Development of RAD1, Low-Cost, Portable, Digital Gamma Radiation monitor

Kh. Luvsanbat[a], T. Turtogtokh[b,c], T. Begzsuren[b,d], U. Enerelt[a,d] , O. Gerelmaa[a], D. Erdenebaatar[b,c]

[a]Department of Biology, National University of Mongolia
[b]Department of Physics, National University of Mongolia
[c]Space science center, Institute of Astronomy and Geophysics, Mongolian academy of Science
[d] Biophysics Division, Institute of Physics and Technology, Mongolian academy of Sciences

Additive manufacturing and open-source affordable instruction provide equal opportunities. Therefore, it is possible to make devices easily, compactly, and cheaply that were expensive, scarce, and large in the previous century. The Geiger-Muller tube is used for primary sensing component for proposed and incorporates digital signal processing to ensure accurate and reliable measurement of gamma radiation. The performance of the developed detector is evaluated through experimental testing and comparisons with commercially available radiation detection devices. The results demonstrate the detector's ability to provide precise and consistent measurements while remaining cost-effective. Moreover, its portability and user-friendly interface make it suitable for various applications, including environmental monitoring, nuclear safety, personal radiation exposure assessment, and most importantly for educational purpose. This low cost portable digital gamma radiation detector makes contribution to the field of radiation detection by presenting an accessible solution that addresses the financial limitations associated with conventional gamma radiation detectors.

I. INTRODUCTION

The accessibility of education in developing countries is often challenged by limited resources and financial constraints, particularly in science and technology [1]. Our research introduces RAD1 a low-cost radiation detector designed for accessible education in developing countries. Radiation education plays a crucial role in empowering individuals to understand the potential risks associated with ionizing radiation and promoting safety measures in various industries [2]. However, conventional radiation detection equipment can be expensive, hindering the ability of educational institutions in developing countries to provide hands-on experiences for students [3]. In response to this challenge, our research focuses on the development of an affordable and user-friendly radiation detector that aligns with the educational needs of resource-constrained environments. The proposed detector incorporates RadiationD V1.1 Cajoe a Geiger-Muller tube module, an essential component for gamma ray detection, and employs a cost-effective design that utilizes common materials such as lead and aluminum [4]. This approach enables students and researchers to perform laboratory experiments that explore the influence of different material thickness on gamma ray detection. By emphasizing cost-effectiveness and simplicity, this research aims to democratize access to radiation education, ensuring that students in developing countries have the opportunity to engage in meaningful experiments that deepen their understanding of radiation physics and safety. In addition, there are many accessible yet affordable low-cost radiation detectors developed for research, training, and radiation safety at the global level, which shows that there is a crucial need for accessible radiation detectors [5-9]. The utilization of locally available materials and an affordable design positions this low-cost radiation detector as a valuable tool for educators, facilitating hands-on learning experiences that are crucial for fostering a generation of scientifically literate individuals in resource-limited settings.

II. Development of device and method

1. Device development

The Rad-1 radiation detector device is based on radiationd-v1.1 Cajoe detector module with Geiger Muller [4]. The main control of the device is made by ESP8266 and 1200mAh battery. The device can work continuously for 10 hours at room temperature. Furthermore, RAD1 has battery charging and over current protection module TP4056 which is shown in Fig 2. Therefore, it can be charged by android phone charge, adapters, and car phone charger, makes it more user friendly.

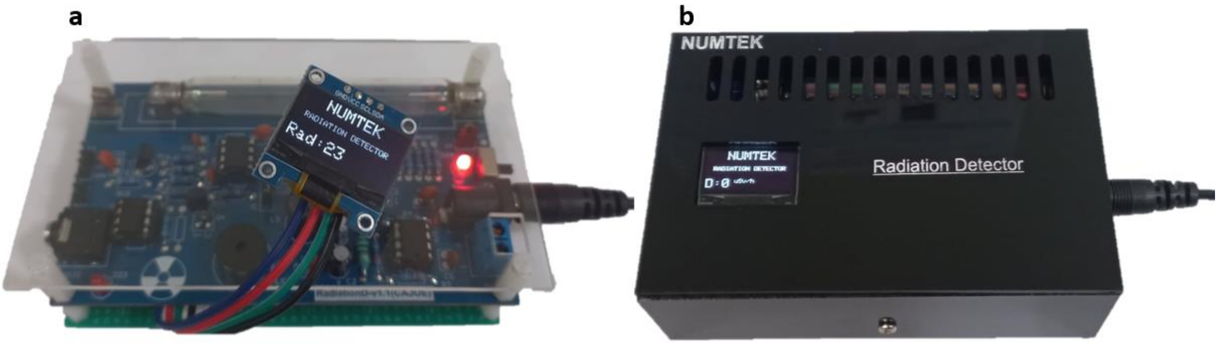

Fig. 1. Rad-1 radiation detector

As shown in Fig. 2, we used commercial ESP8266 microcontroller for counting pulse signals from Geiger tube module, analyzing count data, converting count per minute (CPM) data to uSv/h unit, and showing result data to OLED display at same time. We used U1V10F5 5V step-up regulator for boost 3.7V battery output to 5V supply to microcontroller and Geiger tube module. ESP8266 microcontroller has several advantages of low power consumption, high memory capacity, low-cost, Arduino compatibility, and ultimately built-in wifi capability which makes is perfect choice for affordable, accessible microcontroller for scientific, compact, low-cost instruments [10-12]. Outer case of RAD1 detector made by acrylic sheets that sliced and holed by laser-cutter machine.

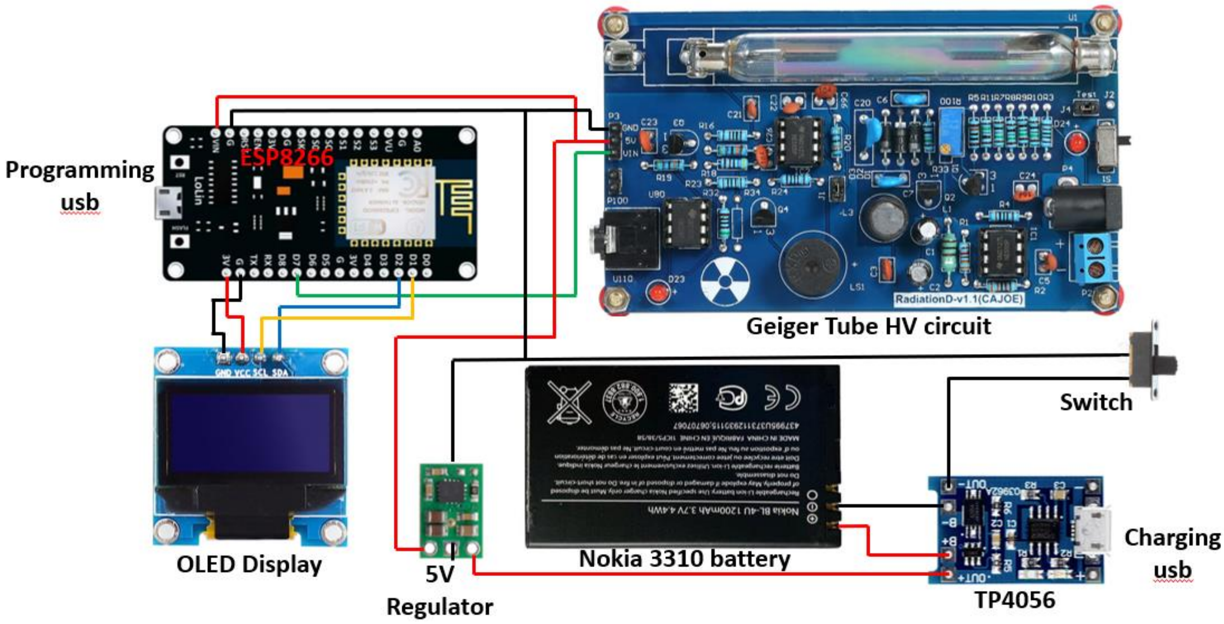

Fig. 2. Overall design schematic of RAD1

The low-cost gamma radiation detector was constructed using RadiationD V1.1 Cajoe module with a Geiger-Muller tube as the sensing element [4]. This module provides affordable radiation detector design for do-it-yourself design attached with M4011 Geiger tube (Tin oxide cathode, temperature range: -40^{0}C ~ 55^{0}C, gamma ray: 20-120mR/h, beta ray: 100-1800, working Voltage: 380-450V, working current: 15uA-20uA). The tube was coupled with an embedded microcontroller for real-time data acquisition and processing. The construction of the detector focused on affordability, utilizing cost-effective components to ensure accessibility in educational settings. The design includes a user-friendly interface for ease of operation. In addition, radiation module has built-in indicator LED and buzzer, so it will give alarm immediately when measured high levels of radiation.

2. Experimental setup

The primary radiation source utilized in this study is Cs-137 (Cesium-137), a commonly used radioisotope emitting gamma radiation [3]. Cs-137 is selected due to its stable production, consistent gamma emissions, and relevance to educational experiments in radiation detection.

The experimental setup included a controlled environment to ensure accurate measurements. Cs-137 was placed at predetermined distances from the detectors, and varying thicknesses of lead and aluminum shield. The RAD1 detector and the Russian scintillation detector were positioned at the same distances from the radiation source to facilitate comparative analysis. Gamma ray from Cs-137 was measured with different thicknesses of Aluminum and Lead. Lead mostly used for its capability of shielding gamma ray effectively. Furthermore, we compared RAD1 detector to industrial grade dosimeter TM-91 which is ~3 times higher price that RAD1. In addition, we calibrated RAD1 with unit of uSv/h using TM-91 which certified for radiation detection of gamma, beta, x-ray (correction factor: 0.99).

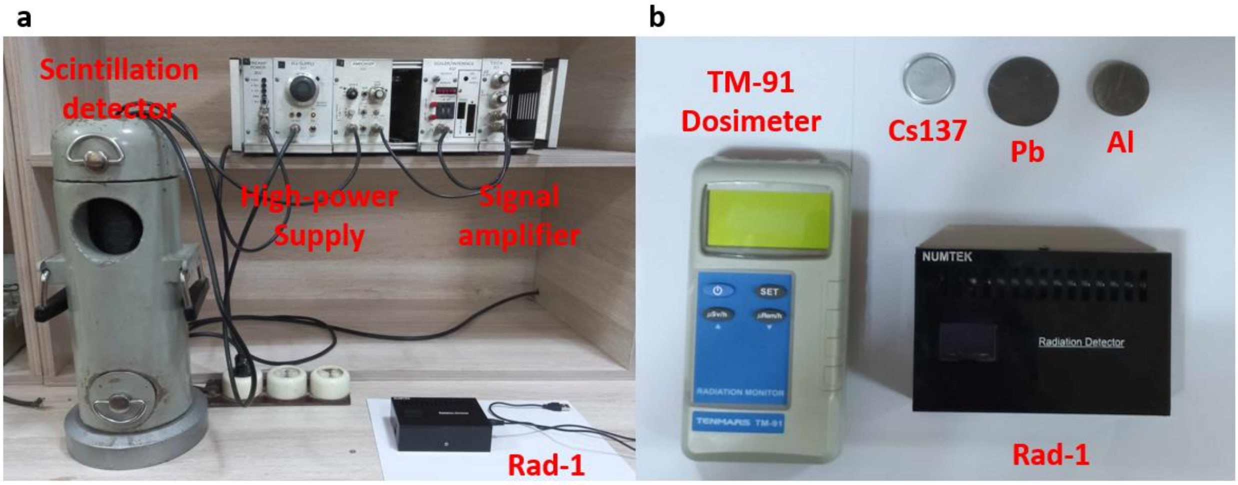

Fig. 3. Experimental setup, a) comparative measurement of Rad1 and scintilliation detector setup, b) comparative measurement and calibration of Rad1 with TM-91 dosimeter setup

3. Data Analysis

Measurements were taken under controlled conditions, and data from detectors were recorded simultaneously. The recorded data include gamma radiation readings for different lead and aluminum thicknesses, as well as background radiation measurements. Statistical analysis and correlation studies were conducted using Excel and Python programming language.

III. RESULTS AND DISCUSSION

Understanding linear energy transfer (LET) is important for the development of new materials, and methods to shield from radiation [13][14]. Furthermore, the better development of medical, industrial, and research nuclear related instrumentation relies on the understanding of LET, radiation shielding, and the interaction between radiation and material [15]. Therefore, it is crucial to include the idea of LET, photo-effect, Compton scattering, and electron-positron generation in the education system.

The investigation into gamma ray energy deposition in different materials, specifically aluminum and lead, provided valuable insights into the interaction of gamma radiation. RAD1 radiation detector demonstrated a clear inverse exponential relationship between lead thickness and gamma ray intensity. Increasing the thickness of the lead shielding resulted in a significant reduction in gamma ray intensity. This observation aligns with the well-established principle of gamma ray attenuation through materials, where higher density and thickness of a shielding material lead to increased attenuation [15]. The data obtained in this study provide a quantitative understanding of the attenuation characteristics of gamma radiation by lead, crucial for educational purposes and practical applications in radiation protection.

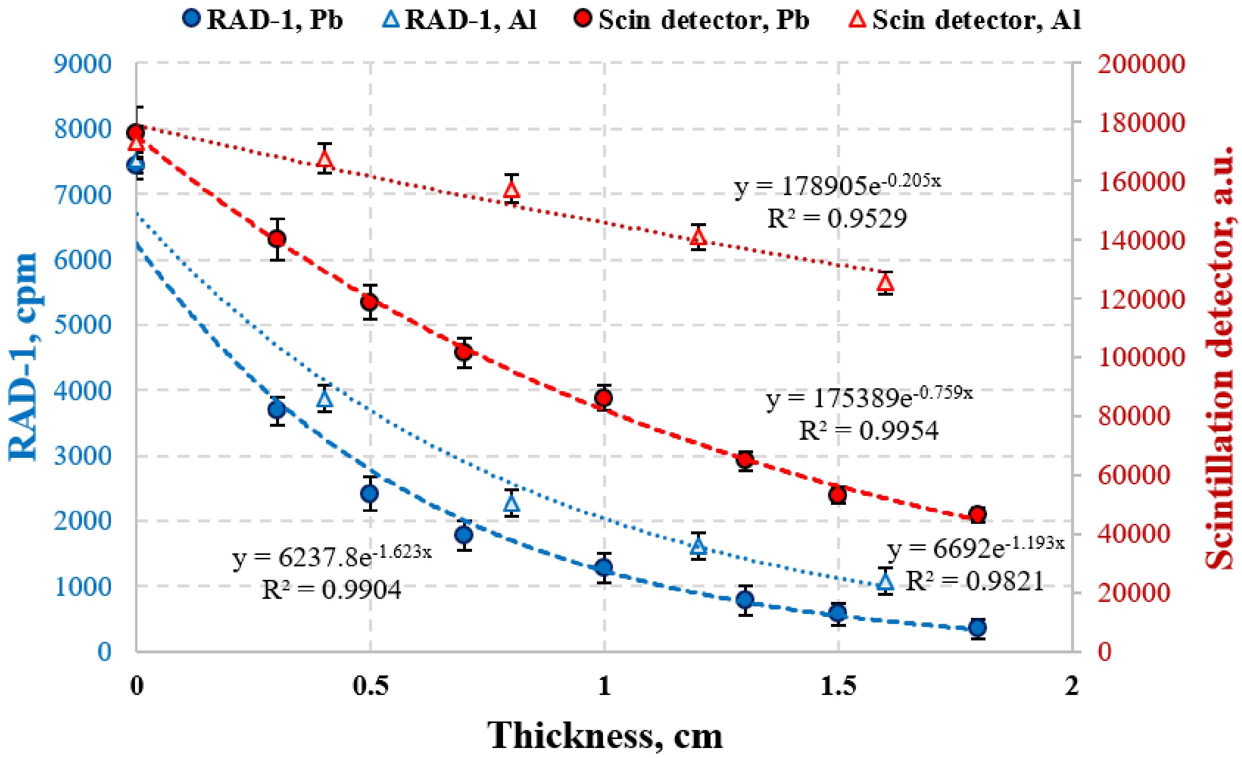

Fig. 4. Radiation shielding experiment with scintillation detector

The RAD1 successfully measured the energy deposition of gamma rays in both aluminum and lead, showcasing the ability to discern the differences in attenuation characteristics between these materials as shown in Fig 4. The results indicated that lead, with its higher atomic number and density, exhibited more effective gamma ray attenuation compared to aluminum. This outcome aligns with theoretical expectations and underscores the detector's capability to distinguish between materials based on their radiation shielding properties.

A comparative analysis between the RAD1 and the TM-91 dosimeter was conducted to validate the accuracy of the measurements and calibrate RAD1 to physical unit of uSv/h. Performance comparison between RAD1 and TM-91 for measuring gamma ray from Cs-137 with different thickness of lead is shown in Fig 5.

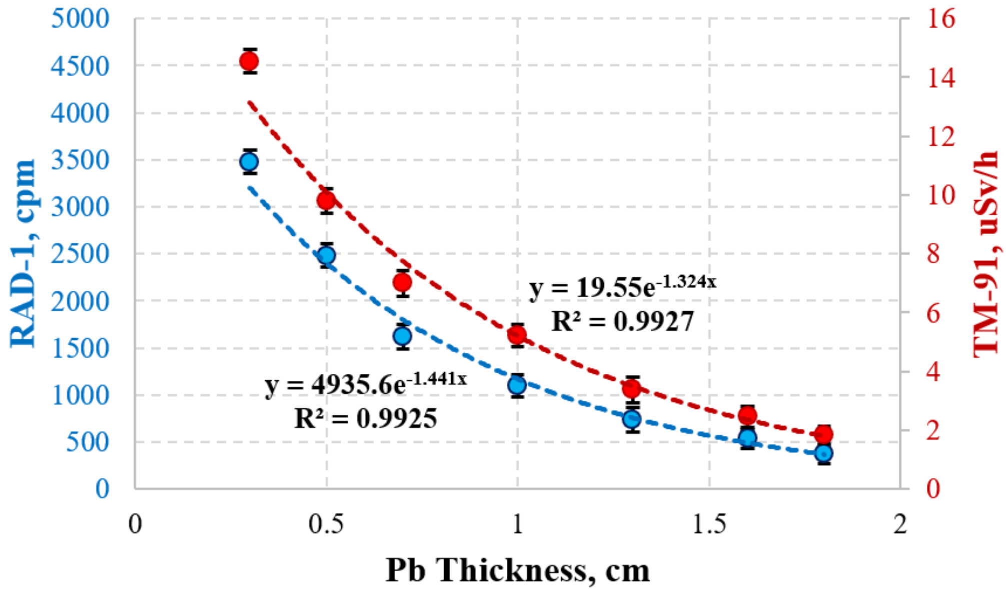

Fig.5. Gamma ray intensity dependent from lead thickness measured by RAD1 and TM-91 dosimeter

As shown in Fig 5, exponential relation between lead thickness and intensity of transmitted gamma ray is exponential agrees with literature equation 1 [15].

$$I_{(x)} = I_o * e^{-\mu x} \quad (1)$$

$I_{(x)}$ is Intensity of gamma ray penetrating lead with x thickness

I_o incident energy of gamma ray

x is lead thickness

μ representing shielding efficiency of material, gradient of equation:

$$\ln(I_x) = \ln(I_o) - \mu x \quad (2)$$

The data demonstrated a strong correlation between the readings of the two devices across various experimental conditions shown in Fig 6.

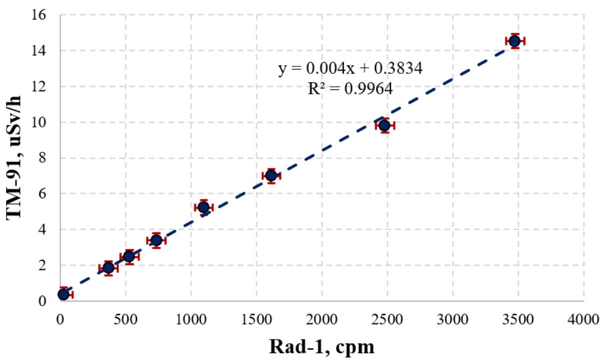

Fig 6. Correlation between RAD1 and TM-91 for measurement of gamma ray intensity

The consistency in results reinforces the reliability of the RAD1 and its suitability for educational purposes as shown in Fig 6. RAD-1 radiation detector works with count per minute algorithm. It can be measured against TM-91 in units of uSv/h, and this test will calculate the amount of gamma radiation with an accuracy of 0.99. Additionally, the affordability of the RAD1 makes it an attractive alternative for educational institutions in developing countries, where budgetary constraints often limit access to sophisticated radiation detection equipment. The results obtained from the experiments underscore the effectiveness of the low-cost gamma radiation detector in educational applications. The measurements obtained from both detectors were in close agreement, with a correlation coefficient of 0.9964. This high level of correlation signifies a 99.64% match between the two detectors in terms of radiation detection. The exceptional compatibility observed between RAD1 and the TM91 dosimeter which is industrial grade and certified suggests that the RAD1 can be a reliable and cost-effective alternative for radiation monitoring in educational purposes. The minor variations observed are within an acceptable range and do not compromise the overall performance of the RAD1.

IV. CONCLUSION

The experimental results indicate that our RAD1 is highly compatible with the industrial dosimeter TM91, with a matching rate of 99.6%. This promising outcome opens up new possibilities for cost-effective radiation monitoring solutions without compromising accuracy in industrial environments. Further studies and field trials will be essential to validate the practical applicability of the RAD1 in real-world industrial scenarios. The readings obtained from the RAD1 portable device align closely with those from the well-calibrated Russian scintillation detector and TM-91 across various experimental conditions. However, the key differentiator lies in the accessibility and user-friendliness of the low-cost portable device. The affordability of its construction materials and the simplicity of its design make the low-cost detector an attractive alternative for educational institutions, particularly in developing countries facing financial constraints. This accessibility is crucial in democratizing radiation education, allowing a broader audience to engage in hands-on experiments and gain a deeper understanding of fundamental principles in nuclear physics. The user-friendly interface of the low-cost device enhances its suitability for educational purposes, enabling students and educators with varying levels of technical expertise to operate the detector effectively. This ease of use contributes to a more inclusive learning environment, empowering individuals to explore and comprehend the complexities of gamma radiation detection without significant technical barriers.

V. REFERENCE

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