# Validation of Calibration of Area monitoring and Individual monitoring Instruments

Lab report

**Pushpraj Bhardwaj**

Roll No: 221126006
M.Sc. Medical and Radiological Physics,
Semester: 4th
Centre for Medical and Radiation Physics,
National Institute of Science Education and Research Bhubaneswar

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# 1 Aim of experiment

To Validate the calibration of radiation survey instruments and Pocket Dosimeters.

# 2 Apparatus Required

1. Radiation Survey Meter
2. Digital Contamination Monitor
3. Micro Digital Pocket Dosimeter
4. Cs-137 source with Lead Shield
5. Calibration Bench and other accessories

# 3 Theory

## 3.1 Radiation Monitoring

Radiation monitoring is carried out:

- To assess workplace conditions and individual exposures
- To ensure acceptably safe and satisfactory radiological conditions in the workplace
- To keep records of monitoring, over a long period of time, for the purposes of regulation or as good practice.

Radiation monitoring instruments are used both for area monitoring and for individual monitoring.The instruments used for measuring radiation levels are referred to as area survey meters (or area monitors) and the instruments used for recording the dose equivalents received by individuals working with radiation are referred to as personal dosimeters (or individual dosimeters).Radiation survey meters and contamination monitors are categories of area monitoring devices where as digital pocket dosimeter is a category of personal monitoring device.

All instruments must be calibrated in terms of appropriate quantities used in radiation protection.

## 3.2 Radiation Monitoring Instruments

Radiation Survey meters and Contamination Monitors are essential hand-held instruments employed for measuring ionizing radiation levels in environments containing radioactive sources or radiation-generating equipment. These instruments utilize gas-filled radiation detectors, semiconductor radiation detectors, or scintillation detectors. Among these options, gas-filled radiation detectors are particularly prevalent. Gas-filled detectors are categorized into three types: the Ionization chamber, the Proportional counter, and the Geiger-Muller (G.M.) counter, each functioning within its specific voltage region.

The Ionization chamber operates in the voltage region where the applied voltage is sufficiently low to ensure that only charged particles undergoing only primary ionisation are detected. This type of detector is commonly used for measuring high radiation levels and is characterized by its ability to directly measure radiation dose rates.

The Proportional counter operates in a slightly higher voltage region and more sensitive compared to the ionization chamber. In this voltage range, the gas amplification factor increases, allowing the detector to accurately measure radiation levels across a wider range, even in low intense radiation fields. Proportional counters are often employed in applications where precise measurements of radiation levels are required, such as in environmental monitoring or medical physics.

The Geiger-Muller (G.M.) counter operates at still higher voltages.Because of the large charge amplification (9 to 10 orders of magnitude), widely used at very low radiation levels (e.g., in areas of public occupancy around the radiotherapy treatment rooms). Exhibit strong energy dependence at low photon energies and are not suitable for the use in pulsed radiation fields. They are considered ‘indicators’ of radiation, whereas ionisation chambers are used for more precise measurements.

GM based monitors Suffer from very long dead-times, ranging from tens to hundreds of ms. For this reason, GM counters are not used when accurate measurements are required of count rates of more than a few 100 counts per second. A portable GM survey meter may become paralysed in a very high radiation field and yield a zero reading. Therefore ionization chambers should be used in areas where radiation rates are high.

Depending upon the electronics used, the detectors can operate in a ‘pulse’ mode or in the ‘mean level’ or current mode. The proportional and GM counters are normally operated in the pulse mode. Because of the finite resolving time (the time required by the detector to regain its normal state after registering a pulse) these detectors will saturate at high intensity radiation fields.Ionization chambers, operating in the current mode, are more suitable for higher dose rate measurements.

### 3.2.1 Semiconductor based Monitoring Instruments

Semiconductor Detectors act like solid-state ionization chambers on exposure to radiation and, like the scintillation detectors, belong to the class of solid-state detectors.

- Extrinsic semiconductors, like silicon or germanium, are used to form junction detectors.
- They too act as solid-state ionization chambers on an application of a reverse bias to the detectors and exposure to radiation.
- The sensitivity of solid state detectors is about $10^4$ times higher than that of gas-filled detectors due to the average energy required to produce an ion pair is very less( 2 to 3 eV ) and the material density (typically 3 orders more) compared to gases.
- This helps in miniaturizing solid-state radiation-monitoring instruments.

### 3.2.2 Contamination Monitoring Instruments

Radioactive contamination is defined as the presence of radioactivity in undesired place. Open radioactive substances are widely used in nuclear medicine, in nuclear technology and also in many fields of research. In those applications radiation protection requires precise measurement of surface contaminations of radio nuclides.

Surface contaminations are measured as activity per unit area [Bq/cm2] for specified radio nuclides. These values are subject to regulatory limits.

**Radioactive Contamination**

- Work with unsealed radioactive materials generates potential contamination of surfaces and it might be spread onto other objects.
- Contamination occurs when material that contains radioactive atoms is deposited on materials, skin, clothing, or any place where it is not desired. Or when radioactive materials may be released into environment as the result of an accident, or as an act of terrorism. Such a release could contaminate the surroundings and expose people.
- Radioactive materials released into the environment can cause air, water, surfaces, soil, plants, buildings, people, or animals to become contaminated.
- A contaminated person has radioactive materials on or inside their body.

Radioactive materials released into the environment can cause air, water, surfaces, soil, plants, buildings, people, or animals to become contaminated.

Radioactive contamination of various surfaces by

• Pure $\gamma$-radioactive radionuclides (existing domestic standards of radiation safety do not include allowable values for contamination by sources of $\gamma$ -radiation).

• -emitting radionuclides: (present the most significant challenge in being measured because almost anything stops an alpha particle).

**Detectors used**

1. NaI(Tl), CsI(Tl) molded into various shapes for detecting $\gamma$-ray contamination
2. ZnS(Ag) : Zinc sulphide powder coatings (5– 10 mg/cm2

   ) on glass or plastic substrates or coated directly onto the photomultiplier window for detecting alpha and other heavy particles.
3. Plastic scintillators for beta detection.

**Instruments for Surface Contamination**

1) Pan Cake / End window GM

2) Gas flow Proportional counters

3) Scintillators

### 3.2.3 Pocket Dosimeter

Pocket dosimeters are used to provide the wearer with an immediate reading of his or her exposure to x-rays and gamma rays. As the name implies, they are commonly worn in the pocket. The two types commonly used in industrial radiography are
• Direct Read Pocket Dosimeter
• Digital Electronic Dosimeter

**Direct Read Pocket dosimeter**

A direct reading pocket ionization dosimeter is generally of the size and shape of a fountain pen. The dosimeter contains a small ionization chamber with a volume of approximately two milliliters. Inside the ionization chamber is a central wire anode and attached to this wire anode is a metal coated quartz fiber. When the anode is charged to a positive potential, the charge is distributed between the wire anode and quartz fiber. Electrostatic repulsion deflects the quartz fiber, and the greater the charge, the greater the deflection of the quartz fiber.

Radiation incident on the chamber produces ionization inside the active volume of the chamber. The electrons produced by ionization are attracted to, and collected by, the positively charged central anode. This collection of electrons reduces the net positive charge and allows the quartz fiber to return in the direction of the original position. The amount of movement is directly proportional to the amount of ionization which occurs. By pointing the instrument at a light source, the position of the fiber may be observed through a system of built-in lenses. The fiber is viewed on a translucent scale which is graduated in units of exposure. Typical industrial radiography pocket dosimeters have a full scale reading of 200 milliroentgens but there are designs that will record higher amounts. During the shift, the dosimeter reading should be checked frequently. The measured exposure should be recorded at the end of each shift.

**Digital Electronic Dosimeter**

Another type of pocket dosimeter is the Digital Electronic Dosimeter. These dosimeters record dose information and dose rate. These dosimeters most often use Geiger-Müller counters. The output of the radiation detector is collected and, when a predetermined exposure has been reached, the collected charge is discharged to trigger an electronic counter. The counter then displays the accumulated exposure and dose rate in digital form.

Some Digital Electronic Dosimeters include an audible alarm feature which emits an audible signal or chirp with each recorded increment of exposure. Some models can also be set to provide a continuous audible signal when a preset exposure has been reached. This format helps to minimize the reading errors associated with direct reading pocket ionization chamber dosimeters and allows the instrument to achieve a higher maximum readout before resetting is necessary.

Here we will validate the calibration of the following monitoring devices mentioned with their model no.s

### 3.2.4 Radiation survey meter [ Model: RM701N]

Radiation Survey Meter (micro) RM701N is a G.M. Detector-based, battery-powered, handheld, ruggedized general-purpose radiation survey meter used for radiation survey, area monitoring, and ambient radiation monitoring. It uses a thick-walled G. M. Tube with Energy energy-compensated filter to detect X-ray and gamma radiation above energies of about 60 keV to 1.3 MeV. It has an overall wall thickness of about 1-2 mm chrome steel. It can measure radiation levels in the range of 0 -10 R/hr .


Figure 1: Figure depicting the GM based Radiation Survey meter (left) and Thick walled GM tube(right)

### 3.2.5 Digital contamination monitor [Model: CM710N]

Digital Contamination Monitor CM710N is a microcontroller-based unit that essentially serves as a low-level alarming survey meter cum beta contamination monitor to measure the contamination of personnel, work areas, flooring, contamination of source housings, ports of therapy machines, industrial sources, etc. It can measure contamination in CPS or CPM mode and low-level gamma dose rate in mR/hr or µSv/h. It consists of a Pancake GM detector housed inside a cylindrical housing with a handle. The contamination probe is fixed into a clamp on one side of the instrument. The probe has a cap for Beta/Gamma selection and can measure dose rate in the range of 0 – 200 mR/hr.

Figure 2: Figure depicting Digital Contamination Monitor(left) with pancake GM detector(right)

### 3.2.6 Micro-digital Pocket Dosimeter [Model: MPD-1501]

Pocket dosimeters are an integrating device that measures immediate cumulative exposure dose by x-rays and gamma rays. The pulses from the detector are counted in a counter that reads in every 5-second interval. It is based on semiconductor detectors and used in the range of 1Sv to 1Sv. The detector mostly used is a Silicon (Si) rectifier diode operating at a low reverse bias voltage of 4V. A charge-sensitive amplifier based on a low-power CMOS IC amplifies the pulses from the detector. The detector and the amplifier circuits are provided with an energy compensation filter, which also acts as electromagnetic shielding and is enclosed in an anti-vibration polyurethane compound to reduce sound wave interference. The pulses from the amplifier are fed to a discriminator with a threshold voltage adjusted to cut off the noise. The pulses at the output of the discriminator are fed to a programmable divider circuit to calibrate the dosimeter so that one count corresponds to 1Sv (137Cs gamma). It provides a continuous digital readout of X and Gamma radiation dose displayed in a 6-digit counter-LCD-display. The block diagram of the pocket dosemeter is shown in Fig.1

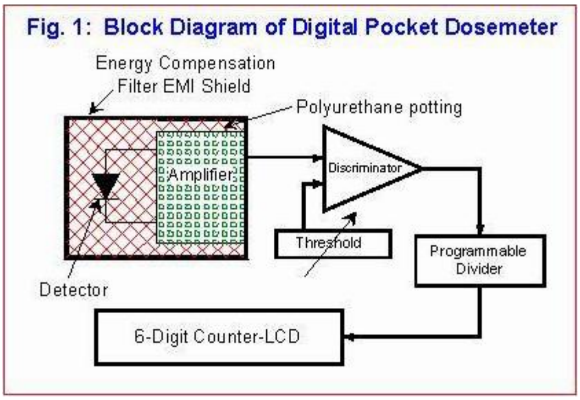


Figure 3: Block diagram of Digital pocket dosimeter


Figure 4: Micro digital Pocket dosimeter at CMRP lab

#### 3.2.7 Calibration of Radiation Instruments

Calibration involves determining the relationship between the output of a radiation measuring instrument and the actual radiation level it is intended to measure under controlled conditions. The primary aim of calibration is to verify the proper functioning of the instrument, ensuring its suitability for monitoring purposes. Additionally, calibration enables the identification of any discrepancies between the measured quantity and its true value, allowing for adjustments to the calibration factor to enhance overall measurement accuracy. Periodic calibration of radiation survey and measuring instruments is imperative to ensure the reliability of readings and comply with regulatory standards. An effective method for calibration involves exposing the instruments to a known radiation field with a known dose rate, typically generated by radioactive sources. Different calibration factors are utilized for beta ($\beta$) and gamma ($\gamma$) radiations. The known dose rate can be derived from the exposure rate constant of the specific radionuclide employed.

# 4 Observation

Source:Cs-137
Activity:3.7MBq
Average Background dose rate is

$$BKG = \frac{0.013 + 0.009 + 0.013 + 0.023 + 0.018}{5} = 0.0152$$

After taking into the account the decay correction as the source is callibrated since september 2022.So present activity is given by

$$A = A_o e^{-\lambda t} = (3.7 \times 10^6) e^{-\frac{0.693}{30.05} \times 1.416} = 3.58MBq = 0.96785 \times 10^{-4} Ci$$

Now the True dose rate in R/hr at 50 cm distance is given by,

$$TDR = \frac{k.A}{d^2} = \frac{(0.33)(0.96785)}{(0.5)^2} = 0.128mR/hr$$

## 4.1 Response for contamination monitor

Figure 5: Figure depicting Experimental setup for Contamination monitor

### 4.1.1 Tabulation

Distance: 50 cm

| **True dose rate (mR/h)** | **Observed dose rate ODR (mR/h)** | | | | | | **Corrected dose rate CDR (mR/h) CDR=ODR-BKG** | **uncertainity (in %)** |
|---|---|---|---|---|---|---|---|---|
| 0.128 | 1 | 2 | 3 | 4 | 5 | Avg | 0.133 | 3.9 |
| | 0.150 | 0.147 | 0.149 | 0.153 | 0.141 | 0.148 | | |

## 4.2 Response for Radiation Survey meter

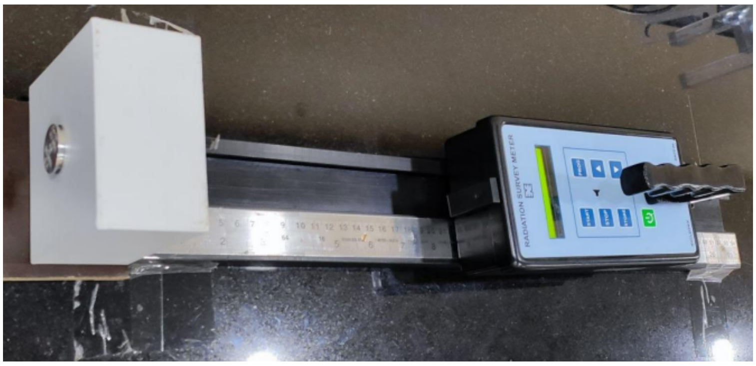

Figure 6: Figure depicting Experimental setup for Radiation Survey meter

### 4.2.1 Tabulation

Distance: 50 cm

| **True dose rate (mR/h)** | **Observed dose rate ODR (mR/h)** | | | | | | **Corrected dose rate CDR (mR/h) CDR=ODR-BKG** | **uncertainity (in %)** |
|---|---|---|---|---|---|---|---|---|
| 0.128 | 1 | 2 | 3 | 4 | 5 | Avg | 0.114 | 11.7 |
| | 0.124 | 0.129 | 0.125 | 0.13 | 0.14 | 0.129 | | |

### 4.3 Response for digital pocket dosimeter

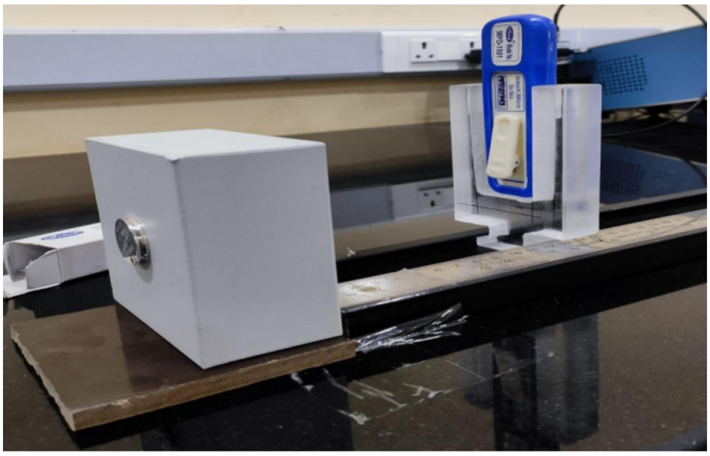

Figure 7: Figure depicting Experimental setup for pocket dosimeter

#### 4.3.1 Tabulation

Distance: 10 cm
The True dose rate in R/hr at 10 cm distance is given by,

$$TDR = \frac{k.A}{d^2} = \frac{(0.33)(0.96785)}{(0.1)^2} = 3.19mR/hr = 3.19 \times 0.876 \times 10^{-5}Gy/hr = 27.94\mu Sv/hr$$

True dose at 10 min = 27.94 $\times \frac{10}{60} \mu$ Sv/min = 4.65 $\mu$ Sv/min
True dose at 20 min = 9.31 $\mu$ Sv/min

| Sr no. | Time(min) | True dose(uSv) | Observed dose(uSv) | | Uncertainty (in%) | |
|---|---|---|---|---|---|---|
| | | | MPD21742 | MPD7143 | MPD21742 | MPD7143 |
| 1 | 10 | 4.65 | 5 | 5 | 7.52 | 7.52 |
| 2 | 20 | 9.3 | 8 | 9 | 13.9 | 3.2 |

# 5 Conclusion

The calibration validation experiment conducted on the radiation survey meter, contamination monitor, and pocket dosimeter yielded uncertainty percentages of 3.9 %, 11.7 %, and 7.5 %, respectively. These values fall comfortably within the acceptable range specified by the instrument manufacturing company, which dictates that the uncertainty percentage should be within ±15 %.

The experiment assessing the calibration of the radiation survey meter, contamination monitor, and pocket dosimeter revealed uncertainty percentages of 3.9 %, 11.7 %, and 7.5 % respectively. These values are comfortably within the acceptable range outlined by the instrument manufacturer, which specifies an uncertainty percentage of ±15 %.

These results affirm the reliability and accuracy of calibration for all three instruments in their intended monitoring roles. Notably, the radiation survey meter exhibited the lowest uncertainty, followed by the pocket dosimeter and then the contamination monitor. Although the contamination monitor showed a slightly higher uncertainty percentage compared to the others, it still falls within the acceptable calibration criteria.

These outcomes provide confidence in the instruments' suitability for radiation monitoring tasks, ensuring precise readings within an acceptable level of uncertainty. Nonetheless, it remains essential to conduct regular calibration checks as per regulatory standards to uphold the instruments' performance and guarantee ongoing accuracy in radiation measurements.

Overall, the validation of calibration confirms the effectiveness of calibration procedures and highlights the significance of periodic checks to maintain the reliability and precision of radiation monitoring instruments.

## References

[1] *CMRP Lab manual*

[2] *https://www.barc.gov.in/technologies/dg/index.html*

[3] *Glenn F knoll Radiation detection and measurement*