Suggestive Experimental Determination Of Alpha And Beta Radiation Contaminations Through Fluorescent Light Yield

Nwosu O B
Department of Physics and Industrial Physics,
Faculty of Physical sciences,
Nnamdi Azikiwe University Awka, Anambra State, Nigeria
bo.nwosu@unizik.edu.ng,

Abstract— **Ionisation and excitation property of alpha and beta radiation to induce ultraviolet and visible light was exploited in an experimental set-up aimed at trying to detect these emitters beyond their normal range in air. Am-241 alpha emitter and Sr-90 beta emitter enclosed in; air, nitrogen and water-filled vacuum chamber, mounted with bare photomultiplier, ultraviolet light transmitter and sets of photon counting electronics revealed good results. It confirmed alongside other researchers the emissions of ultraviolet and visible light, with the ultraviolet light yield up to 75% of the total light yield, suggesting that ultraviolet light could possibly be tracked as the nuclear signature owing to its advantages. Good counts at atmospheric pressure was equally recorded both within and beyond the Am- 241range in air unlike tracking radiations; suggesting that this method could possibly overcome the short range constraints encountered in measuring their radiations. The ultraviolet photon counts in air for alphas were found to be more than that for betas; suggesting that we could possibly use signal strength to differentiate between the two emitters. Good counts were obtained both in pure nitrogen and in air for alphas; suggesting that despite the more damping influence of other components of air, that this method can still be viable. The experiments also revealed that water does not produce much ionization and excitation light like air.**

Keywords—Am-241, ultraviolet radiation, alpha radiation, Beta radiation, ionisation, photon

1.0 INTRODUCTION

There has been need to develop detectors capable of detecting alpha and beta radiations beyond their short range in air. Being non-penetrating, instruments cannot detect alpha radiation even through a thin layer of dust, water and paper unlike penetrating gamma and neutron radiation. Alphas are known to have ranges between 2- 10cm in air

and 20-125μm in water [1]. Betas are known to have ranges between 0-10m in air and less than 2cm in water [1]. Attempts have been made in trying to monitor these radiations both indoors and outdoors after contaminations, nuclear/radiological accidents, in explorations etc. Long range alpha detector LRAD measures the ions created by the alphas in air when they are transported with the help of air flow and directed into the ion chamber [2]. This detector is said to have a smaller sensitivities for electrons. Alpha-Track Detectors; a piece of plastic that suffers radiation damage when it is exposed to alpha radiation; Electret Ion Chambers, Grab Sample (Kusnetz Method), are all used in environmental monitoring of radon [3]. However just like the Environmental Protection Agency's very low base scanner mobile laboratories van, they require that they are never kept beyond the range of the suspected alpha and beta emitters. Scintillation detectors and semiconductor detectors from low flying aircraft can map the distribution of gamma-ray emitting alpha and beta emitter (like uranium and plutonium) [4]. However this cannot detect pure emitters that have no or very low accompanying gamma ray. This study has suggested and explored a new and indirect principle aiming to detect both pure emitters (Sr-90) and those with accompanying gamma (Am-241), by going for the induced ultraviolet (UV) light photons emitted through their excitation and ionisation properties.

2.0 BACKGROUND THEORY

The UV and VIS light has been considered very importance by the chemists because their energy difference corresponds to that of electronic state of atoms and molecules [5]. This Optical spectroscopy is based on the Bohr-Einstein relationship as given in equation 1.0

$\Delta E = E_2 - E_1 = h\upsilon$ .1.0

This links the discrete atomic or molecular energy state Ei with the frequency υ of the electromagnetic radiation, *h* is the Planck's constant (6.626E-34Js) [5] Photon emission from ionisation and excitation process spans across different fields of physics like nuclear, atomic, solid state and molecular physics and is quite complex. The expression for the energy loss of radiation and stopping power in a medium during ionisation and excitation has been studied by; [6,7] and others and expressed for the alphas as equation 1.2 and for electrons as equation 1.3

$S = -\frac{dE}{dx}$ (MeV/m)=

$$4\pi r_o^2 z^2 \frac{mc^2{}_A}{\beta^2} NZ\left[\ln\left(\frac{2mc^2}{I}\beta^2\gamma^2\right) - \beta^2\right] \quad .1.2$$

$S = -\frac{dE}{dx}$ (MeV/m) =

$$4\pi\gamma r_o^2 \frac{mc^2{}_A}{\beta^2} NZ\left[\ln\left(\frac{\beta\gamma\sqrt{\gamma-1}}{I} mc^2\right) + \frac{1}{2\gamma^2}\left(\frac{(\gamma-1)^2}{8} + 1 - (\gamma^2 + 2\gamma - 1)\ln 2\right)\right] \quad .1.3$$

In addition to energy loss by collision, beta particles also loose energy through Bremsstrahlung which yield photons of a continuous energy spectrum; Cherenkov radiation which corresponding to the frequencies between the blue region of the visible and the near-visible part of the electromagnetic spectrum [1], and through Delta rays.

Emission of UV and VIS has in the past been observed by some researchers. [8,9] reported the emission of ultraviolet photons in air from the decay of Th-229 Isomer.[10] who equally obtained similar result corrected that such UV emission process as claimed above was actually caused by the sample's radioactivity on the N_2 gas of the air surrounding the sample. [11] showed that, both X-rays sources and radioisotopes excites valence electron and causes fluorescent light emission that is UV dominant at (330-383nm) and visible light at 500nm. [12] has also reported on fluorescence emissions induced by extensive air showers on mainly electrons and positrons in the Earth's atmosphere. They however showed a quenching process of the photon yield in air which was attributed to the radiative de-excitations being reduced by collisions between excited nitrogen molecules and further molecules in the gas. Several other groups have also investigated some aspect of the fluorescent emission from nitrogen molecules in air e.g. [13,14.15] Burner, 1967; Kimoto *et.al* 1996, Colin *et.al*, 2007. One major goal of all these experiments was to obtain an absolute fluorescence yield either for the main contributing band at 337.1 nm or for the entire spectrum in the range of interest between about 300 – 420 nm. The optical experiment of [16] found and confirmed that the observed light was caused by alpha-particle induced fluorescence in air, because in the absence of air no significant light emission was discernible. Measurements of the spectral distribution of light caused by fluorescing air and N_2 gas was also reported by [17]. It again showed strong peaks at 3371, 3537, 3577, 3756, 3805, 3914, 3998, 4059, 4270, and 4278 Å with the two strongest two peaks at 3371 and 3577 Å, respectively. These researchers have also pointed out to the low light yield from this process. Gibson J.H classified the UV photons as UVC (0.5%) photons (wavelengths shorter than 290 nm). UVB radiation (1.5%) (290 - 320 nm), UVA (6.3%), (wavelengths 320-400 nm). This UV light according to Gibson J.H work represents just 8% of the total solar irradiation as against 42.3% from visible light. Therefore, because UV light reportedly has a lower background light compared to VIS and more dominant, emphasis is laid on it.

3.0 METHODS AND EXPERIMENTAL SET UP

The adopted method is the photon counting method. The objective is to trap and count the number of UV fluorescence photons in pure nitrogen gas and air caused by alpha and beta emitter's ionisation and excitation effect. Employed materials and apparatus include

1. *Vacuum chamber*: Has a removable glass lid for the introduction of the radioactive source (fig1) and approximately 7cm in diameter, 19cm deep. It has a valve in one of its arm to let in air or nitrogen gas, and connected to vacuum pump through another arm to suck them out.

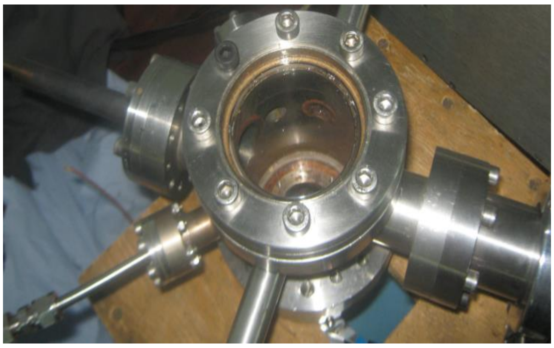

Fig1. The snap shot of the vacuum chamber used in the experiment

2. *Am-241*: Has a half-life of 432.2 years, source strength of 3.4x105 Bq, energy range of alphas of between 5.38 and 5.55 MeV, equally emit gamma-rays of 26, 33, and 59.78KeV and has a range of 4cm in air and 0.06cm in water [18,19].

3. Sr-90: Pure beta emitter of energy 2.28MeV, half-life of 29.1yrs, maximum range in the air is roughly 9m and 1.1cm in water, source strength is 5mC [20,21] .

4. SCHOTT UG5 glass: UV optical band transmitter, 200nm- 400nm [22] attached to the glass face of the vacuum chamber to cut off Visible light and transmit UV light (fig 2)

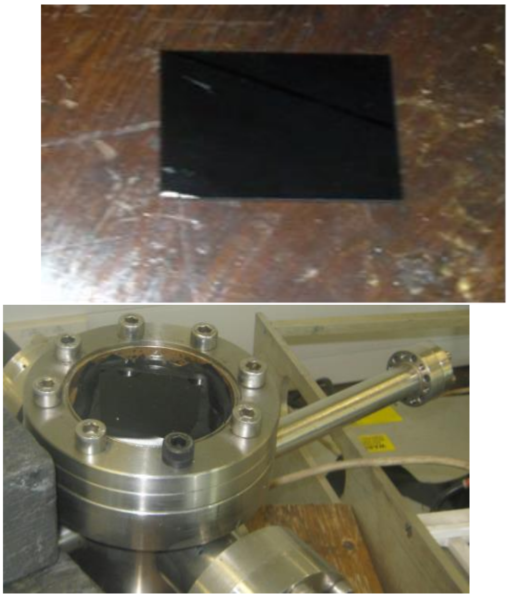

Fig 2 The UG5 glass on the desk and coupled on the chamber face

5. Bare photomultiplier tube (9813QA, Thorn EMI): is a photomultiplier tube devoid of scintillator that was mounted on the chamber for photon multiplication (fig3).

Fig 3 The 9813QA, Thorn EMI photomultiplier tube before and during use.

It was accompanied by sets of carefully selected photon counting electronics shown on fig4

Fig4 Sets of photon counting electronics used in the experiments.

R-L HV3 power supply to power the PMT; Rate-meter to count and display photon in count/sec; TC 203 Linear amplifier further helps in amplifying and filtering of the photon signal from the PMT; Simple Channel Analyzer (SCA) has high stability and resolution necessary for use in high resolution counting experiments; and vacuum pressure metre at the top to indicate chamber pressure.

The vacuum chamber was coupled together with the air inlet valve, vacuum pump and vacuum pressure meter. The photomultiplier tube was mounted onto the glass face of the vacuum chamber on introduction of the source and coupled together. The HV cable from the PMT was connected to the HV3 power supply; and the other SIG cable connected to the TC203 linear amplifier. The second DC output terminal of the TC 203 was connected to the DC input terminal of the SCA. The output cable from the CSA was connected to the input terminal of the Rate-meter. The HV3 power supply was set at 1500V and 271.6μA (an ideal voltage for the bench-top power supply; Hamamatsu, 2006). The upper and lower level of the SCA for the spectrum being analyzed was set at 0 and 10 respectively. The coarse gain of the linear amplifier was set at 500 (ideal for low light counting, [23], while the fine gains was at 5 and the time constant at 1microsecs. Pressure valves controls the chamber pressure while readings were obtained at these pressures. The pictorial view of the set-up is shown on fig 5.

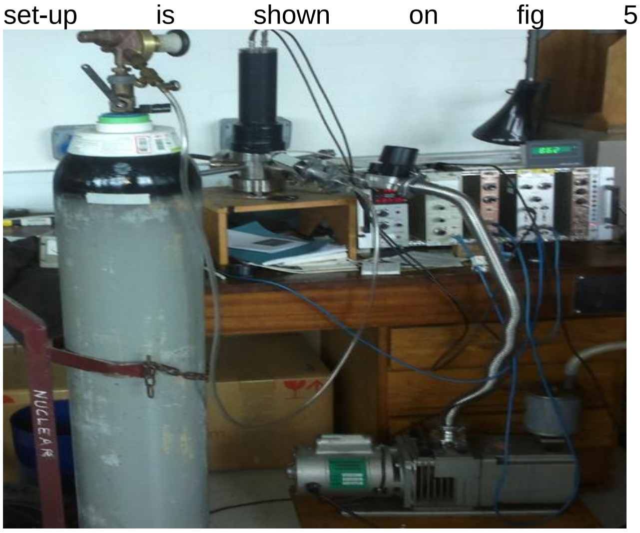

Fig 5: the experimental set up comprising all that was discussed

4.0 MEASUREMENTS, RESULTS AND DISCUSSION

Air and Nitrogen was let into the chamber with the source already in to ionise and excites them. Readings were first taken without the UG5 glass then later it was added.

4.1 Background count:

The chamber was left empty without any radioactive materials and an average of 3count per sec was recorded by the Rate meter at all the pressures, this's graphically shown on fig 6

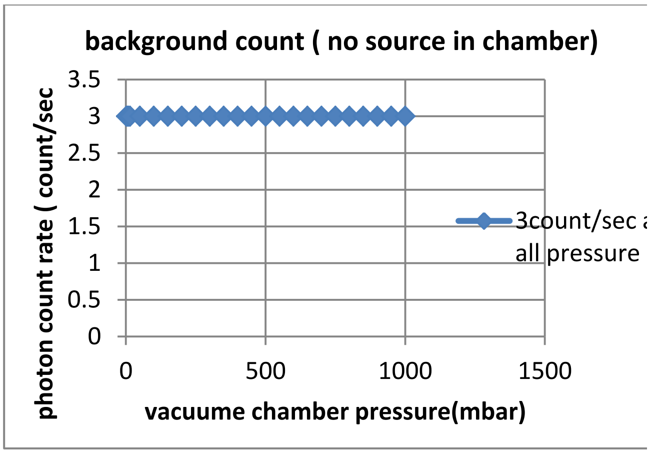

Fig6 Graph of the background count (3count/sec)

This measurement was used to show the level of light photons around and those trapped in the PMT. It served as the background count and was subtracted from subsequent readings. Since the photomultiplier tube has very high sensitivity, it may detect extraneous light other than that to be measured, so besides the encased black metallic body to do this, the tube was further and always covered with very dark cloth during and after usage to avoid any form of light getting through.

4.2 UV light photon count.

Nitrogen gas was introduced into the chamber with the ^{241}Am source now placed in. Photon count was made without the UG5 glass, then later with it. The readings were used to plot the graph on fig7

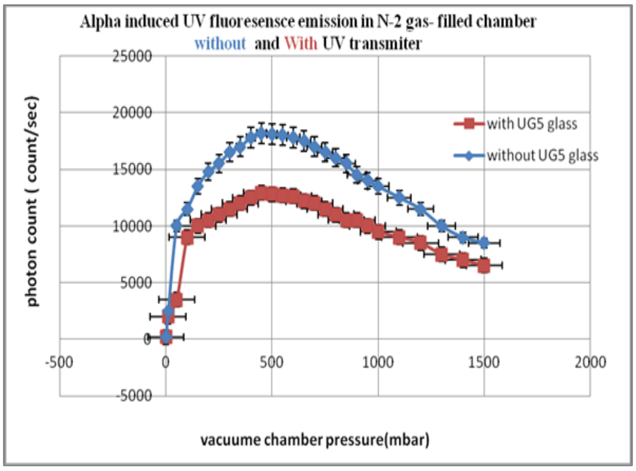

Fig 7 the graph of photon count at different N_2 gas pressures

Quantitatively, it's noticeable that higher count rates were obtained without the UG5 glass filter compared to that with the UG5 filter. Recall that without the UG5 glass, both the UV and visible light produced enters the tube, but with the UG5 (UV transmitter), the visible are blocked off and only the UV allowed in. Observe again an appreciable quantity of counted UV light (with UG5 glass), about 75% of the entire count. [10,11] and others pointed out that the fluorescence yield is UV dominant. The subsequence experiment tracked only the UV light. Qualitatively, noticeable is the dome shape of the graph, rising with increase in pressure up to a maximum and then falling even as pressure was still being increased probably demonstrating what as [12] pointed out as quenching process.

4.2 Tracking UV light photon within and beyond the Am-241 range in air.

Am-241 has a range of 4cm in air so it was first placed 3.5 cm away from the detector face and later at 6.5cm, then the UV photon count obtained was shown graphically on fig 8

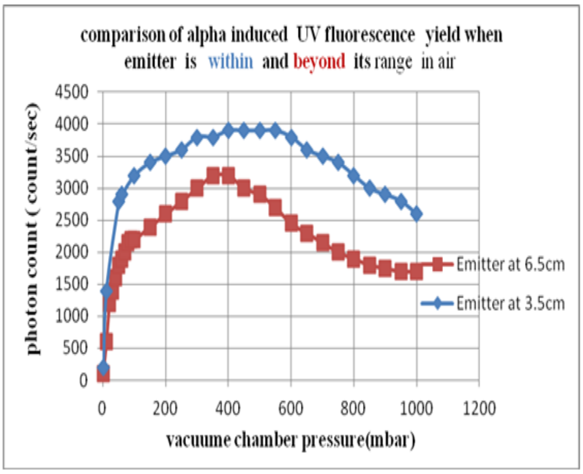

Fig8 comparison of alpha UV photon yield (with UG5 glass) in air obtained within emitter's range and beyond the range.

It can be noticed here that appreciable count was obtained in each case.

Notice that the count at atmospheric pressure (1000mbars) obtained when PMT was within the alpha range (3.5cm) was 2597count/sec and when placed beyond the range at 6.5cm was 1697 count/sec. The difference is not so much, probably this may signifies that we can actually place our sensor beyond the alpha range and still get a good count without losing much light signal unlike in radiation counting. In radiation counting you won't get any signal beyond the 4cm range of the ^{241}Am. Comparing this UV photon count in air with that in pure nitrogen of 9497 count per-sec at atmospheric pressure (1000mbar), though there is a big difference but we could still notice a good count in air despite the more damping influence of other gases component of the air.

4.3 UV alpha count in air Versus UV beta count in air

The photon count air for alpha and beta from the same position were taken and the values used to plot the graph on Fig 9

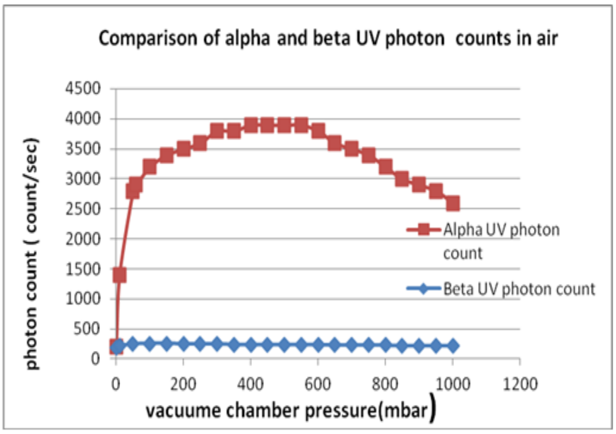

Fig 9 comparison of alpha and beta photon count in air

The UV photon count in air at atmospheric pressure (1000mbar) for alpha emitter is 2597count per sec and that of beta is 217count per sec. This huge difference is because the ionization and excitation power of alpha is much more than that of the beta, the alpha being more massive (4u) and doubly charged and beta very light (0.00055u) and singly charged. Again the alpha range is just 4cm and it will exert all its energy within the 7cm diameter of the chamber producing much count, conversely little interaction of the 9m ranged Sr-90 beta particle will occur within the 7cm chamber diameter, coupled with its lower ionisation tendency. These have led to less ionisation light production, however bigger counts were obtained without the UG5 but they are mostly Bremsstrahlung and Cherenkov light from the steel body of the chamber. However in open survey it will possibly have more space to exact all it's energy, nevertheless it will still yield less light than alpha. These differences in count could possibly help us distinguish between beta signature and alpha signature.

5.0 SUMMARY OF THESE FINDINGS AND SIGNIFICANCE.

Advances in technology have made it possible to use remote sensors or cameras to collect light signals from a distance without having to make any physical contact with those objects we could employ same in this case, having discerned the following from this work.

From the above experiment, it has been demonstrated and confirmed alongside other researchers that excitation and ionisation effects by alpha and beta particles on nitrogen and air molecule induces light emission in both the UV and Visible light range, and that the UV light yield has above 75% of the total light yield. It is then suggested that this UV photon be tracked as alpha and beta signature during radiological survey. This is because measurement using light instead of radiation offers unique and appealing advantages. It's non-destructive to the sensitive nature of the monitoring equipment. Recall that germanium detector do suffer radiation damage to its crystal. Light also has high speed property and extremely high detectability. Other research has also shown UV to have lower background light than VIS. Hence through this method and using a good remote sensor we could probably detect pure alpha and beta as well as those having accompanying gamma rays.

It was discerned from this work that when the alpha emitter (241Am, range 4cm in air) was placed both within its range (3.4cm) and beyond its range (6.5cm) in the air-filled chamber, that appreciable UV signal was recorded 2597count/sec and 1697 count/sec respectively. This probably shows that placing our sensor within and beyond the alpha range will both successfully detect light signals. Recall that beyond any alpha range the instrument can never detect any signal, recall that in alpha spectroscopy not even air is allowed into the chamber to avoid loss of signals. Hence this method could possibly navigate over the close range detection constraint suffered in ground mobile laboratory tracking the alpha and beta radiation. Hence we could track alpha beyond their range in air with a low flying drone or air craft with our remote sensor hanging at a safe distance or from high frame trucks.

It was also discerned from this work that the UV fluorescence light yield in air which is predominantly from ionisation and de-excitation was far much lower in beta fluorescence count than that obtained from alpha fluorescence count, 217count/sec and 2597count/sec respectively. This disparity in count is due to the differences in their ionization and excitation power which is higher in alpha because it's doubly charged and 7300 time more massive than a beta particle and the space limitation offered by the body of the chamber.

Significantly, during survey we could possibly use this signal differences to differentiate and discern alpha signature from beta signature. Hence, high count/signal could probably be from an alpha emitter and low signals from a beta emitter.

CONCLUSIONS AND SUGGESTION FOR FURTHER WORKS

The quantitative figures counted in these experiments are not final; however they are strongly indicative of the favourable trend that could be obtainable from this method. The reason why this figures here probably cannot be final is that; the fraction of photons collected by the detector depends on a number of factors which when improved can improve counts. For instance when the large glass face of the chamber was changed to a smaller and more focussing one it was discovered that photon counts significantly increased almost 10%. PMT or sensor with a larger face will likely cover more area and detect more photon during survey. The use of some high power sensor like CCD_s (Charge-Coupled Device) which is said to have high quantum efficiency will improve the result drastically [23]. These CCD_s are said to be currently being adopted by the astronomers. The survey and the counting could be done at clear dark and dry night to further eliminate any possibility of UV sunlight/starlight background light and moisture absorption and attenuation effect. A sunblind lens could as well be attached to the face of the camera to further improve UV sensitivity. Use of linear optical amplifiers is also another way [24].

Acknowledgements:

I wish to acknowledge the staff and personnel of school of Physics and Astronomy and the Schuster Laboratory University of Manchester for providing me with these expensive necessary equipment and materials for this work. I wish to also acknowledge TETFUND Nigeria tertiary education trust fund) who funded this program through Nnamdi Azikiwe University Awka, Nigeria.

REFERENCES

[1] James E M, 2004. Physics for Radiation Protection: A Handbook; WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim. 116- 220

[2] Nicholas T and Sheldon L, 2011. measurement and detection of radiation , Third edition, CRC press taylor and Francise Group Boca Raton, new York. pp 1-180

3] Herman C and Thomas E J, 2009 Introduction to health physics, McGraw-Hill Companies, Inc. 703 – 706

[4] Sanderson D C W, Allyson J D, Riain, NS, Gordon G, Murphy S and Fisk, S,1994 . An Aerial Gamma Ray Survey of Torness Nuclear Power Station on 27-30 March.

Sanderson D C W, Allyson J D, Cresswell A and McConvile P; 1997; An Airborne and Vehicular Gamma Survey of Greenham Common, Newbury District and Surrounding Areas.

[5] Heinz-Helmut P,1992 .UV-VIS Spectroscopy and its application, Springer- Verlag, Berling Heidelberg New York London Paris.pp 1-15

[6]Bethe H A,1930 Ann. physik 5,325.

[7]Bloch F, 1933 Physik 81, 363 and Ann. Phys.16, 285

[8] Irwin G M, and Kim K H, 1997. Phys. Rev. Lett. 79,number .20

[9] Richardson D S, Benton D M, Evans D E, Griffith, J A R and Tungate G. 1997.physical review lettervolume 80, number 15

.[10] Shaw R W, Young J, Cooper P S P, and Webb O F, 1998. physical review letters, volume 82, number 6

Bohr N, 1940 Phys. Rev.58,654; Phys. Rev. 59, 270(1941)

[11] Padmanabha Rao M A. 1998. X-ray source emits not only X-rays but also low energy electromagnetic radiation, Presented at 1998 Symposium on Radiation Measurements and Applications, The University of Michigan, Ann Arbor

Padmanabha Rao M A; 2009. Braz. J. Phys. vol.40 no.1

[12]Bianca K and Michael U, 2009 Fluorescence emission induced by extensive air showers in dependence on atmospheric conditions; proceedings of the 31st ICRC, ŁODZ , 2009; (gotten from- arXiv:0906.5487v1 [astro-ph.HE] [Retrieved 25/04/12]

[13]Bunner A N, 1967; Cosmic ray detection by atmospheric fluorescence, Ph.D. Thesis, Cornell University, p86

[14]Kakimoto F *et al,*1996. Nucl. Instr. Meth. A 372- 527

[15]Colin P *et al,* 2007Astropart. Phys. 27, 317

[16] Utter S B, Beiersdorfer P, Barnes A, Lougheed R W, Crespo L,Urrutia J R,

[17] Davidson G, and Neil R O, 1964; J. Chem. Phys. 41,

[18]Knoll G F, 2000. Radiation detection and measurements; third edition; John Wiley and sons Inc. pp 711-721

[19] Japet T O, Passell C I, Brown E, and Perlman I, 1954. Physical review Volume 97, Issue 1, 142-150

[20] http://ozradonc.wikidot.com/strontium-90

[21] Edgardo B and Richard B, 1986 Table of radioactive isotopes, John Willey &sons pp20 -30, Appdx E1

[22]http://www.uqgoptics.com/materials_filters_schott_uvTransmitting_UG5.aspx

[23] Hamamatsu K K , 2006 . Photomultiplier tubes, basics and application,3rd edition 1-60

[24](www.Wikipedia.org/wiki/charged_coupled_devic)

[25] Garrison J C and Chiao RY, 2007. Quantum Optics, University press 499