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# Analysis of Tube Leakage of X-Ray Radiation Using Geiger Muller Sensor Equipped with Data Storage

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**ABSTRACT** X-ray radiation (ionization) cannot be felt directly by the five human senses. Therefore, radiation monitoring is needed, one of which by using a survey meter. The purpose of this research is to directly monitor the level of radiation exposure and leakage of X-ray tube containers in the work area. This was done to ensure the safety and health of workers in the radiation transmission area, so that it is in accordance with the ALARA (As Low As Reasonably Achievable) principle, which is stipulated in the Decree of the Minister of Health RI No. 1250/Menkes/SK/XII/2009 concerning Guidelines for Quality Control of Radiodiagnostic Equipment as Standard Values for X-Ray Radiation Monitoring. This research is an experimental study with a survey meter equipment module design using a Geiger Muller sensor equipped with data storage. This module design method uses Arduino programming as data processing and is displayed on the CHARACTER LCD. Test analysis was carried out by comparing the measurement value of the module with the standard value as a standard for comparison. Based on the measurement results, the X-ray tube leak test value resulted in a standard AAT survey meter value of 0.001 both using a closed and unsupplied 2mm Pb circuit, namely 0.00097 mGy/hour and 0.00092 mGy/hour. Meanwhile, the results of the tube leakage test using a survey meter, both circuits, modules, and standard survey meters show a passing grade test value of < 1mGy/hour. In conclusion, the module design using the Geiger Muller sensor is feasible to use.

**INDEX TERMS** Survey Meter, Geiger Muller, Arduino

## I. Introduction

Radiation can be interpreted as energy radiated in the form of particles or waves. Radiation cannot be felt directly by the five human senses. Therefore, radiation monitoring is needed, one of which by using a survey meter. Radiation monitoring aims to determine firsthand the rate of radiation exposure in a work area to ensure that the safety and health of workers who will work in the radiation-transmitting area are in accordance with the principles of ALARA (As Low As Reasonably Achievable) [1][2].

The safety and security aspects of radioactive substances from sender to receiver are things that must be guaranteed so as not to harm humans, because radiation from radioactive substances cannot be felt directly by the human senses. Therefore, a detector is needed to monitor the rate of radiation exposure [3] [4]. The dangers of radiation in certain amounts can cause ionization of human body cells and can damage body cells [5]. The nature and severity of this radiation influence depends on the dose the tissue cell receives. The unit size of the dose for humans is called rem. In this case, the biological effects of radiation can be classified into two types: deterministic effects and genetic effects [6][7][8]. In the procedure of testing and measuring X-ray radiation, a survey meter is required to measure the level of radiation exposure and provide data on measurement results in cacah per minute (CPM) or mR/hour [9][10]. Each nuclear radiation gauge consists of two parts, namely detectors and supporting equipment. The radiation measuring instruments which are commonly used are survey meters with several types such as ionization chamber detectors, Muller Geiger detectors, and proportional detectors. All of this measurement equipment is used in the field of radiation areas, so they are designed to display fast data. Radiation detectors are the most important part of the radiation measuring system that serves to convert the amount of radiation into electrical signals or pulses [11]. Research in the field of radiation monitoring systems has been frequently done, both in the field of design and development of radiation monitor systems [12]. Currently, many Digital Survey meters have been created using Geiger-Muller gas filling detectors as gamma, X-ray, and Beta radiation detectors, with the principle of working from radiation (gamma rays or beta particles) entering the detector, then the radiation ionizes the gas in the tube and produces positive ions and negative ions (electrons) that are proportional to the intensity of radiation [13][14][15]. Utilization of Geiger-Muller gas filling detector in the design of survey meter is possible to measure X-ray radiation and can be used properly for Conformity Test [16]. Measurement of radiation leak container X-ray tube is one of the parameters of the Conformity Test conducted to ensure that the collimator is covered perfectly and the radiation leaking from the collimator is still within the admission criteria [17]. X-ray tube container leak testing aims to determine the position and value of the tube container leak [18][19]. In 2015, N. N. Ghuge et al. designed a survey meter to determine how much radioactivity at the site of a nuclear accident using a radiation detector containing Geiger Muller's gas cylinder, which would detect radioactivity, and could measure gamma radiation. The results of radiation intensity measurements are displayed on the LCD and store data in memory so that it can be analyzed further. The system is designed using digital display techniques using PIC microcontrollers, LCDs, keys, and USB interfaces [20][21]. However, this study has not done calibration/ measurement comparison between the design of the survey meter tool with the standard survey meter so that the value of measurement errors is not known. In 2016, Ivan Morales et al. conducted research by designing, assembling, and calibrating microcontroller-based Geiger-Muller dose gauges [22]. The design uses the Geiger Muller Detector, a Texas Instruments MSP430 low-power microcontroller, a front-end analog circuit, and a high voltage and overall system calibrated to measure the dose rate of its equivalent with high accuracy. The advantage of this research is the production of high-quality and inexpensive options for radiation detection in vulnerable environments, such as hospitals and hazardous waste storage centers for radiation accidents. Meanwhile, the shortcoming of this research is that the design of the tool is still not equipped with the storage of measurement results. In 2016, Nur Aira Abd Rahman et al. designed a digital radiation survey meter with a Muller Geiger tube detector LND7121 and an Atmega328P microcontroller (survey meter prototype) using the Arduino Uno platform through Timer 16-bit on the microcontroller as an external pulse counter. This was done to generate a second count or CPS measurements converted to dose rate techniques by Arduino for displays results in micro Sievert per hour (μSvhr-1) and linear measurement results for dose rates below 3500 Sv/hr [23]. This research developed a Survey meter design that can send serial data of measurement results from the radiation measurement area via SMS text to the host server, so that this system can work with two-way communication for data transmission, request status, and configuration settings. This module was designed to consist of GSM, Geiger Muller tube detector, Geiger Muller tube detector, voltage level converter, SIM circuit, and Atmega328P microcontroller as control to send, receive, and AT commands to process data to GSM module and Firmware to communicate between devices and hosted servers. Integration of this module with Survey meters/radiation monitoring devices will create a mobile and wireless radiation monitoring system with rapid emergency alerts at high radiation levels [24]. The advantages of this study are that data can be received for outdoor emergencies. Meanwhile, the disadvantages are that it spends a lot of battery consumption (battery quickly depleted), excessive use of graphic LCD if only to display the output of numbers and sending data via SMS is difficult to accept because it is difficult to detect GSM / GPRS signals in the radiology room. Georgia Kusmiran Barends conducted similar research on measuring radiation exposure (X-ray fluoroscopy device). The design of this tool uses a Geiger Muller detector tube where the detector output is processed using Arduino Uno and the measurement results are displayed on the Character LCD and Android in the form of numbers in microSievert and Counter Units Per Minute. The measurement results of the module were compared with a standard survey meter that was calibrated so that it was known that the accuracy value of the tool using the Geiger Muller detector was 90.71% for measuring background radiation in an enclosed space. In this study, the measurement of X-ray radiation was only carried out on one unit of fluoroscopy equipment. There was no data that explained how to test, the condition of the tool, and the design of the tool and it was not equipped with a measurement data storage system [25]. Measurement of X-ray tube leaks in radiology aircraft based on standard methods as stipulated in the Decree of the Minister of Health of the RI. No. 1250/MENKES/SK/XII/2009 On Quality Control Guidelines for Radiodiagnostic Equipment [26]. Writing, et al, (2016) carried out a radiation leakage test on an X-ray Rigaku Radioflex-200 EGS-2. This test includes determining the position of the leak using a radiographic film and determining the dose rate using a digital pocket dosimeter. The dose was at 0.1128 R/hour at a distance of 1 (one) meter from the focal point so that the leakage value of the X-ray aircraft is still below the permissible value. Ujang, et al. 2019 analyzed the Wonsolution WSR-40 Radiographic Performance Test as a standard requirement required for X-ray aircraft Conformity Test, especially for medical exposure by measuring radiation leakage on five sides, i.e., left, right, front, rear, and 1 meter above the housing. X-ray tube, the measurement results have an average value of 0.0245 mGy/hour while the allowed pass value is 1 mGy/hour [27]. Based on the research literature above, it can be concluded that the use of the Arduino microcontroller is more practical, inexpensive, and easier than other microcontrollers and data transmission using GSM/GPRS is more suitable for sending data outside the radiology room. In addition, [28] survey meter design using Geiger Muller detector does not require much cost for X-ray radiation measurement, and the results of X-ray radiation measurements in the form of numbers simply use character LCD. However, not many studies use data storage of X-ray radiation measurements in the design of survey meter tools. In the design of this tool, X-ray radiation measurements will be developed with several technological innovations from radiation measuring instruments using a Geiger Muller tube detector and the measurement results can be displayed in the form of numbers in microSievert or milliRoentgen units on an LCD equipped with X-ray radiation measuring devices for data storage. This innovation is expected to facilitate the use of tools for the safety of radiation measuring instruments when measuring and reading ionizing radiation such as X-ray radiation and measurement results can be stored for a long time. The use of the Arduino Microcontroller and MicroSD Card is the result of developing practical technology (hardware and software) at a fairly affordable price. The purpose of this research is to design an x-ray radiation measuring instrument that will be used to test the leakage of x-ray radiation tubes using the Geiger Muller Sensor which is equipped with data storage. X-ray tube leakage measurement testing using a Survey meter tool design with a Geiger Muller sensor was carried out on 5 (five) X-ray devices according to the Conformity Test method and each measurement result was stored on a microSD card. The purpose of this study was to analyze the results of radiation measurements of the leakage container of x-ray tubes using the Geiger Muller circuit and the Geiger Muller module.

## II. Materials and Methods

### *A. Experimental Setup*

Data collection was done 5 times based on working methods / steps in accordance with the Decree of the Minister of Health of the RI. No. 1250/MENKES/SK/XII/2009 On Quality Control Guidelines of Radio diagnostic Equipment for home leak test of X-ray tubes. Measurement of radiation intensity in X-ray tube containers was further compared to standard survey meters that have been calibrated.

1) Materials and Tool

This study used an Arduino UNO as a programming source, Geiger muller/ Geiger counter module to capture X-rays, character LCD for survey meter display, push button, SD card module as data storage that has been read by the tool, battery as a tool supply, and charger module/power bank module to charge the battery on the tool.

2) Experiment

Measurements were carried out 5 times in each measurement setting of the intensity of the container or tube leak using the design of survey meter tools (modules and circuits) with a comparison tool, namely Fluke Ray Safe 452 Radiation Survey meter.

### *B. The Diagram Block*

FIGURE 1 shows the diagram block of this study, in which when the device is turned on, the system starts working. The entire range of device systems including High Voltage Circuit, IC Microcontroller, Signal Input Circuit, and 16x2 Character LCD gets voltage from the battery module.

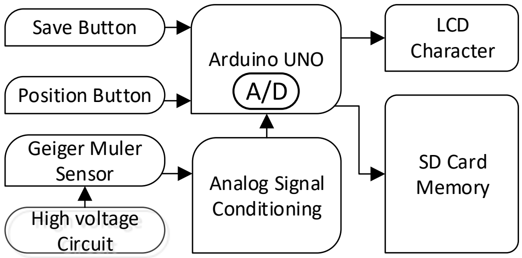


FIGURE 1. The Diagram Block Circuit Module System

The High Voltage circuit serves to increase the voltage of the battery so as to produce a high voltage output to activate the Muller Geiger Tube Detector Frame which requires a high DC voltage (150-200V), but the tube voltage suggested by the manufacturing company is 500V. The potential difference in the anode and cathode of the Muller Geiger tube makes the electric field and pair of electron ions get a considerable additional kinetic energy. In addition, there was a separation event of negative ions and positive ions. When the detector detects the presence of charged radiation entering through the tube window, the electrons will move towards the cathode of the detector resulting in a current, the frequency of the voltage counter is proportional to the intensity of the radiation received. The output voltage of the detector is then processed by the microcontroller. The result of the enumeration is then processed by converting each voltage counter then multiplied by one minute, resulting in the number of counters that are chopped in one minute or called CPM (Count per Minute). CPM is then converted into units of value μSv (MicroSievert) by multiplying the result of the CPM by the conversion of factors from the type of tube used to produce output in units of mR (milli Rontgen). The results of the microcontroller data processing are then displayed to a 2x16 LCD and stored on an SD card memory.

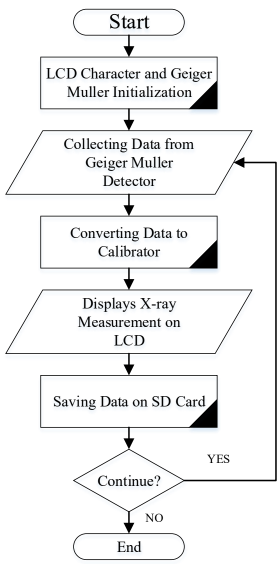


FIGURE 2. Flowchart of data processing on x-ray radiation module using Geiger Muller sensor

### *C. The Flowchart*

FIGURE 2 shows the flowchart of this study, in which when the device is turned on, the module will initialize and the Muller Geiger sensor works. Then, the sensor can read the radiation from the x-ray device. Data from Geiger Muller is further processed on Arduino which is then displayed on the character LCD. The data displayed in the character LCD will be stored on the SD card. The reset will restore the system to its original state otherwise the sensor will continue to read the x-rays and then display on the character LCD. After the reset, the process is complete.

## III. Result

The results of the Survey Meter Module Equipment Design is as follow. **FIGURE 3** shows a survey meter equipment module used for data collection. The series of survey meter equipment modules above consist of Arduino UNO as a programming source, Geiger Muller/ Geiger Counter circuit to capture X-rays, character LCD for survey meter display, push buttons, and batteries as a tool supplier, and charger module/ power bank module to charge the battery on tool.

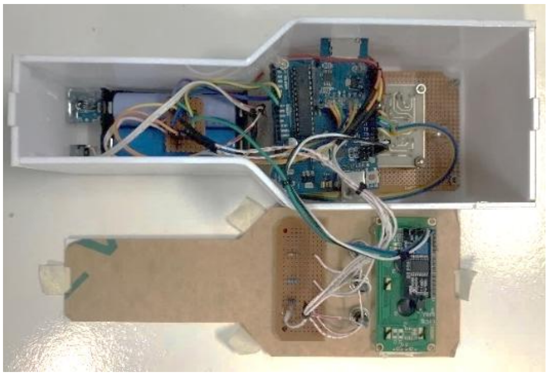

**FIGURE 3. The Entire Module Circuit Geiger Muller Module**

### *1) Measurement Result With Standard Survey Meter*

Measurements were carried out 5 times in each measurement setting of the intensity of the container or tube leakage using the design of survey meter tools (modules and circuits) with a comparison tool, namely Fluke RaySafe 452 Radiation Survey meter. Measurement of X-ray tubes covered with Pb 2mm (TABLE 1)

**TABLE 1**
**Error between Survey Meter (Circuit) and survey meter (standart) Covered with Pb 2 mm**

| Area | Mean (µGy/h) | | Error | % *Error* |
|---|---|---|---|---|
| | ***Survey meter*** **(Circuit)** | ***Survey meter*** **(Standard)** | | |
| **Right** | 14.50 | 14.80 | 0.30 | 2.0 |
| **Front** | 33.84 | 34.56 | 0.72 | 2.1 |
| **Left** | 23.14 | 25.96 | 2.82 | 10.9 |
| **Top** | 15.90 | 19.92 | 4.02 | 20.2 |
| **Back** | 5.68 | 5.06 | 0.62 | 12.3 |

As shown in TABLE 1., it can be explained in the graph as shown in FIGURE 4 that the correction value is the difference from the average value of survey meter (circuit) with survey meter comparison. The percentage of error is the difference from the average tool module with the average of correct values that are considered to be correct where the survey meter comparison value (calibration) is considered always correct. The largest correction values and error percentages in upper area measurements were 4.02 µGv/h and 20.2% respectively. FIGURE 4 describes an average diagram pattern between the Survey Meter (Circuit) and Survey Meter (Standard) of the 2 mm Pb Coated area, where in the front position is the largest average error, which is 33.84 and 34.56

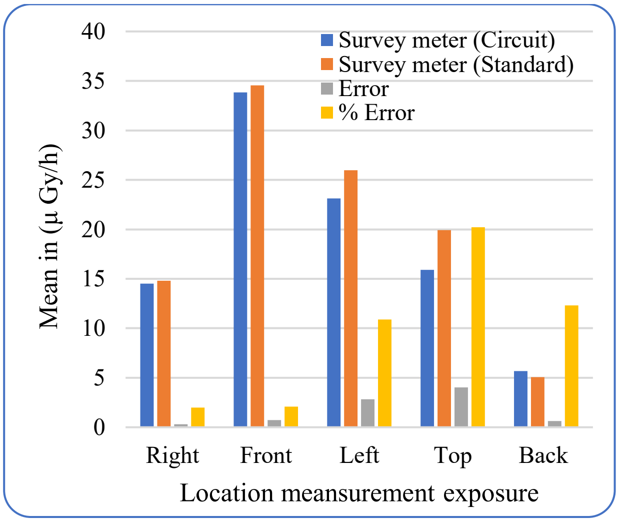


**FIGURE 4. Mean exposure between survey meter (design) and survey meter (standard) covered with Pb 2 mm**

**TABLE 2**
**Error Value and % Error between Survey Meter (Module) and survey Meter (Standard) Covered with Pb 2 mm**

| Area | Mean (µGy/h) | | Error | % *Error* |
|---|---|---|---|---|
| | ***Survey meter*** **(Module)** | ***Survey meter*** **(Standard)** | | |
| **Right** | 14.94 | 14.80 | 0.14 | 0.9 |
| **Front** | 32.44 | 34.56 | 2.12 | 6.1 |
| **Left** | 26.14 | 25.96 | 0.18 | 0.7 |
| **Top** | 18.64 | 19.92 | 1.28 | 6.4 |
| **Back** | 5.62 | 5.06 | 0.56 | 11.2 |

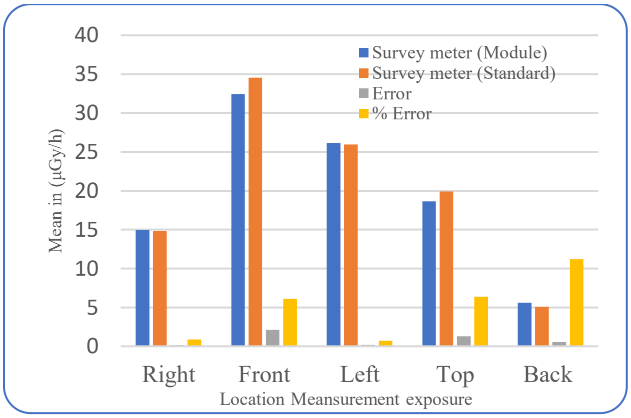


**FIGURE 5. Mean exposure between survey meter (design) and survey meter (standard) covered with Pb 2mm**

Correction value is the difference from the average value of survey meter (module) with survey meter comparison (TABLE 2). The percentage of error is the difference from the average tool module with the average of correct values that are considered to be correct where the survey meter comparison value (calibrator) is considered always correct. The largest correction value on the front area measurement is 2.12 μGv/h, while the largest percentage of errors in the rear area measurement is 11.2%, but the correction value is only 0.056 μGv/h. FIGURE 5 describes an average diagram pattern between the Survey Meter (Circuit) and Survey Meter (Standard) of the 2 mm Pb Coated area, where in the front position is the largest average error, which is 32.44 and 34.56. Measurement of X-ray tubes not covered with Pb 2mm (TABLE 3)

TABLE 3
**Error Value and % Error between Survey Meter (Circuit) and survey Meter (Standart) not Covered with Pb 2 mm**

| Area | Mean (μGy/h) | | Error | % Error |
|---|---|---|---|---|
| | *Survey meter* (Module) | *Survey meter* (Standard) | | |
| Right | 13.92 | 15.96 | 2.04 | 12.8 |
| Front | 32.02 | 36.32 | 4.30 | 11.8 |
| Left | 21.30 | 24.20 | 2.90 | 12.0 |
| Top | 16.72 | 18.10 | 1.38 | 7.6 |
| Back | 6.12 | 5.98 | 0.14 | 2.3 |

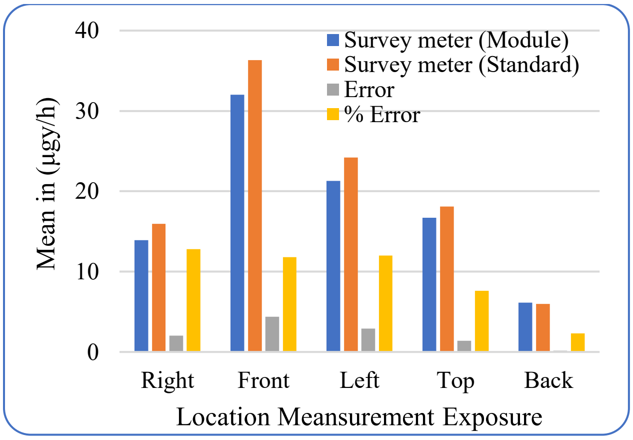


FIGURE 6. **Mean exposure between survey meter (design) and survey meter (standard) covered Pb 2 mm**

The largest error value on the front area measurement is 4.30 μGv/h, while the largest percentage of errors in right area measurements is 12.8%, but the error value is only 2.04 μGv/h. The smallest percentage of errors in the rear area measurement is 2.3% with an error value of 0.14 μGv/h (TABLE 3). FIGURE 6 describes an average diagram pattern between the Survey Meter (Circuit) and Survey Meter (Standard) of the 2 mm Pb Coated area, where in the front position is the largest average error, which is 32.02 and 36.32

TABLE 4
**Error Value and % Error Between Survey Meter (Module) and Survey Meter (standard) not Covered with Pb 2 mm**

| Area | Mean (μGy/h) | | Error | % Error |
|---|---|---|---|---|
| | *Survey meter* (Module) | *Survey meter* (Standard) | | |
| Right | 13.48 | 15.96 | 2.48 | 15.5 |
| Front | 30.18 | 36.32 | 6.14 | 16.9 |
| Left | 18.62 | 24.20 | 5.58 | 23.1 |
| Top | 16.00 | 18.10 | 2.10 | 11.6 |
| Back | 6.22 | 5.98 | 0.24 | 4.0 |

The largest error value on the front area measurement is 6.14 μGv/h, while the largest percentage of errors in the left area measurement is 23.1%, but the error value is only 0.06 μGv/h. The smallest percentage of errors in the rear area measurement is 4.0% with an error value of 0.24 μGv/h (TABLE 4). From the two tables above obtained the smallest error value on the measurement of the back area both in covered and non-covered conditions Pb 2mm.

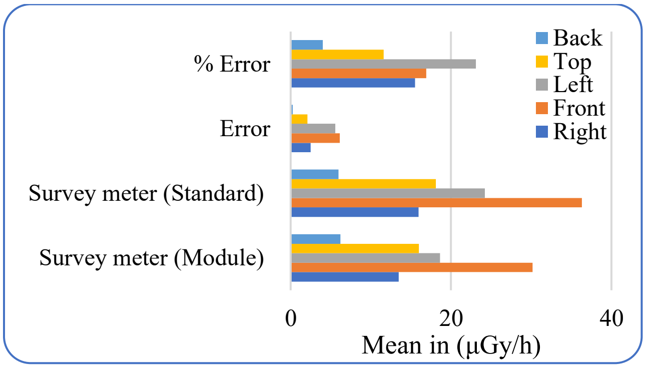


FIGURE 7. **Graphic Mean between Survey Meter (Module) and Survey Meter (standart) not Covered with Pb 2 mm**

FIGURE 7 describes an average diagram pattern between the Survey Meter (Circuit) and Survey Meter (Standard) of the 2 mm Pb Coated area, where in the front position is the largest average error, which is 30.18 and 36.32

*2) X-Ray Tube Leak Test Results*

Based on the table above, a corrected value with a covered condition of Pb on the circuit obtained 0.00097 mGy/h, in modules of 0.00093 mGy/h and at standards of 0.001 mGy/h. Meanwhile, the value is corrected with the condition of not covered Pb on the circuit of 0.00092 mGy/h, on the module of 0.00097 mGy/h and at the standard of 0.00105 mGy/h. The smallest error value was compared by standard survey meter with 2 conditions in the survey meter above using a circuit. It can be concluded that the measurement of tube leakage using survey meters either circuit, module, or standard survey meter shows a good test pass value that is ≤1.

TABLE 5
**Corrected Value Comparison in X-Ray Tube Leak Test**

| Corrected Value (mGy/h) | | | | | | Grade passes test (mGy/h) |
|---|---|---|---|---|---|---|
| Covered by Pb | | | Not Covered by Pb | | | |
| Standar | Circuit | Design | Standar | Circuit | Design | |
| 0.001 | 0.00097 | 0.00093 | 0.00105 | 0.00092 | 0.00087 | ≤ 1 |
| **0** | 0.00003 | 0.00007 | **0** | 0.00013 | 0.00018 | |

## IV. Discussion

The survey meter design has been thoroughly examined and tested in this study, both survey meters (circuits) on modules and survey meters (standard). There is a difference in the error value, namely the largest error in the front area, amounting to 4.3 and the smallest error in the back area, which is 0.14. Based on dose measurements in the right, left, front, top and back areas of the X-ray tube in the area covered by 2mm Pb and not covered by 2mm Pb, it can be stated that the measurement error value lies in the front and back areas. Furthermore, the results of the measurement of X-ray Tube Leakage were obtained based on the steps in accordance with the Decree of the Minister of Health of the RI. No. 1250/MENKES/SK/XII/2009 concerning Guidelines for Quality Control of Radiodiagnostic Equipment for X-Ray Tube Leakage Tests at Home. The smallest error value was obtained in the measurement of the back area both in closed and unclosed conditions of 2mm Pb. In addition, next the results of the X-Ray Tube Leakage test are tube leakage measurements using a survey meter either in series, module, or standard survey meter showing a good passing test value, namely 1.

## V. Conclusion

The purpose of designing the equipment in this module is to design survey meter equipment using the Geiger Muller sensor. The results of this study obtained the largest average radiation rate value in the front area, both survey meters using circuits, using modules and standard survey meters. The results of the tube leakage test using a survey meter for circuits, modules, and a standard survey meter show a good passing value of 1mGy/hour. In closed conditions the 2mm Pb survey meter using circuits and modules tends to be more precise because it has a smaller standard deviation than the standard survey meter. However, in the open condition, the standard 2mm Pb survey meter tends to be more precise because the standard deviation is smaller than in circuits and modules. In future research, it is expected that more modifications to size improvements, hardware design to be easy to carry and store, and display modifications for direct data storage on smartphones.

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