integrated net counts and the shielding thickness is the same as that in average values. Although the individual data have deviated from the data with crosses, Figs. 6 (B) and (C) indicate that individual students can qualitatively understand the exponential relationship by only using their own data.

It was concluded that sources fabricated from potassium chloride chemicals are convenient educational tools for illustrat-

ing naturally existing radiation and radioisotopes, and they enabled better comprehension of the characteristics of radiation, particularly those related to time, distance, and shielding. However, while the relationship between radiation counts and distance and that between radiation counts and shielding thickness are similar, it is difficult to distinguish the relationship following the inverse-square law in Fig. 5(A) from the exponential relationship in Fig. 6(A).

4. Evaluation of course based on comments by students

The sheet for measurement data contained a column labeled “Discussion and Impressions (write freely)”. Students described any terms or issues they wanted to write about in this column. All the columns were examined. There were many responses sympathetic to the present training in laboratory measurements using sources. Typical ones of their comments are listed in Table 1. These comments can be classified into two categories. The first indicates comprehension of radiation and protection against exposure to it through the training in laboratory measurements ((1)–(5)) and the second indicates goodwill toward the measurements using sources ((6)–(10)). Judging from these comments, the training in laboratory measurements was effective for students who were new workers in the field of radiation.

5. Summary

The radiation sources were fabricated for educational use with a method of formation and compression from commercially available potassium chloride chemicals that anyone can obtain. They were then applied to training new workers in laboratory measurements. Four measurements to evaluate background radiation, find the dependence on time, the dependence on distance, and the dependence of shielding effects were done with a GM survey meter. The measurements of the dependence on time revealed linearity between radiation counts and elapsed time. The measurements of the dependence on distance demonstrated the inverse-square law. The measurements of the dependence on shielding proved the exponential relationship between the effectiveness of shielding and its thickness. All these results demonstrated that the potassium chloride radiation sources are useful aids in courses on protection against radiation and favorably received by many students who took part in this training. Students using sources could easily understand the existence of natural radiation and feel naturally occurring radioisotopes. It was also found that the data sheets were very important for car-

Table 1. Typical comments described by students.

Comments indicating comprehension of radiation and radiation protection

- (1) I knew a great deal about natural radiation through practicing the laboratory measurements.
- (2) I could obtain results that were exactly the same as those explained in the lectures.
- (3) I could understand that distance and shielding were very important to safely handle radiation sources.
- (4) I will now pay attention to time, distance, and shielding when exposed to radiation.
- (5) It was important to understand how to use a GM survey meter to carry out experiments safely and precisely.

Comments indicating goodwill toward the measurements using potassium chloride radiation sources

- (6) I enjoyed practicing the laboratory measurements feeling they were similar to measuring natural radiation.
- (7) It was meaningful training to reconfirm the three basic principles that protect workers against exposure to radiation.
- (8) It was a good opportunity for us to take part in unique training using potassium radiation sources.
- (9) It was good for me to actually experience radiation through training.
- (10) It was a unique idea to use potassium chloride to fabricate the radiation sources for educational use.

rying out measurements smoothly in practice within short periods of time. The sources were fabricated more than two years ago, since then used many times, and no deterioration or problems were found in terms of brittleness and hygroscopicity.

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