Technical Data

Application of a Hand-made Air GM Counter as a Radiation Education Training Material for Secondary School Education

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The application of a hand-made air GM counter as a training material is presented based on evaluation by 16 participants of a workshop by International Atomic Energy Agency (IAEA) technical cooperation programme (TCP) project RAS0079, held in Japan in 2019. A questionnaire survey was administered to evaluate the attributes of the device as well as each respondent's self-assessment of their level of understanding and ability to communicate associated content. The performance of participants in the lecture tests related to the device was also analyzed. The device had an overall effectiveness rating of 8.3/10 with all attributes above 8/10. The respondents' level of understanding and ability to communicate was significantly different before and after using the device. The study also revealed some knowledge deficiencies that can be addressed by using such simple devices and may need more attention for future teacher training programmes.

KEY WORDS: radiation education, hand-made air GM counter, teacher training, nuclear science and technology, radiation properties, radiation experiments, simple devices, secondary school science.

I INTRODUCTION

The posterity of nuclear science and technology (NST) requires interested, motivated, passionate, and well-informed youths who choose to pursue careers in NST. Some serious events associated with nuclear industries, such as the Chernobyl disaster and Fukushima Daichi Nuclear Power Plant accident, have shrouded the benefits of nuclear applications and the ensuing public concerns, apprehensions, misunderstanding, and misconceptions¹⁾ have the potential to fester if not strategically addressed. On the other hand, the demand for knowledge pertaining to radiation has been known to spike with such incidences^{2, 3)} and it is important that accurate and balanced information is provided. Thus, radiation education is important for allaying public fears, clearing misunderstandings and misconceptions, demystifying NST, and also for stimulating interest for NST careers in youths through targeted initiatives for the public, schools, and other avenues.²⁻⁶⁾

The International Atomic Energy Agency (IAEA), in consultation with United Nation Educational Scientific and Cultural Organization (UNESCO), recognised the need for early NST education when reports from expert panels in 1968, 1970, 1975 emphasised secondary schools as the main target for generation of interest in NST.⁷⁾ Though, NST education programmes in secondary schools are not a global occurrence, they have been generally included in curricula of countries that have advanced nuclear technology. Where these are not included in formal education programmes, outreach activities, typically spearheaded by nuclear institutions have taken place in other countries. However, such activities offer only limited exposure⁷⁾ and sustainability of these efforts requires a formal inclusion of NST content in school curriculum and, more importantly, where such is included, the content must actually be delivered. There have been reports of cases where such content, though available in official curriculum, albeit insufficient, has not been taught due to lack of "adequate" or "sufficient" knowledge, qualification or competence on the part of the teachers.^{8, 9)} Because teachers represent a key component of sustained efforts for NST posterity, it is vital to empower them, through training, with knowledge and competence to confidently communicate NST content to students.^{7, 10)}

Appropriate experiments are important for effective science education.¹¹⁾ For secondary school radiation education, these experiments must demonstrate the basic properties of radiation which typically include the inverse square law, attenuation by shielding, and radioactive decay. These experiments can generate "excitement," "interest,"

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and “inquisition” in students. Some devices that have been employed in various secondary school radiation education outreach activities include cloud chambers, survey meters and hand-made air GM counters.^{5, 10} Such devices were employed at a recent IAEA training of trainers’ workshop, tagged TTWS2019 under the RAS0079 Technical Cooperation Project which drew 16 participants from 12 countries. It took place in Japan from 17 February to 1 March 2019 hosted by Professor Takeshi IIMOTO of The University of Tokyo.

TYNA,¹¹ addressing general science issues, highlighted the role of simple experiments in motivating teachers to use science experiments. Though the hand-made air GM counter is considered a simple and low cost device for secondary school radiation education,^{12, 13} it is important to obtain the perspective of teachers on its capability as a tool for demonstrating the basic radiation experiments. HIROSE et al (1999) pointed out the importance of inclusion of NST-related experiments for both pre-service and in-service training of teachers. Thus, in addition to the participants’ feedback on the device, this study explores the effectiveness of the hand-made air GM counter as a training material by evaluating its impact on the TTWS2019 participants’ level of understanding and ability to communicate radiation topics. This gives an indication on the device’s potential contribution to NST human resource development.

II MATERIALS AND METHODS

2.1 The respondents

There were 16 participants ($N=16$) from 12 countries who attended the “training of trainers” workshop. Some represent countries with their own established secondary school NST projects including teacher training, for example Philippines and Sri Lanka. Other portfolios include working in teacher training college (Myanmar), coordinator for science teachers and training at a national science park (Israel), trainers and specialists in innovation with the education ministry (Oman), coordinators and directors in the education ministry (Cambodia, Lebanon and Malaysia), and school principal (Mongolia). They represent strong authority figures in terms of teacher-training and science education needs, and can, thus, provide an important perspective based on their experiences and subsequent roles as trainers of others in their respective

countries in the quest to meet the RAS0079 goal of reaching one million students and teachers by 2021. Their response, though not necessarily applicable to all teachers and trainers, can provide a good indication and overview of what could be likely expected from the wider teaching community in their respective countries.

2.2 The hand-made air GM counter (HMAGM)

The device’s development is spearheaded by the Japan Science Foundation and it has undergone some modifications from earlier versions^{13, 14} especially on the high voltage modules and count display panel. The HMAGM set (**Fig. 1**) consists of a GM tube and a high voltage module which, now, includes a 10-second countdown timer that also serves as a count display. The GM tube comprises a stainless-steel anode, black drawing paper for a cathode and is encased in a transparent container with a removable lid which constitutes the end-window. It uses air as the active gas and 10% butane as the quench gas.

2.3 Experiments and assessment

Each participant assembled his own GM tube, placed the quench gas, and then worked in pairs doing experiments on inverse square law, shielding effect, and radioactive decay. A monazite source was used for the distance and shielding experiments while thoron gas from a lantern mantle was used for the radioactive decay experiment. The HMAGM, detecting mostly beta particles especially in the distance experiments and low energy gamma rays for the shielding experiments, is also unique in that it allows direct and practical observation of radioactive decay by alpha emission through the injection of the thoron gas into the GM tube. At the end of the experiment, questions related to the experiment were asked and each participant responded independently. These questions can be grouped into two categories: radiation properties and measurement (including detection). The day before the experiment, the participants had also received lectures on radiation properties, under basics of nuclear physics, and radiation measurement. They were also tested after each lecture and the list of questions from the lectures ($L_{\text{properties}}$ and $L_{\text{measurements}}$) and the experiment with HMAGM is provided in **Table 1**.

2.4 Evaluation of the HMAGM

Afterwards, a questionnaire was administered, in hard copy,

Fig. 1 The hand-made-air GM counter with set-up for inverse square law.

Table 1 List of questions given after lectures (L₁) and the HMAGM experiment.

L ₁ Properties	L ₁ Measurement	GM Experiment
γ -ray are produced by...	Which radiation detector measures light (photons) to detect radiation?	What kind of detector is a GM counter?
Which one has highest penetrating power?	Which radiation detector is good to identify radioactive materials contained in a sample and measure the radioactivity? (hint: both the number and energy of radiations should be measured)	Which of the following information cannot be obtained with a GM counter?
Bq is a unit for...	Which detector can NOT measure energy of radiations?	What type of pattern is common to radioactive decay and radiation shielding?
Removing one or more electrons from an atom is called...	A radioactive source is counted for 10 min and gives 2000 counts. The source is removed and background measurement for 20 min gives 400 counts. What is the net count rate?	Which of the following materials used in the experiment is the most effective as a shielding material?
A 120 Bq radioactive source has a half-life of 6 years. In 18 years, the source will be...Bq	A radioactive source emits 2000 radiations per second. Your detector measures a net count rate of 100 cps. What is the counting efficiency of the instrument?	Why was thoron gas placed inside the GM tube in the radioactive decay experiment?

to each participant for assessment of the HMAGM and self on a 11-point scale (0 to 10). The focus was on rating the attributes of the GM counter: how well it illustrated radiation properties, measurement and its contribution to the participants' level of understanding and ability to communicate. The emphasis in this case was the current cohort of participants. The choice of a 11-point rating scale was based on PRESTON and COLMAN's¹⁴⁾ assessment wherein the 11-point scale was indicated as allowing respondents to "express their feelings adequately," an important aspect for the present study. In that study,¹⁵⁾ the 11-point scale fared comparably with 7-point scale in terms of reliability and validity, and performed best in terms of discriminating power. All these influenced the decision for the 11-point scale. **Table 2** provides an overview of the contents of the questionnaire.

III RESULTS AND DISCUSSION

Teachers are a key stakeholder in future NST educational activities, it is important to get their perspective on the device

to evaluate its full potential as a teaching aid for them and the students they subsequently teach. Any successful replication of the practical exercises with this device is strongly impacted by their opinion, understanding, and confidence.

3.1 Evaluation & contributions of the HMAGM

The experiments conducted with a GM counter, conventional and HMAGM, represent basic and fundamental introduction to radiation science. These are key aspects that must be understood by everyone seeking knowledge on radiation including how to protect themselves via distance and shielding.

Findings from the study by SHIMIZU et al.⁵⁾ showed that "detection of radiation by students and its visualisation are very helpful in educating school children on radiation." The HMAGM, not only captures detection of radiation but also show its properties. How well the HMAGM can illustrate these properties is an important feature for the eventual user targeted in this study as they take on the responsibility of delivering radiation content to the students. From the feedback

Table 2 Summary of survey questionnaire for rating the HMAGM. The applicable attribute for each question is shown with a tick mark, while a cross mark is otherwise.

Attribute	Question: On a scale of 0 to 10			
	Rate the following for the experiment	Rate the ability of the experiment/system to address the following	Rate your understanding of the following before and after experiment	Rate your ability to communicate the following before and after experiment
Simplicity	✓	×	×	×
Clarity	✓	×	×	×
Science	✓	×	×	×
Engagement	✓	×	×	×
Detection principle	✓	✓	✓	✓
Measurement Principle (counting)	✓	✓	✓	✓
Natural background counting	×	✓	✓	✓
Inverse square law	×	✓	✓	✓
Shielding effect	×	✓	✓	✓
General/overall	<ul style="list-style-type: none"> On a scale of 0 to 10, how effective can you rate the air GM experiments at delivering content to students On a scale of 0 to 10, how strongly do you think you can be able to replicate the GM tube design in your own institutions? (space included for explanation). 			

of the participants in this study, the device is very effective at illustrating these properties as evidenced by the high rating it received in all attributes summarised in **Table 3**. When asked to rate their ability to replicate the device in their own country, the rating was 6.1 ± 2.2 owing to the requirement for very high voltage (5,000 V): citing safety concerns and, mainly, difficulties to access it. This means that in cases, where this is made available as part of a kit, the device can easily be applied as a training material for teachers and experiment aid for students. Thus, this HMAGM can contribute to teacher training especially in scenarios where resources are scarce, limited, unavailable, and expensive, a typical case at the secondary school level. To address safety concerns for replication, set-ups can be pre-assembled by the demonstrators so that students simply use the device to conduct the experiments. The self-assembly of the GM tube and preparation of the quench gas accords the trainees a practical appreciation of the underlying theory and mechanism of detection and measurement. In this way, they can learn from some failures arising from improper assembly and inadequate or excessive quench gas thereby solidifying their understanding. To address inconsistencies due to improper assembly of the GM tubes and incorrect amounts of quench gas, pre-assembled and sealed GM tubes were also provided to be used during the experiments. Most participants opted to use their self-assembled GM tubes.

An important aspect of science education, in general, is experimentation and the motivation to use science experiments for teaching or learning can be greatly influenced by the

teacher's competence.¹¹⁾ The first three attributes: simplicity, clarity, and engagement; also speak to the potential for motivating teachers to apply this device in their school experiments and assimilate into their own pedagogical content knowledge. These would also impact content delivery for the rest of the highlighted attributes. To support this, **Table 4** summarises each participant's self-assessment on their level of understanding and ability to communicate the content before and after the experiment. It is clear from the responses that the participants felt more confident and competent after the experiment with HMAGM. A paired *t*-test for the self-assessments on level of understanding and ability to communicate before and after experimenting with HMAGM shows a significant difference ($P < 0.05$) for both scenarios. While conventional GM tube can illustrate these highlighted attributes and perhaps perform much better, the simple HMAGM gives trainees the unique and evidence-based opportunity to understand what goes into such detectors and why that is the case. This, if understood, will likely improve their confidence in delivering the associated content in the classroom. While it may be enough for students to just use the device, the authors believe that it is important for the teachers to understand the underlying mechanism for the detection and measurement process.

3.2 Connection to the performance on related content during the IAEA TTWS workshop

Figure 2 shows the frequency distribution of the performance of the participants on the questions that were given immediately after the experiment with the HMAGM as listed in **Table 1**. Also shown are the performance for lecture questions on radiation properties (including inverse square law, shielding, and radioactive decay) and radiation measurement (including detection).

Participants fared much better in the questions after the practical HMAGM experiment compared to the contents' theory particularly on measurement. Thus, a coupling of the content with the practical experiment is more effective. In the study by SHIMIZU et al.⁹⁾ it was found that 50% of students found contents of lectures on radiation were difficult to understand which influenced their level of interest in the topic. However, the use of devices helped to stimulate this interest. They indicated that most schools do not have devices for radiation education and that teachers did not have sufficient knowledge to teach on radiation. Thus, in the present study, the HMAGM could be responsible for the better performance

Table 3 Participants' evaluation of the HMAGM. (rating is given with standard deviation).

Attribute	Rating (/10)
Simplicity	8.3 ± 1.2
Clarity	8.6 ± 1.0
Engagement	8.8 ± 1.1
Science	9 ± 1.1
Detection principle	8.6 ± 1.1
Measurement principle (counting)	$9.1 \pm 1.1^*$
Background counting	8.9 ± 1.6
Inverse square law	8.8 ± 1.2
Radioactive decay	8.8 ± 1.3
Shielding effect	9.3 ± 1.1
Overall effectiveness	$8.6 \pm 1.2^*$

*based on 15 relevant responses

Table 4 Participants self-assessment with respect to radiation-related content.

Attribute	Level of Understanding (/10)		Ability to Communicate (/10)	
	Before	After	Before	After
Detection principle	5.4 ± 2.2	8.5 ± 1.4	5.1 ± 2.5	8.1 ± 1.5
Measurement principle (counting)	5.5 ± 2.6	8.4 ± 1.4	5.2 ± 2.5	8.3 ± 1.4
Natural background	5.9 ± 2.5	8.9 ± 1.4	5.5 ± 2.2	8.4 ± 1.4
Inverse square law	5.9 ± 3.0	8.4 ± 1.5	5.8 ± 3.1	8.2 ± 1.4
Radioactive decay	6.4 ± 2.8	8.5 ± 1.4	6.1 ± 2.8	8.3 ± 1.4
Shielding effect	6.8 ± 2.8	8.7 ± 1.4	6.2 ± 2.7	8.4 ± 1.4

to somewhat similar question because in all the three cases the questions were given immediately after the activity. There is a possibility that the questions in the HMAGM may have been easier for the participants but, together with the participants feedback (Table 4), it can be argued that the use of the HMAGM made a significant impact on their performance.

The performance (Fig. 2) and feedback from the participants (Tables 3 and 4) confirms the need for practical exercises for a complete understanding of NST topics^{9, 11)} and highlight HMAGM as simple, low-cost and effective tool for partially achieving this goal. It further highlights the deficiency, hence need for more focus or detail, in the area of radiation detection and measurement topics for future teacher training programs.

IV CONCLUSION

This study has demonstrated that a hand-made air GM counter is an effective device for use as a training material because its use produced an increased level of understanding and ability to communicate radiation properties. The participants' assessment of the device confirms its simplicity and capability to illustrate radiation properties. Well-trained and confident teachers represent a key stakeholder in the posterity of nuclear science and technology education. Their in-service or pre-service training that incorporate appropriate practical exercises using simple devices, such as a hand-made air GM counter can boost their confidence and competence in delivery NST topics to students.

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Fig. 2 Frequency distribution of participants' performance.

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