ORIGINAL PAPER

Plastic scintillator detector for qualitative and quantitative measurements of gamma radiation

Vaishali M. Thakur[1] · Nitin Bhosale[1] · Amit Jain[1] · Mukesh Sharma[1] · L. M. Chaudhari[2] · Probal Chaudhury[1]

Abstract

Background Plastic scintillator detectors are rugged and easily manufactured in desired shape, sizes and response time to gamma radiation is prompt as compared with any other scintillator detectors. Being popular these detectors are used in radiation monitors one of the application to restrict radioactive material movement. These are used in gross counting mode to know the presence of radioactivity. Therefore secondary survey is required to know the nature of the radionuclides.

Purpose The feasibility study of Cylindrical Plastic Scintillator Detector (CPSD) was carried out for the qualitative and quantitative assessment of gamma emitting radionuclides.

Methods In this work limited gamma spectrometry was carried out using NE110 equivalent cylindrical plastic scintillating material of 5.1 cm diameter and 100 cm long. CPSD is optically coupled to photomultiplier tube (PMT). The detector signal is processed using preamplifier, shaping amplifier and further analysed by a multi channel analyser (MCA). CPSD gamma spectrum consists of Compton continuum and Gaussian shaped Compton edge energy (λ_e) appearing as Compton maxima energy (λ_{max}). Photon transport simulation is used to characterize λ_{max} as a signature for radionuclides emitting gamma energy/energies. In case of unresolved gamma energies, it appears as weighted effective Compton maxima energy. The prominent gamma energies observed across nuclear industries are in the energy range 0.03–3 MeV. It is grouped as low energy, intermediate energy, high energy and ultra-high energy window. The simulated spectrum is obtained suing Gaussian broadening parameters deduced from experimentally measured spectrum. The efficiency response function is developed from simulated response of detector to standard gamma sources under known source detector configurations.

Results The mono energetic gamma emitting radioisotopes are identified against λ_{max} from data library. Qualitative analysis of spectrum is used to discriminate artificial radioactive material from naturally occurring radioactive material using gamma photon, corresponding Compton edge and expected Compton maxima in each energy window. The provisional quantitative assessment is carried out using efficiency deduced from response function. The detection efficiency varies within 1%–0.2% for 0.03 to 3 MeV gamma energies. In this study efficiency for ^{137}Cs source is 0.26% with FWHM 0.092 MeV and the results re within 15% for the measured activity. Estimated sensitivity and spectral dose rate coefficient for CPSD are 77 cps/μR/h and 44.29 nGy/kcps respectively. The MDA or MDL of the most prominent radioisotopes used in nuclear industry are estimated. CPSD showed an ability to detect 149 kBq, ^{137}Cs radioisotope at 1 m distance.

Conclusion CPSD can be utilised for gamma isotope identification with limited gamma spectroscopy tool in contamination and dose rate measurements monitors.

Keywords Plastic scintillator detector · Gaussian broadening · Compton edge · Compton maxima · Weighted effective Compton maxima · Gamma spectrum · Multi-channel analyzer

Introduction

Plastic scintillator detectors are widely used for the dose rate monitors because of less cost, availability in large size with attenuation length of 4 m and easily moulded into desired

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Extended author information available on the last page of the article

shape. It is hydrophobic material unlike NaI(Tl) detector with least probability of getting contaminated due to small adsorption coefficient for chemical reactivity and dust. Therefore, it is rugged detector and can be used in many environmental conditions. Plastic scintillator detector shows distinct Compton continuum along with broaden Compton edge in absorbed energy distribution. NE110 equivalent

plastic scintillation material have an average scintillation emission of 9200 photons per MeV gamma energy. The response time to emit scintillation is within 4–10 ns which is faster as compared to conventional GM and NaI(Tl) detectors. Plastic scintillator detectors are used for different applications of radiation measurements [1, 2] like contamination monitors, portal monitors and camouflaged single pole monitors etc. These monitors are provided with audio/visual alarm to notify unauthorized radioactive material movement. An artificial radioactive material (ARM) or naturally occurring radioactive material (NORM) could stimulate genuine and innocent (no threat) alarms respectively if the radiation field exceeds the set alarm level. The innocent alarms could cause a loss of credibility. The isotopic identification could be decisive in alarm assessment. This paper describes the purpose of having an add-on tool for qualitative assessment of radioactive material using limited gamma spectrometry technique to enhance the ability of plastic scintillator detectors based radiation monitors.

Material, method, theory and measurements

Cylindrical plastic scintillator detector (CPSD) of 5.1 cm in diameter and 100 cm long is wrapped with thin aluminium foil. It acts as a reflector to enhance the scintillation collection efficiency at photo multiplier tube (PMT). The detector housing is a 100 cm long cylindrical polyvinyl chloride (PVC) pipe with one end cap. PMT is coupled with open end of the detector using silica gel acting as a light guide to the scintillations produced during gamma interaction. The inner diameter of the PMT enclosure is 5.2 cm and attached with detector housing PVC pipe with a screwing arrangement to protect the detector module from dust, light and moisture. The assembled CPSD and PMT is connected to male B14A fourteen-pin cap connector as shown in Fig. 1a. Fourteen pin B14A base female sockets with divider networks interconnect the PMT and preamplifier (PA) electronics. The gamma ray energy deposition is expressed with energy loss in the detector by dE/dx (MeV/cm). The self-absorption of

produced scintillation in the detector is negligible. The operational voltage of PMT is set to 830 V. The photoelectrons produced at the end of PMT is processed by preamplifier which is further processed through shaping amplifier set at 1 microsecond pulse shaping time. The lower level discriminator (LLD) and upper level discriminator (ULD) are adjusted to optimum values 150 mV and 10 V respectively to accommodate an energy range from 0.03 to 3 MeV. The detector signal after shaping is processed through Mutli-Channel Analyser (MCA). The energy deposited in the CPSD is distributed along the 1024 channels of MCA and analysed using gamma spectrometry technique [3], as given in Fig. 1b. The spectroscopic data analysing software installed in computer is capable of radioisotope identification.

Energy calibration of MCA

XCOM photon mass absorption cross section software based on Berger report [4] is used to study the photon interaction of CPSD. In the plastic scintillator detector energy distribution spectrum for ≤ 0.1 MeV gamma emitting photon energy, photo peak with long tail towards higher energy end is observed. Thereafter interaction of gamma emitting photon energy ≥ 0.1 MeV is mainly due to Compton scattering interaction which is dominant over photoelectric effect. Therefore, photo peak is absent unlike NaI(Tl) or HPGe detectors, but broaden Compton edge (λ_e) [5] distinctly appearing along with Compton continuum in the energy distribution spectrum of plastic scintillator detectors. In the experimental spectrum, Compton edge gets broaden [6, 7] about centroid energy called Compton maxima (λ_{max}) due to fluctuation in energy deposition, scintillation transfer through detector, charge collection and electronic noise while processing electronic signal. The experimental spectra of CPSD with standard gamma sources viz ^{241}Am, ^{137}Cs and ^{22}Na were acquired. The simulated spectrum without Gaussian Broadening (GB) superimposed to experimental spectrums to correlate Compton energy with channel number as depicted in Fig. 2.

For above applied electronics and electrical parameters in the ^{241}Am spectrum, photo peak 0.059 MeV with long
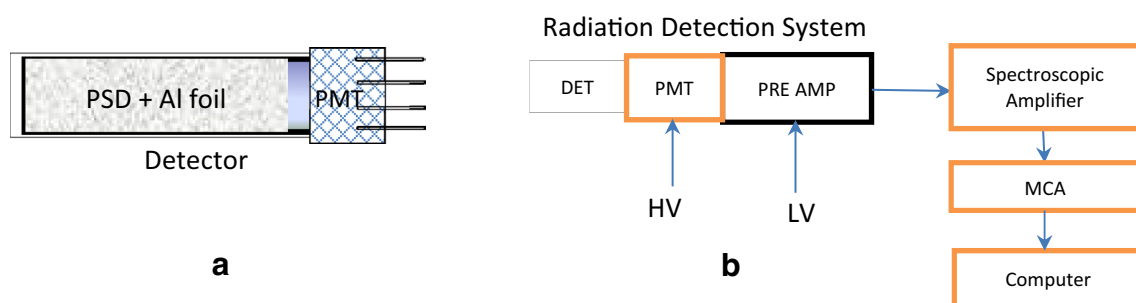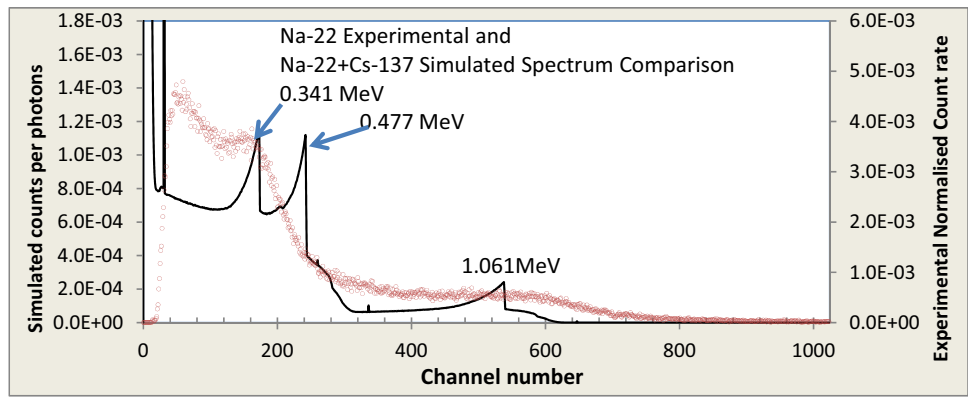

Fig. 1 **a** CPSD Ddetector, **b** gamma spectroscopy

Fig. 2 Cylindrical plastic scintillator detector energy calibration curve

tail appeared at channel number 31. In case of ^{137}Cs source energy spectrum λ_e, 0.477 MeV is observed at channel number 231. For ^{22}Na spectrum two distinct λ_e, 0.341 and 1.061 MeV are observed at channel number 160 and 550 respectively.

The energy calibration is done using standard gamma emitting sources to address fixed channel number to characteristic single or effective Compton maxima energy. Poor resolution causes unresolved peaks, 0.341 and 0.477 MeV energies of ^{22}Na and ^{137}Cs sources respectively as seen in Fig. 2. The simulated spectrum without Gaussian broadening (GB) for mixed sources ^{241}Am, ^{22}Na, ^{137}Cs, and ^{60}Co is superimposed to identify channel number corresponding to distinct Compton edges as shown in Fig. 3.

The scaling is chosen to show Compton edges in the spectrum. Mono energetic ^{137}Cs ($\lambda_e = 0.477$ MeV), closely spaced dual energy source ^{60}Co (Effective $\lambda_e = 1.039$ MeV), widely spaced dual energy source ^{22}Na (Distinct $\lambda_e = 0.341$ MeV and $\lambda_e = 1.061$ MeV) and ^{241}Am (Photo peak $E_\gamma = 0.060$ MeV) sources are used for energy calibration.

The graph of energy against channel number is a linear fit for given electronic set up parameters. Energy gain 1.907 keV per channel is obtained through fitting coefficient (slope m) with calibration constant 9.1 keV as shown in Fig. 4. The set

LLD defines the cut off energy window 0–0.03 MeV for this detection system. The entire energy range is grouped as low energy window (0.03–0.15 MeV), intermediate energy window (0.15–0.6 MeV), high energy window (0.6–1.2 MeV) and ultra high energy window (1.2–3 MeV).

Qualitative measurement: method to identify gamma source

Compton edge λ_e can be calculated using Eq. 1 for any incident gamma energy E using the rest mass energy of electron $m_{0C}{}^2$.

$$\lambda_e = E * \left\{ 1 - \frac{1}{1 + \frac{2E}{m_0 C^2}} \right\}. \tag{1}$$

It is observed that face value of λ_{max} slightly drifted from estimated value of λ_e expressed in Eq. 2.

$$\lambda_e - \lambda_{max} = \Delta\lambda \tag{2}$$

The percentage drift between λ_e and λ_{max} was calculated for standard gamma emitting radioisotopes. The intrinsic property of Gaussian dtribution is a full width at half

Fig. 3 Compton edge and photo-peak for Standard radioactive sources without Global Broadening

Fig. 3 Compton edge and photo-peak for Standard radioactive sources without Global Broadening
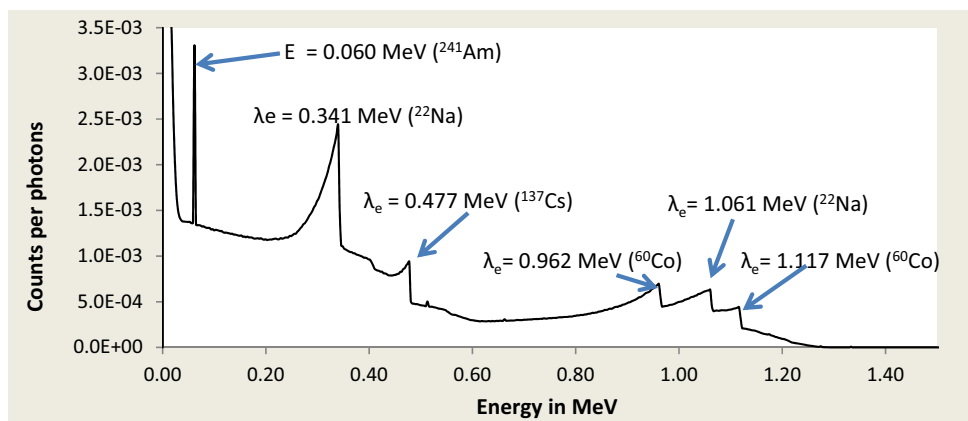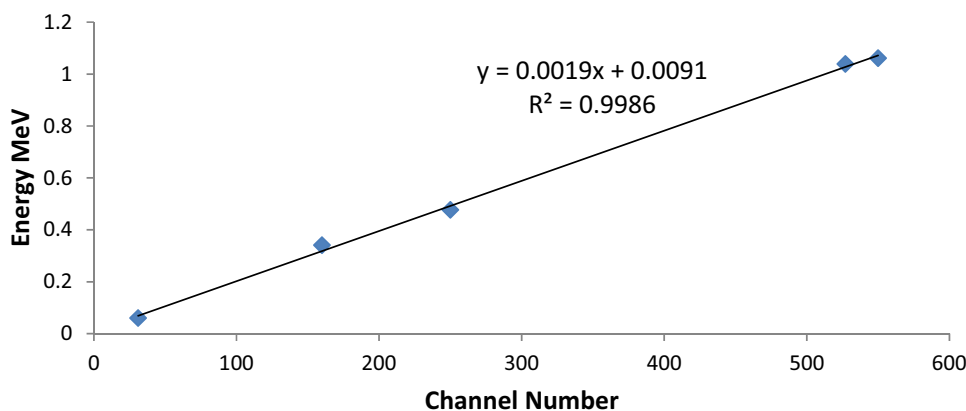
Fig. 4 Linear relationship between Compton edge energy and Channel number for 1024 channel multi-channel analyser

maxima (FWHM). ΔE has direct relation with variance (σ^2) of distribution, where σ is standard deviation as given in Eq. 3.

$$\Delta E = 2.355\sigma \tag{3}$$

FWHM varied linearly with scintillation production and quadratic with charge collection from PMT. ΔE is obtained using Eq. 3 from standard deviation σ of experimental spectrum. To determine standard deviation σ, a Gaussian function $f(E)$ Eq. 4 is fitted to experimental spectrum of standard gamma emitting radioisotope. The parameter "A (MeV)" represents Gaussian peak height while "B (MeV)" represents mean or centroid energy and "C (MeV^2)" represents variance.

$$f(E) = A * \exp\left(-\frac{(E-B)^2}{C}\right) \tag{4}$$

The numerical iteration method is used to obtain Gaussian fitting parameters A, B and C. The value of standard deviation σ (MeV) can be calculated from Eq. 5.

$$\sigma = \sqrt{C/2} \tag{5}$$

CPSD gamma spectrum showed limited finite resolution as compared to NaI(Tl) detector. In case gamma photos energy < 0.10 MeV, isotope identification is done with photo peak. ^{241}Am is demarked in spectrum with photo peak. For gamma photons energy > 0.10 MeV isotope identification is done with local λ_{max} or global effective Compton maxima energy (λ_{effmax}) demarking in the spectrum. In case of isotopes with identical Compton edge or deviation within 10%, probable isotope presence can be stated. ^{137}Cs decay process emits mono energetic gamma 0.661 MeV hence can be identified using corresponding λ_{max}. The distinct local λ_{max} 0.458 MeV is demarked in the spectrum as depicted in Fig. 5a with 4% drift from the expected 0.477 MeV energy.

The radioisotope can be identified easily if it is having more than two well resolved local λ_{max} as depicted in Fig. 5b. The Compton edge energies 0.361 and 1.115 MeV

together concludes the presence of ^{22}Na source. The drift in the energies are 5.8 and 5.1% respectively from the expected 0.341 and 1.061 MeV energies.

^{60}Co or ^{177}Lu like sources are identified with global λ_{effmax} appeared in spectrum. Radioisotope ^{60}Co is having single λ_{effmax} 1.039 MeV from two unresolved gamma energies 1.17 and 1.33 MeV. It is measured as 1.029 MeV, drifted by 1.1% from the expected energy as shown in Fig. 5c.

The radioactive material like Natural uranium (^{238}U) or Thorium isotope (^{232}Th) can be identified with the global λ_{effmax} for closely spaced gamma energies. Relative percentage drift (%Δλ) and ΔE observed during this study are tabulated in Table 1. The relative Compton drift is observed within 1–11%.

Data library was developed for identification of radioisotope in given energy window to explore the features of energy spectrum like identifying unknown radioactive source.

It is having the information regarding name of radioisotope, number of prominent gamma energy/energies and corresponding yield. The Compton edges for distinct gamma energies are listed in the library. In case of closely placed gamma energies λ_{effmax} is listed in the library.

A test spectrum is stored in the library which runs during initialisation to restore calibration parameters to set values. It is necessary to build a simulated gamma spectrum library for the system according to expected radioactive sources and their combination likely to be acquired.

Gaussian broadening (GB) parameters are necessary to generate simulation spectrum. The quadratic fitting between experimentally deduced ΔE (Eq. 3) and estimated Compton edge λ_e (Eq. 2) are used in Eq. 6 to obtain GB with numerical iteration method.

$$\Delta E = a + b\sqrt{E + cE^2}. \tag{6}$$

"a" represents noise of instrument, "b" scintillation production and "c" charge collection to produce pulse corresponds
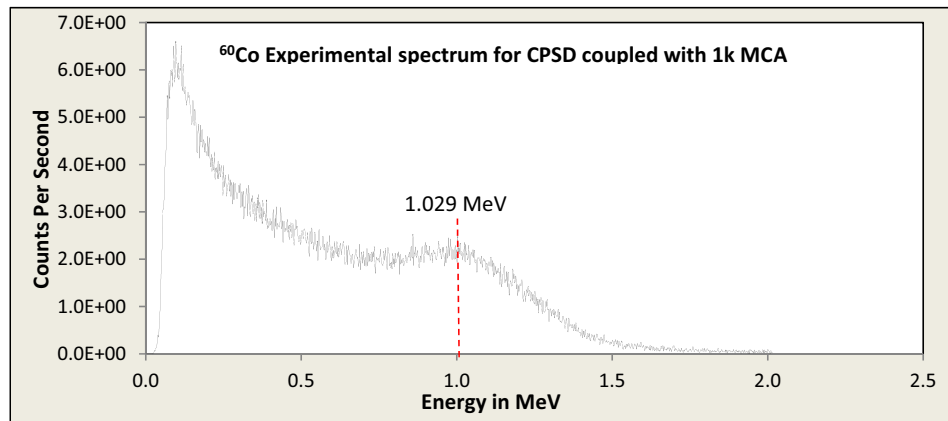
Fig. 5 **a**: $\lambda_e = 0.477$ MeV appeared as $\lambda_{max} = 0.458$ MeV drifted by 4% for ^{137}Cs. **b** $\lambda_e = 0.341$ MeV and $\lambda_e = 1.061$ MeV appeared as $\lambda_{max} = 0.324$ MeV and $\lambda_{max} = 1.047$ MeV for ^{22}Na source with 5.2 and 1.5% drift respectively. **c** Effective $\lambda_e = 1.039$ MeV appeared as $\lambda_{max} = 1.029$ MeV drifted by 1.1% for ^{60}Co
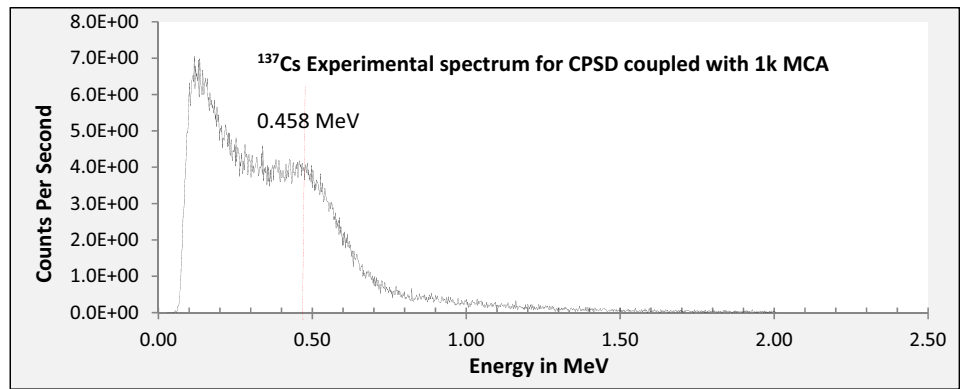
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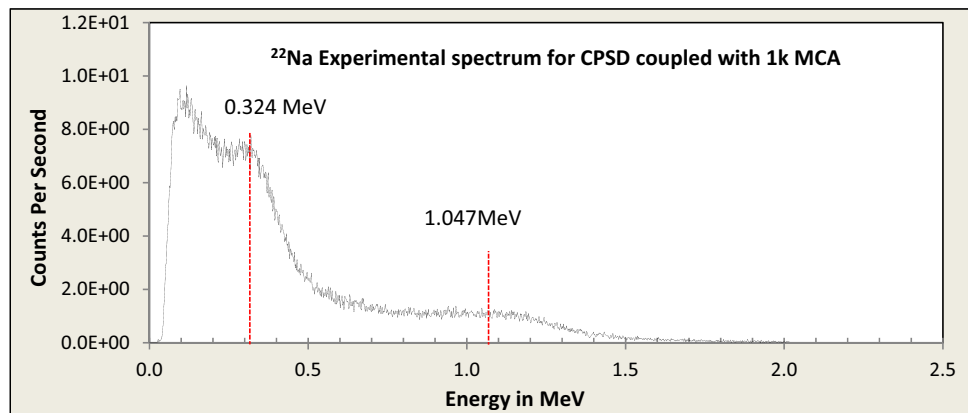
b

c

to incident gamma ray. GB parameters are obtained with numerical iteration method.

The qualitative identification is trivial. ^{137}Cs source decay process emits mono energetic gamma emitter hence can be identified using λ_{max}. ^{60}Co or ^{177}Lu like sources are identified with λ_{effmax} appeared in spectrum. The spectrums of radionuclides like ^{232}Th, ^{226}Ra or Natural Uranium contained many λ_{effmax} due to multiple closely spaced gamma rays. For mixed sources spectrum, isotopes are identified with local and global λ_{max}. The stripping of known spectrum stored in data library from recorded mixed gamma energies spectrum is used for identification of radionuclides. Health physicist experience in thgiven situation is helpful for the confirmation of presence of radioisotope.

Characteristic of CPSD

To study inheritance background in detection system, background spectra were acquired for 24 h, 12 h, 8 h, 1 h and 1000 s at working place. The effective gross count rates

Table 1 Relative compton drift (Δλ%) and FWHM (ΔE) for CPSD

Isotope	E_γ (MeV)	λ_e(MeV)	λ_{max}(MeV)	Δλ%	ΔE (MeV)
Cs-137	0.662	0.477	0.458	3.98	0.092
Co-60	1.1725	0.963	1.059*	1.12	0.112
	1.3322	1.118			
Na-22	0.511	0.341	0.361	5.8	0.099
	1.274	1.061	1.116	5.1	0.140
Lu-177	0.113	0.035	0.084*	10.51	0.014
	0.208	0.0931			
K-40	1.460	1.243	1.176	5.33	0.190

*Weighted effective Compton maxima (λ_{effmax})

variations are within 10%. To assess the activity level quickly, a background is counted once in a day for 15 min as soon as the system is put on for monitoring.. The average count rate 328 ± 25 was observed for the CPSD under study for acquisition time of 15 min. The background spectrum is used to estimate detection limit for prominent radioisotopes and used to set the alarm level as per the user requirement. The background spectrum and measured spectrums are normalised to acquisition time. The provisional activity estimation is done after subtracting background spectrum from the measured spectrum.

Detection efficiency

Detector efficiency is essential for the source strength estimation. It depends on intrinsic property of the detector and geometry factor arising due to solid angle between the source and the detector. Like NaI(Tl) or HPGe detector an attempt was made to evaluate efficiency of the CPSD. An absolute efficiency is function of gamma energy and geometric configuration between source and detector during the measurements. The standard gamma energy emitting point sources ^{241}Am, ^{177}Lu, ^{137}Cs, ^{40}K, ^{60}Co and ^{232}Th are chosen to cover the energy range 0.03–3 MeV. The efficiency was estimated for fixed geometry having source to detector distance 5 cm from geometric centre of CPSD. The simulated and experimental spectra are generated for identical source detector configuration to compare corresponding λ_{max} as depicted in Fig. 6a to f. The superposition of experimental with simulated spectrum showed good agreement in λ_{max} values but Compton continuum and Gaussian tail showed deviation. The probable reason is scattering from surrounding. The experiment is carried out at working place where other than surrounding air, furniture and wall of room produced scattering in the gamma ray. These scattered gamma ray re-entered into the detector to increase contribution in each channel. In simulated spectrum source, detector and surrounding air is taken into consideration due to which

response found slightly lower as compared to experimental spectrum.

As per regulatory requirements alarm level was set to 100 μR/h based on daily planned radioactive material inventory movements around or within nuclear facility. The acquisition time is optimised at 15 s. The average counts (events) for 100 μR/h dose rate is 114,044 with statistical variation of 7800 counts. It gives variation around 6.8%, and therefore confidence level of 95% is used to report the quantity of radioactive material.

The background count rate spectrum subtracted from the upgraded acquired count rate spectrum to estimate the provisional activity. Radioisotope quantification is done with provisional activity estimation in terms of "count rate" as shown in Fig. 7. The distinct λ_{max} is identified from acquired spectrum. Gaussian function fitted to the spectrum using Eq. 4 and σ is derived from Eq. 6 to fix region of interest (ROI) around centroid λ_{max}. Total area A is estimated from bounded region between ROI in the experimentally measured spectrum. The portion below "2σ" appeared as trapezium area subtracted from total area to get effective or net counts as depicted in Fig. 7.

Net counts estimated from bouned area P after subtracting Compton background area Q of higher energy from total area A corresponds to radioisotope under investigation. Net count rate is obtained by normalising net area with acquisition time. The ratio of registered count rate in ROI to the expected gamma emission rate of radioisotope under investigation is the "detection efficiency" as depicted in Eq. 7.

$$\varepsilon \% = \frac{Net\ Count\ Rate\ (cps)}{\%\ yeild * S(Bq)} * 100 \qquad (7)$$

In low energy window, ^{241}Am photo peak is considered for efficiency estimation while for ^{137}Cs and ^{40}K distinct λ_{max} is considered. The efficiency of ^{60}Co is determined from λ_{effmax}. The detection efficiency decreased exponentially with increasing incident gamma energy as shown in Fig. 8. For the CPSD used in the system below 0.2 MeV energy detection efficiency is greater than 1% and decreases further with increase in energy. For the 0.2–3.0 MeV energy range, detection efficiency decreases from 1 to 0.2%. The efficiency is low compared to NaI(Tl) or HPGe detectors due to which only provisional activity estimation is possible with CPSD based limited gamma spectrometer.
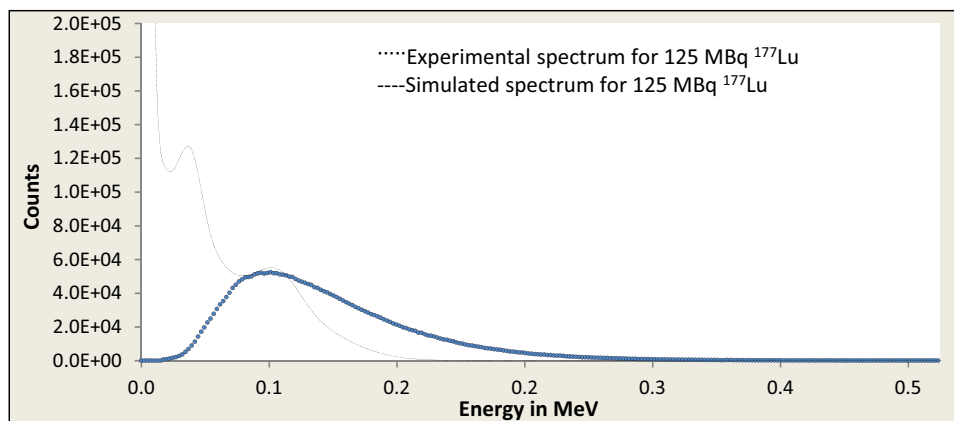
CPSD sensitivity

Total amount of energy absorbed in CPSD for different gamma energy was studied to know the sensitivity. CPSD sensitivity is estimated using ^{241}Am, ^{137}Cs, ^{60}Co and ^{232}Th standard sources. The characteristics λ_e of corresponding gamma energy of these sources are falling in the energy
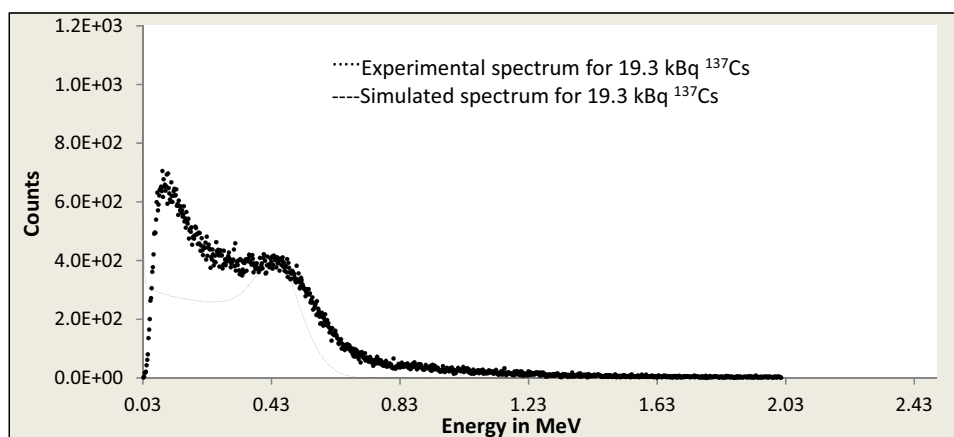
Fig. 6 **a** ^{241}Am Simulation and Experimental Spectrum for CPSD. **b** ^{177}Lu Simulation and Experimental Spectrum for CPSD. **c** ^{137}Cs Simulation and Experimental Spectrum for CPSD. **d** ^{60}Co Simulation and Experimental Spectrum for CPSD. **e** ^{40}K Simulation and Experimental Spectrum for CPSD. **f** Th-232 Simulation and Experimental Spectrum for CPSD
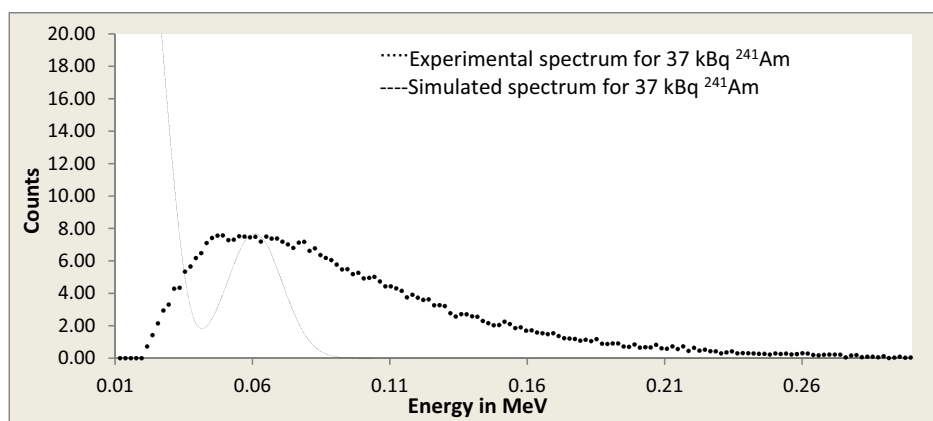

window 0.03–0.15 MeV, 0.15–0.6 MeV, 0.6–1.2 MeV and 1.2–3.0 MeV respectively. The sensitivity is estimated using net count rate in above energy windows. The sensitivity in low energy window is 78.38 cps/µR/h while ultra-high energy 76.18 cps/µR/h. The deviation is < 3%. An average sensitivity of detection system is 77 cps/µR/h as given in Table 2.

It concludes that the detector sensitivity is energy independent and needed in many applications like contamination monitors, portal monitors etc. This value is useful while setting alarm level based on background radiation dose rate.
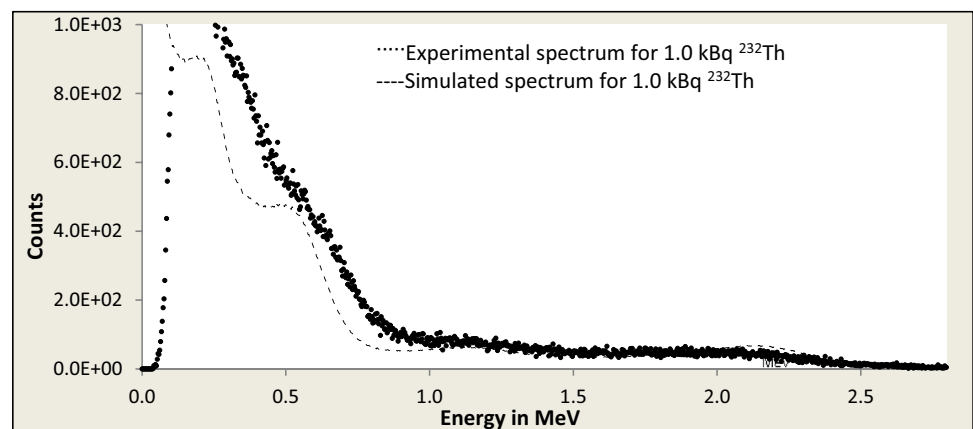
Fig. 6 (continued)
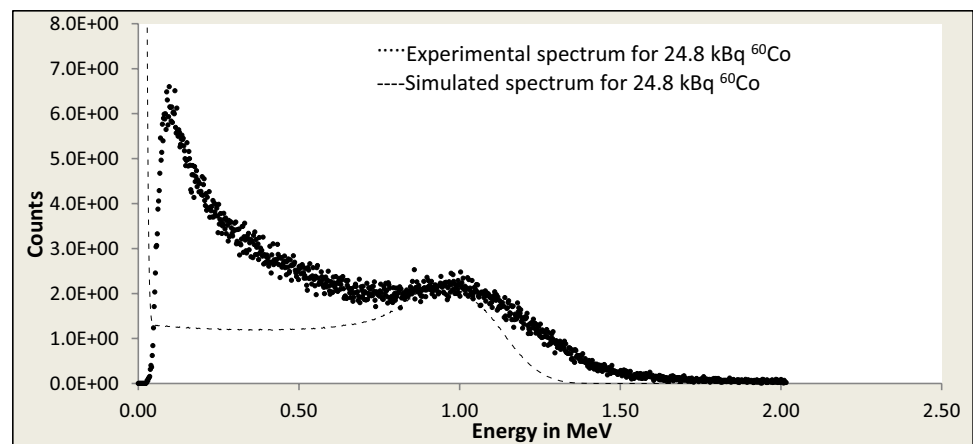
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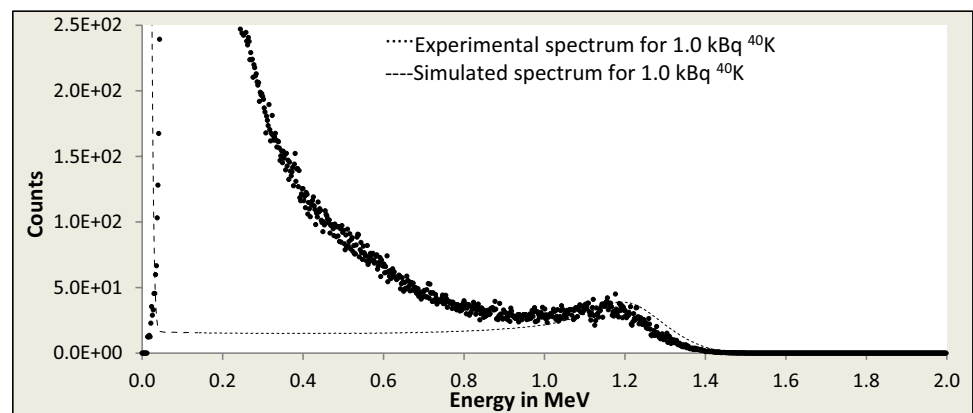
e

f

CPSD dose rate coefficients

Energy deposition in the detector during acquisition time is appeared as gamma energy absorption spectrum. For estimating an absorbed dose rate, the absorbed energy in the detector for unit time (MeV/h) is normalized with the detector mass (kg). Spectral Dose Rate Conversion Factor

(DCF_s) is deduced from the ratio of the absorbed dose rate (nGy/h) to net registered count rate (kcps) in the detector. The DCF_s for different gamma energy depends upon the amount of energy deposited in detector. It is noticed that absorbed energy in the detector is independent of detector to source geometry configuration as given in Table 3. It is required for the application of detector as dose rate meter

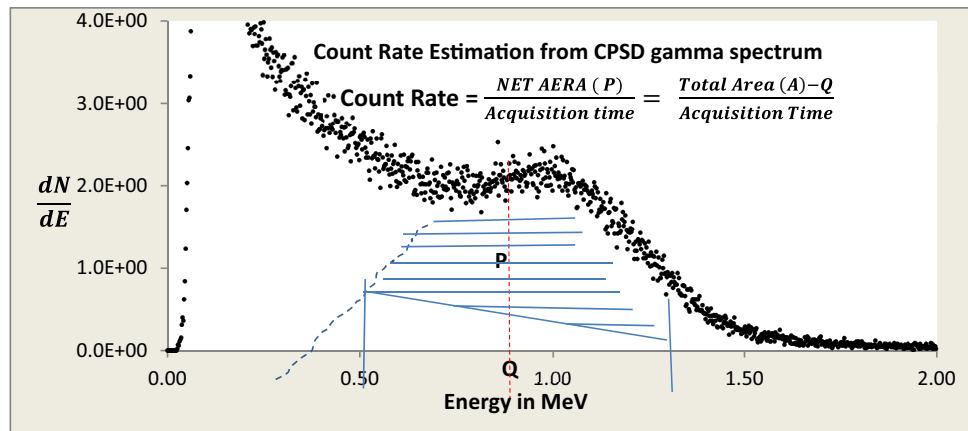**Fig. 7** Source activity estimation in term of "Count Rate"

Count Rate Estimation from CPSD gamma spectrum

$$\text{Count Rate} = \frac{NET\ AERA\ (P)}{Acquisition\ time} = \frac{Total\ Area\ (A) - Q}{Acquisition\ Time}$$

Fig. 8 CPSD Detection percentage efficiency for point source

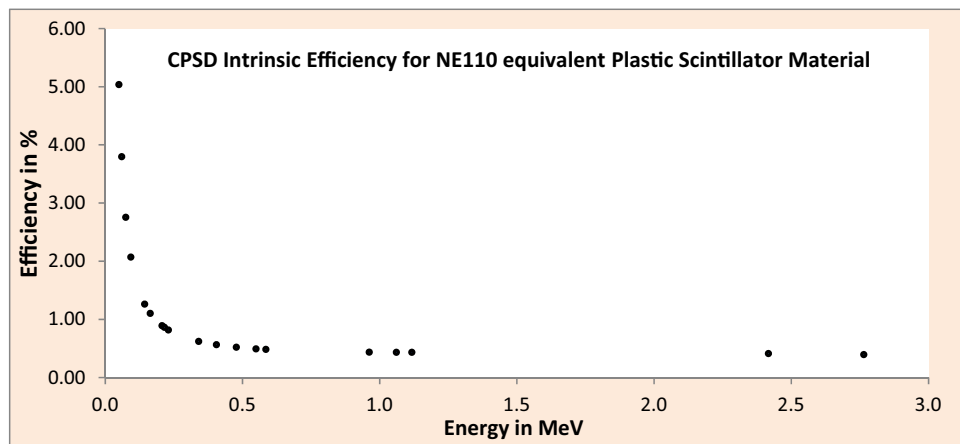CPSD Intrinsic Efficiency for NE110 equivalent Plastic Scintillator Material

Table 2 Measured CPSD sensitivity for each energy window

Sr. no	Compton maxima fall in the energy range energy in MeV	Sensitivity cps per µR/h
1	0.030–0.15	78.38
2	0.15–0.6	77.93
3	0.6–1.2	77.23
4	1.2–3.0	76.18
Average sensitivity		77

cum spectrometer. The average DCFs 45 nGy/h per kcps is observed for the CPSD. The absorbed dose rate estimated from the acquired spectrum count rate above cut off energy 0.03 MeV using DCFs.

Response function of CPSD and minimum detectable level/activity estimation

The minimum detectable level (MDL) and minimum detectable activity (MDA) are decisive parameters in contamination or activity measurement which are measured in terms

Table 3 Spectral dose rate coefficients for plastic scintillator detector

Radioisotope	Energy window (MeV)	Compton maxima in spectral distribution (MeV)	Estimated dose rate from spectral distribution (nGy/h per kcps)
Lu-177	0.03–0.15	0.093	44.94
Ba-133	0.15–0.60	0.187	43.59
Cs-137	0.15–0.6	0.477	43.73
Co-60	0.6–1.2	1.039	44.89

of "cps" and "Bq" respectively [8, 9]. CPSD background spectrum acquired for 15 min is used to estimate MDL and MDA of the radioisotopes under consideration. The distinct and feeble or expected λ_{max} peaks are marked in the spectrum and compared with the simulated spectrum of expected radioisotopes corresponds to λ_{max}. For every λ_{max} Gaussian function is fitted using Eq. 4. The net area bounded is evaluated in term of count rate. MDA determination is possible for single λ_{max} (^{137}Cs) and λ_{effmax} (^{60}Co). In case of radioisotopes having more than one λ_{effmax} e.g. ^{232}Th, ^{133}Ba, ^{131}I, etc., MDL estimation is only possible. The estimated count rate from background spectrum used to determine MDL and MDA for expected radionuclide in radiological field using Eqs. 8 and 9.

$$MDL\ (cps) = \frac{3 + 3.29 * \sqrt{R_b * T_{s+b} * \left(1 + \frac{T_{s+b}}{T_b}\right)}}{T_{s+b}} \qquad (8)$$

$$MDA\ (Bq) = \frac{MDL}{Gamma\ yeild * Eff} \qquad (9)$$

The contamination level is considered as hot spot resembles to point source. In Portal monitor maximum distance between the detector and source is 30 cm. Therefore, MDL and MDA are estimated for two point source geometries as 5 and 30 cm. In case of camouflaged single pole detector based monitor, source to detector distance 100 cm is considered for activity estimation. The estimated values are given in Table 4 considering 15 min background spectrum and 15 s sample spectrum acquisition time for standard sources under consideration.

Results and discussion

Gamma isotope identification could be easily done with single λ_{max} appearing in the spectrum. In case of more than one λ_{max} identification is carried out by listing radioisotope in energy window and comparing it with λ_{max} or λ_{effmax} of the probable radioisotopes present. Compton edge drift $\Delta\lambda$ due to Gaussian broadening drift is in the range 1–12%. The calibration subroutine restores calibration parameter if test source spectrum finds shift in the channel number. The channel gain for absorbed energy is 1.903 keV/channel for CPSD based limited gamma spectrometer. The inheritance background of the system is 385 ± 25 cps. The acquisition time for monitoring is 15 s. The provisional activity estimation is done with 95% confidence level. CPSD showed comparable sensitivity in each energy window in the energy

Table 4 MDL/MDA for point/hot spot at 5, 30 & 100 cm from CPSD Centre

Isotope	E_Υ (MeV)	λe (MeV)	Energy window MeV	Portal monitor				Limb monitor	
				MDL (cps) (5) *	MDA (kBq) (5) *	MDL (cps) (30) *	MDA (kBq) (30) *	MDL (cps) (100) *	MDA (kBq) (100) *
Cs-137	0.662	0.477	0.15–0.6	7.42	3.34	51.01	22.99	330.65	149.03
K-40	1.460	1.243	1.2–3.0	11.00	64.58	75.69	444.23	490.60	2879.54
Am-241[p]	0.059	–	0.03–0.15	0.20	0.03	1.35	0.20	8.78	1.29
Ba-133 [g]	0.267[a]	0.186	0.15–0.6	2.97	0.63	20.46	4.32	132.61	27.99
Co-60 [g]	1.257[a]	1.039	0.6–1.2	6.04	1.40	41.57	9.60	269.48	62.22
I-131[p]	0.080	–	0.03–0.15	4.89	4.27	33.66	29.39	218.20	190.52
I-131	0.358[a]	0.211	0.15–0.6	7.62	3.34	52.43	23.00	339.89	149.08
Ra-226	0.315[a]	0.138	0.03–0.15	3.35	1.69	23.03	11.61	149.31	75.24
Ra-226	0.561[a]	0.376	0.15–0.6	5.99	2.15	41.18	14.79	266.92	95.88
Ra-226	1.683[a]	1.514	1.2–3.0	11.15	19.16	76.73	131.83	497.36	854.55
U-238	0.556[a]	0.325	0.15–0.6	10.79	22.89	74.26	157.48	481.34	1020.84
U-238	0.791[a]	0.581	0.15–0.6	8.32	7.85	57.26	53.98	371.18	349.89
U-235	0.181[a]	0.074	0.03–0.15	0.23	0.02	1.57	0.14	10.18	0.90
Th-232	0.249[a]	0.123	0.03–0.15	2.41	0.58	16.58	3.97	107.50	25.75
Th-232	0.712[a]	0.507	0.15–0.6	7.98	2.69	54.88	18.48	355.75	119.79
Th-232	2.463[a]	2.089	1.2–3.0	6.00	46.32	41.29	318.65	267.65	2065.55

Note: "a" for weighted average energy in corresponding energy window. MDA reported in terms of "kBq" from ROI around Photo-Peak (superscript p) & from ROI around global Compton Maxima (superscript g). MDL reported in terms of "CPS" from ROI around Local Compton Maxima

*Numbers in () is the distance in cm from source to the centre of the detector

range 0.03–3.0 MeV. The average sensitivity is 77 cps per μR/h. The absorbed energy distribution showed the ability of CPSD to resolve deposited energy. The energy spectrum obtained with 1024 channel MCA consists of broaden Compton edge along with Compton continuum. For plastic scintillator detector, photo peak observed with extended long tail below 0.1 MeV gamma energy and above is completely absent. The gamma spectrum above 0.1 MeV gamma energy is comprised with Compton continuum and distinct Compton maxima. The average spectral dose rate coefficient (DCF_s) for CPSD is 44 nGy/h with 3.14% deviation. DCFs is used as multiplication factor to calculate dose rate from the acquired spectrum of CPSD. The detection efficiency varies within 1–0.2% for 0.03 to 3 MeV gamma energies. The MDA or MDL of the most prominent radioisotopes used in nuclear industry are estimated. CPSD showed an ability to detect 149 kBq, ^{137}Cs radioisotope at 1 m distance.

Conclusion

CPSD based monitors can be utilized for gamma isotope identification with limited gamma spectroscopy tool. The finite resolution property of detector is utilized to analyse radioactive material qualitatively. The quantification of material is possible in terms of count rate (cps). The irregular geometry of material limits the quantitative analysis. Plastic Scintillator detector can be used in survey meter for moderated dose rate measurements. The qualitative assessment ability can be improved by incorporating various analysis methods being used in gamma spectrometry. These detectors are mostly proposed to be used in low and moderated level of radiation field.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Authors and Affiliations

Vaishali M. Thakur[1] [ORCID] · **Nitin Bhosale[1]** · **Amit Jain[1]** · **Mukesh Sharma[1]** · **L. M. Chaudhari[2]** · **Probal Chaudhury[1]**

✉ Vaishali M. Thakur
vmthakur@barc.gov.in

Nitin Bhosale
bnitin@barc.gov.in

Amit Jain
amitj@barc.gov.in

Mukesh Sharma
mksharma@barc.gov.in

L. M. Chaudhari
drlmc2021@gmail.com

Probal Chaudhury
probal@barc.gov.in

[1] Radiation Safety Systems Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

[2] Department of Physics, Nowrosjee Wadia College, Pune 411001, India