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RADIATION DETECTORS TEST FOR X-RAYS AND GAMMA RAYS SENSITIVITY

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ABSTRACT

Radiation monitoring is an integral part of good health physics practice at every medical facility performing any radiation therapy activities. It is the core disciplines of RSOs, Health Physicists, Medical Physicists, radiologists, and Nuclear Medicine Techs to be acutely aware of radiation exposure rates for facility staff and patients. Radiation Safety Officers are responsible for all RCA (Radiation Controlled Areas) areas in the buildings. They have the responsibility to keep track of a critical RCA that requires radiation monitoring by using contamination survey meters, area monitoring, or passive and active dosimetry for facility staff or patients.[3] In this research work, a set of measurements was taken on one of the radiation detectors used in measuring radioactivity, which is the SAPHYMO radiation detector (SAPHYMO, type SPP-2-2NF, scintillation meter, made in France. SN: 992287 – 001923, SN: 992287 – 001925, SN: 00245950, and SN: 03771), to determine the scope of use of the device. The results of the measurements showed the device's high response to radiation after being exposed to gamma rays and X-rays at different distances. It is noted that the measurement rate is very high at short distances. These results confirm the use of the device in environmental measurements and health facilities.

KEYWORDS: Detector, Monitoring, gamma-rays, Radiation, Response, X-rays, environment.

I. INTRODUCTION

A sensor is a device, or an element of a system used to measure physical, chemical, biological, and any other parameters, and is fundamental for monitoring, measurement, and control systems.[2] Radiation is defined as the energy emitted from a source through a medium in the form of waves and particles, from radio waves - the lowest wavelength, to gamma radiation - the highest energy in the electromagnetic spectrum. A nuclear detector is a unique instrument that is used to detect nuclear particles such as alpha particles, beta particles, gamma-ray, X-rays, protons, neutrons, etc., based on the principle of ionization.[3] When a highly energetic nuclear particle enters a material medium, it ionizes the medium, and, through different sensor mechanisms, the radiation can be detected. The detection of such energy requires different types of sensors, broadly classified in Figure (1).

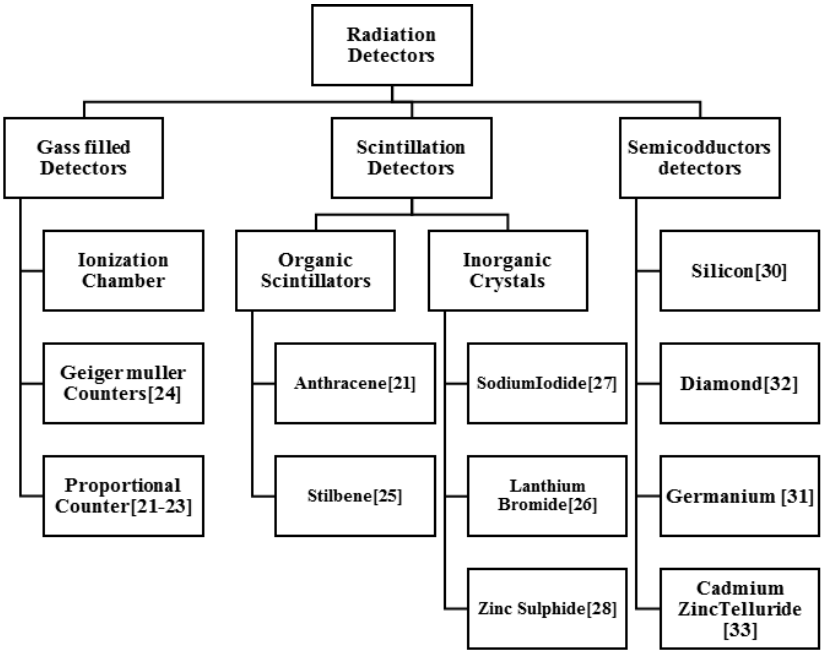

Fig. 1: The classification of radiation detectors.

Radiation detectors can be classified into different types. The following are some of these.

a. GAS-Filled Detectors

The gas-filled detector is the simplest, compared to a scintillator detector or a semiconductor detector. This type of detector consists of a metallic cylinder, or one made of other materials such as plastic, containing an electrode filled with inert gas as the medium and is connected to the pure capacitive load or an electrical circuit with a power supply, load resistor, and a signal. In the case that an incident ionizing radiation enters the medium; it ionizes the inert gas and produces ion-free electron pairs which are later subjected to the electric field. While the positive ion moves toward the surface of the cylinder, the free electron moves toward the electrode and into the electric circuit, generating an electric pulse or count before it returns to the metallic cylinder recombines with the positive ion, and becomes neutral again. There are three types of Gas-Filled Detectors - an ionization chamber, a proportional counter, and a Geiger-Muller Counter.[5]

An Ionization Chamber is the simplest form of a gas-filled detector that measures the exposure rate of X-ray and gamma radiation and the dose absorbed via the application of the Bragg-Gray principle, operating at a low voltage that does not induce an avalanche of electrons and does not have a dead time issue.[15] An ionization Chamber can detect alpha particles and beta particles with the application of a thin window.[10] Applications that utilize ionization chambers include radiation survey instruments[7], a radiation source calibrator, and the remote sensing of ionization.[30]

The work in[15] states that the radial electric field between the cathode and the anode is generated by applying a positive high voltage to the anode, higher than the ionization chamber to induce the gas amplification phenomenon, which is the acceleration of free electrons from the initial ionization in a strong electric field inducing Townsend avalanche. This secondary type of ionization occurs at the threshold field of the order of 106 V/m.[30]

The proportionality between the size of the output pulse and the total loss of energy as a result of the incident radiation defines the proportional counter and is reliable for alpha and beta discrimination and used as a soft X-ray spectrometer for contamination screening[21], as well as for neutron detection.[3]

b. Geiger-Muller Detector

The Geiger-Muller (GM) tube follows the same mechanism as a proportional counter by inducing a Townsend avalanche, but the gas amplification caused by a single avalanche is higher, in the order of 106–108 [30]. The de-excitation of secondary free electrons releases an ultraviolet photon with sufficient energy to cause another avalanche originating from the gas or even the tube wall, and an uncontrolled chain avalanche occurs throughout the entire volume of gas in the cylinder. This entire process takes between 200 µs–400 µs to complete. During this time, the Geiger-Muller detector is dead, and incapable of detecting further nuclear particles. Adding alcohol, for example, 10% ethanol, inside the gaseous tube may absorb the excess energy in the form of vibrational and rotational energy. Thus, it helps to reduce the dead time of the counter before it can count again. Since a low energetic particle can cause an avalanche across the entire chamber, the Geiger-Muller counter cannot differentiate the energy of the incident particles based on the pulse size for selective energy counting.[3] Nonetheless, the Geiger-Muller counter is a reliable instrument that can be used to detect the presence of charged particles, neutrons, and photons.[7]

c. Scintillation Detector

Scintillation is the property of a material medium that when a charged particle enters, it absorbs its energy and leads to the emission of light. There are two types of scintillation, the first is counter—organic scintillation, such as anthracene[15] and stilbene[30], and the second is inorganic crystal scintillators such as lanthanum bromide (LaBr3)[14], sodium iodide (NaI)[1], and zinc sulfide (ZnS).[10] The ultraviolet light formed in the scintillator focuses on a photocathode, thereby inducing a photoelectric effect, and later hits a series of dynodes with a different potential difference that will undergo amplification in the photomultiplier tube. The collection of the electrons is interpreted by a pulse amplifier. Besides gamma rays and charged particles, a scintillation detector is often used in wavelength-dispersive X-ray fluorescence spectrometers and can be applied to detect a high-energy X-ray.[14]

d. Semiconductor Detector

A semiconductor detector is an alternative to gas-filled and scintillation detectors. A compact detector, with a solid density of 1000 times greater than gas, can provide more carrier information for a given incident radiation event than is possible compared to other types of the detector.[30] When using a PN junction diode doped with silicon[5], germanium[2], diamond[14], or cadmium zinc telluride (CZT)[6], the incident radiation enters the depletion region, causing the thermal excitation of the electron (~3 eV) from a valance band to a conduction band, creating electron-hole pairs in a reverse bias configuration. Through the collection of electron-hole pairs, a detection signal is formed. Since the thermal excitation of an electron is low, a semiconductor detector can provide an enhanced energy resolution and is used for general charged particle spectroscopy[6], alpha particle spectroscopy[15], X-ray spectroscopy[6], gamma- ay[24], and personnel monitoring.[8] Unfortunately, this excellent detector is susceptible to performance degradation from radiation-induced damage.

II. RADIATION DETECTOR AND FOR MONITORING PURPOSES

All celestial bodies, including the earth, are products of certain energetic astrophysical processes known as nucleosynthesis, initiated by an explosive event called the Big Bang. After billions of years, and still ongoing, a series of nuclear processes, including fusion, neutron capture, proton capture, energetic particle interaction, and spallation, introduced the various nuclides known to us today.[15] This means that all living things are subjected to radiation exposure anywhere and at any time as radionuclides can be found naturally in air, soil, water, and food. According to[26], humans are exposed to radiation doses as high as 82% from cosmic and terrestrial sources, the inhalation of radioactive gas radon, and its decay product inside any building, which all occur naturally. Furthermore, the ingestion of Potassium-40 in food can also lead to exposure.[24,8] Thus, radiation exposure needs to be measured whether the radiation originates from background radiation or any other nuclear activity, for safety purposes.

a. Environmental Monitoring

As mentioned before, the formation of the Earth through a prolonged process of nucleosynthesis resulted in a significant number of radionuclides. They can be found terrestrially and at sea and can be categorized into

I. Pprimordial radionuclides, which include the radionuclides that are not completely decayed and as old as the Earth.

II. Secondary radionuclides, the product of decayed primordial radionuclides, and

III. Cosmogonic radionuclides which are the product of stable nuclides being continuously bombarded by cosmic rays in the atmosphere.[21] The distribution of these radionuclides, with the addition of anthropogenic radionuclides from human activities, varies from one place to another, and the radioactivity should be monitored.

b. Survey Meters

An important aspect of radiological safety for personnel is the performance of radiological surveillance. The surveillance gives the data needed to evaluate radiological conditions in rooms or areas of a facility and prescribe appropriate engineering and administrative controls to protect the workers. Personnel trained in radiation survey techniques and operation of monitoring instrumentation conduct these surveys. Proper evaluation of radiation levels in areas where work is to be performed ensures that no unanticipated personnel exposures occur and maintains worker exposures within established guidelines and regulatory limits.[23] The frequency of performing radiation surveys depends on various parameters, with an important parameter being the potential for fluctuation of radiation levels in the given area of the facility due to any changes in facility conditions or operating modes, e.g. shutdown versus operation. Another parameter is how often workers will access the given area. In the US, there is a regulation that continuously habited areas (that is, workers present 2,000 hours per year) of a nuclear facility must maintain exposure levels below an average of 5 PS v/h (0.5 mrem/hour) and as far below this average as reasonably achievable.[30]

III. EXPERIMENTAL WORK

To judge the sensitivity of The SAPHYMO radiation detector, it was used to measure the radioactivity at different distances from the radiation source. An analysis of the results can assist in determining the scope of the use of the device.

Experimental work was carried out in the Secondary Standard Dosimetry Laboratories (SSDL), where the distances of the radiation detectors from the radiation source were adjusted by laser beams. The detectors were monitored inside the laboratory by camera and television to take measurements during irradiation.

Devices and equipment that used to carry out the work were

a. X-Ray machine: with an output voltage of 13.5 KV to 320 KV and a maximum current of 22.5 mA, model MGC-30, manufactured by PHILPS.

b. Cesium radiation source (CS-137): serial number n40095 and with a radioactivity of 0.001Ci.

c. Four radiation detectors: SAPHYMO, type SPP-2-2NF, scintillation meter, made in France. SN: 992287 – 001923, SN: 992287 – 001925, SN: 00245950, and SN: 03771.

(A) Saphymo **(B) The gauge**

(C) Scintillometre **(D) The probe**

Fig. 2: The main components of the SAPHYMO radiation detector.

These components were used to carry out the experimental work by utilizing the TV camera to monitor the devices during irradiation and follow the measurement. The three laser beams were used for alignment and adjustment. Besides these, a 20 mm lead thickness and a set of holders were also used.

IV. MEASUREMENTS AND RESULTS

Two radiation sources were used in this work. One was an X-ray, and the other was a gamma ray cesium-137. The first set of measurements was done to detect the X-ray. To increase the reliability of the work, four detectors of SAPHYMO, type SPP-2-2NF with the serial numbers mentioned before were used. The x-ray source was adopted to 100 (KV) and the detectors were set at different distances from the source. The distances of the radiation detectors from the radiation source were adjusted by laser beams. The detectors were monitored inside the laboratory by camera and television to take measurements during irradiation. Pieces of 20 mm thick lead were placed between the detector and the X-ray machine to attenuate the X-rays. Then the radiation of the sources was measured at different distances. The average and the Uncertainty were computed as illustrated in table (1) here under.

Table 1: The first set of measurements.

Volt (KV)	Distance (cm)	average measurement (C/S)	Uncertainty
100	50	12500	10%
	60	9175	11%
	70	7150	10%
	80	5350	12%
	90	4475	11%
	100	3525	13%
	110	2825	14%
	120	2200	12%
	130	1500	11%
	140	962.5	10%
	150	857.5	12%
	160	757.5	12%
	170	672.5	12%
	180	580	13%
	190	475	13%
	200	392.5	12%
	210	307.5	14%
	220	225	11%
	230	150	12%

The average distances with the inverted square distances were plotted as shown in figure (1) below.

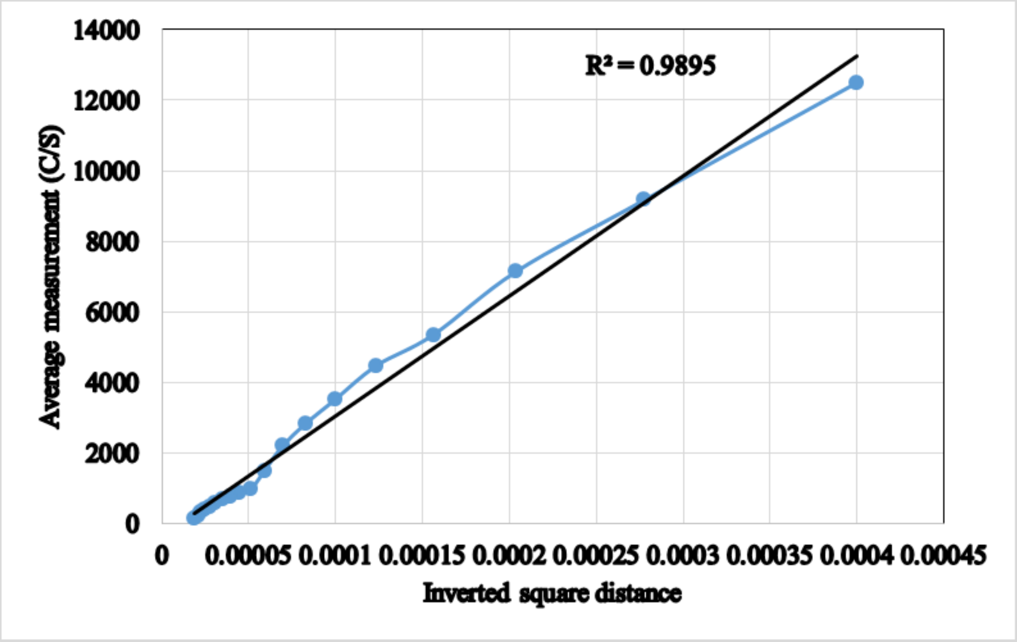

Fig. 3: The detected radiation against the inverted square distance at 100 kV X-rays.

A second set of measurements was carried out by adopting the x-ray source at 200 (KV) and applying the same procedures. The results were found as

Table 2: The second set of measurement.

Volt (KV)	Distance (cm)	average measurement(C/S)	Uncertainty
200	100	14300	9%
	110	11925	8%
	120	9500	8%
	130	8050	7%
	140	6475	8%
	150	4875	8%
	160	4025	10%
	170	3450	12%
	180	2300	13%
	190	1700	14%
	200	1150	14%

Again, the average distances with the inverted square distances were plotted as shown in figure (4) below.

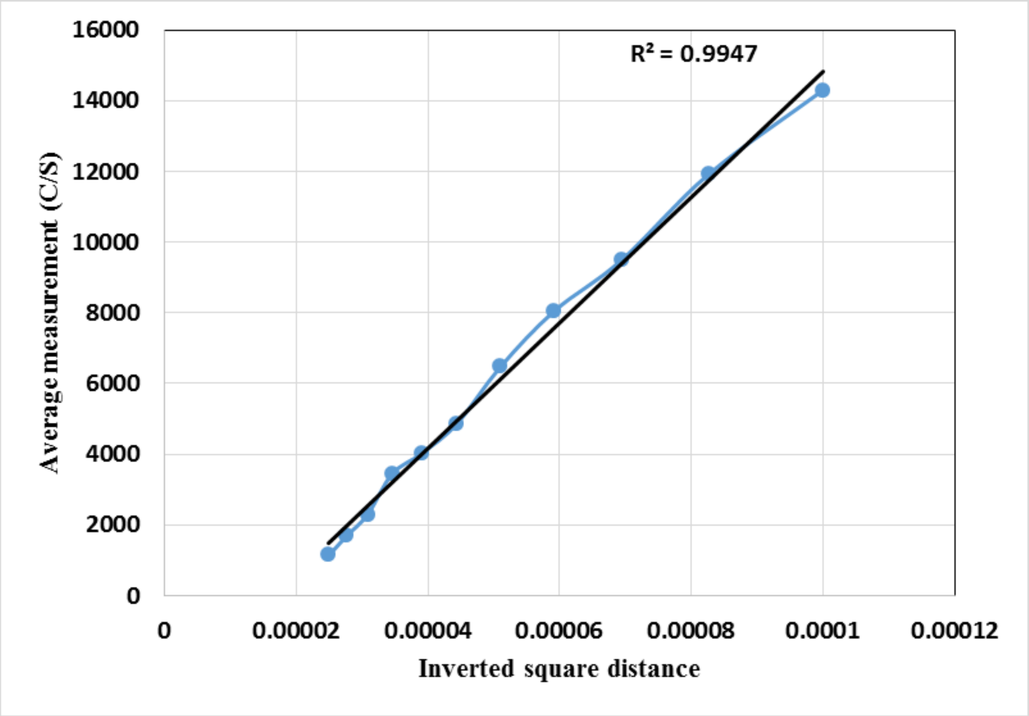

Fig. 4: The detected radiation against the inverted square distance at 200 kV X-rays.

From Figures (3) and (4), it can be noted that the radiation detector measurement shows a linear relationship with the inverse square of the distance from the X-ray radiation source at 100 KV and 200 KV, indicating an investigation of the inverse square law.

Form Table1, it can also be noted that, the uncertainty values in measuring low X-rays at 100KV or their quasi-stability are close, compared to Tables 2, 3, and 4. We note the divergence in the uncertainty values when measuring high X-rays (200KV) and when measuring gamma rays from a source (Cs-137). This shows that the device measures with high quality at low radiation energies.

The X-ray sources were used again to make the third set of measurements taking distances from 300 cm up to 360 cm. The results of these measurements were obtained as arranged in table (3) below.

Table 3: The average measurements and distance from 300 cm to 360 cm at 200 KV X-rays and the uncertainty of the measurement.

Volt (KV)	Distance (cm)	average measurement(C/S)	Uncertainty
200	300	812.5	7%
	310	707.5	8%
	320	547.5	8%
	330	472.5	11%
	340	382.5	12%
	350	292.5	13%
	360	202.5	14%

Figure (5) below illustrates the graphical relationship between the obtained results of the inverted square distance and the average measurements at 200 kV X-rays.

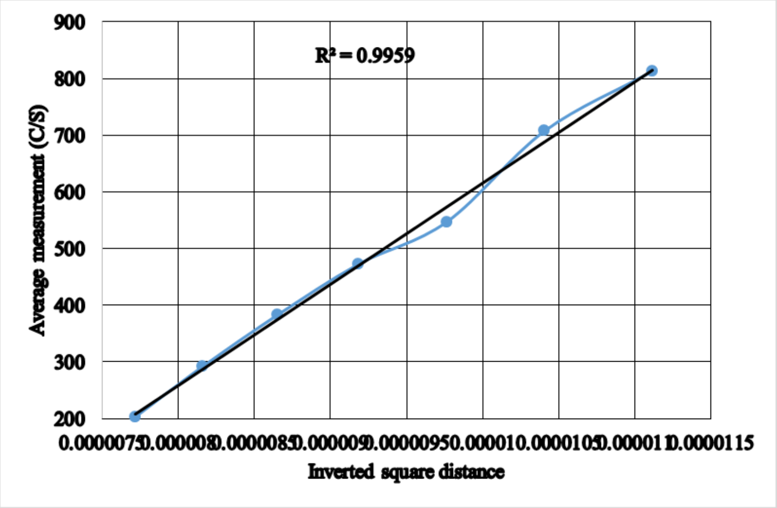

Fig. 5: The relation between the measurement and inverted square distance at 200 kV X-rays.

From Figures (4) and (5), it is shown that the radiation detector measurement is in a linear relationship with the inverse square of the distance from the X-ray radiation source at 200 kV. This also means that investigating the inverse square law, and the linear relationship implies that the detector is linear with the radiation intensity.

Finally, the X-ray source was changed to the gamma rays one (Cs-137). The radiation was measured at distances varied from 40 cm to 350 cm. The results of the average measurements and the uncertainty are tabulated as shown in table (4).

Table 4: The average measurement of Cs-137 and the uncertainty of the measurement.

Radiation Source	Distance (cm)	average measurement (C/S)	Uncertainty
Cs-137	40	14187.5	6%
	50	9437.5	5%
	60	6512.5	6%
	70	4950	5%
	80	4000	6%
	90	3225	7%
	100	2675	9%
	110	2200	10%
	120	1870	11%
	130	1600	12%
	140	1400	9%
	150	1250	5%
	175	962.5	6%
	200	768.8	7%
	225	638.8	11%
	250	525	10%
	275	456.3	11%
	300	435	10%
	350	362.5	9%

From Table (3) and Table (4), it can be noted that the device can measure at a distance far from radioactive sources, which means that the device can measure low radiation, enhancing its use in environmental fields.

Figure (6) below represents the relationship between the measurement and inverted square distance at the energy of Cs-137.

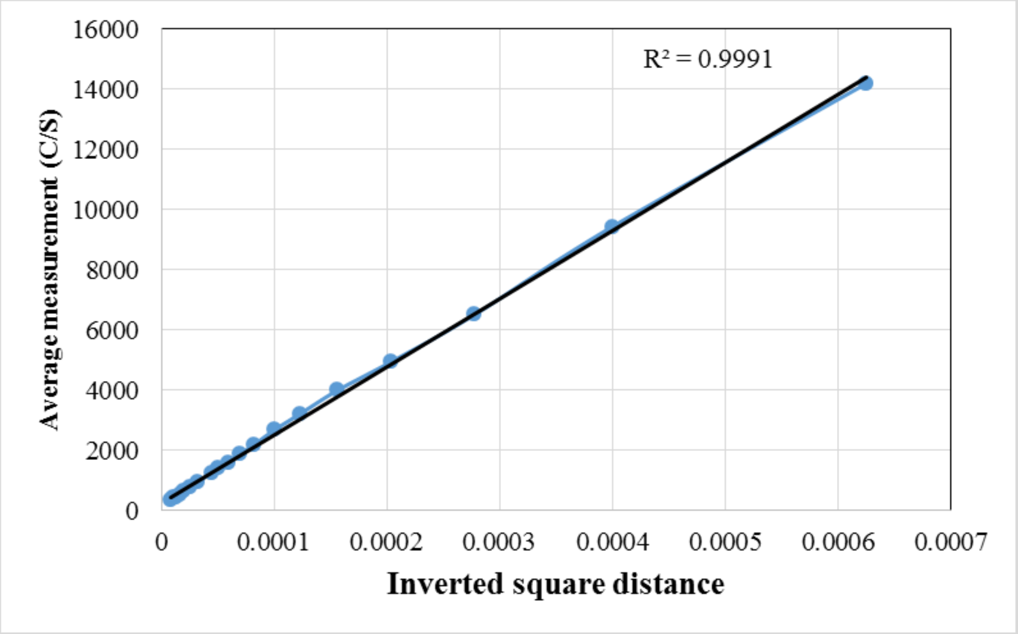

Fig. 6: The relation between the measurement and inverted square distance at the energy of Cs-137.

From Figure (6), it can be noted that there is an inverse relationship between the radiation detector measurement and the distance. It is clear that the relationship is inverse with the radiation source (Cs-137), and an increase in the distance measurement is met by a decrease in the radiation detector measurement.

V. CONCLUSIONS

Since radionuclides can be found naturally in air, soil, water, and food. All living things are subjected to radiation anywhere and at any time, thus for safety purposes, it is important to judge suitable detectors to deal with the situation whether the radiation originates from background radiation or any other nuclear activity.

This research work tried to explore the sensitivity of various detectors (SAPHYMO, type SPP-2-2NF, scintillation meter, made in France. SN: 992287 – 001923, SN: 992287 – 001925, SN: 00245950, and SN: 03771) to both X-ray and gamma-ray. From the experiments carried out and results obtained, it can be concluded with the following points.

- The sensitivity of all detectors used satisfied the inverse square low.
- The detectors' sensitivity is linear with the radiation intensity.
- The detector's sensitivity is inversely proportional to the distance from the radiation source.

- All detectors used in this work can be used successfully to measure low radiation, so it can be recommended to be used in environmental fields.

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