Use of phoswich detector for simultaneous monitoring of high energy photon and its applications in *in vivo* lung counting

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Abstract

A phoswich detector system with associated pulse shape discrimination (PSD) electronics is being used for monitoring of actinides in lungs by the measurement of low energy photons. The PSD electronics of the system is modified in order to simultaneously record both lower energy photon (LEP) spectrum and higher energy photon (HEP) spectrum. Phoswich system with modified PSD electronics was evaluated for its suitability to analyze the high energy gamma photon spectrum. The parameters like energy linearity, variation of FWHM with energy, efficiency linearity and room background are studied. During the evaluation process, presence of ^{137}Cs in the CsI detector portion of phoswich was detected. The HEP spectrum recording feature helped in identification of the interference from ^{41}Ar (a site specific interference at Kalpakkam) without any additional monitoring system. This feature also enabled us to quantify the interference of ^{41}Ar in LE regions. Muscle to fat ratio is one of the parameters required in choosing the correct efficiency factor during lung counting of actinides. Measurement of ^{40}K in subjects enables one to estimate the muscle / fat composition. The ^{40}K measurement with the present system showed that activity of 100Bq can be achieved. This paper discusses the details of the PSD electronics for simultaneous monitoring of HEP and its utility in *in vivo* lung counting.

Key words: Phoswich, pulse shape discrimination electronics, lung monitoring, simultaneous high energy photon measurement.

Introduction

A phoswich detector with PSD electronics has been recently commissioned at RSD, IGCAR as part of its in vivo monitoring program. The PSD electronics has been optimized for obtaining only LEP spectrum upto 200 keV[1]. The pulses resulting from the NaI(Tl) portion i.e., mainly LEP interaction are selected by the PSD and used for the measurement. The pulses from the CsI portion i.e, mainly HEP interactions are not being utilized for any spectral measurements. But these pulses originating from CsI can give valuable information about the nature of HEP present in and around the detector.

During lung measurement with phoswich system, the presence of natural radionuclide ^{40}K and any gamma emitting fission products in the subjects interfere with LEP measurements. Usually a wholebody counting measurement is carried out prior to lung monitoring in order to identify and estimate the activity of such radionuclides. Any other man made gamma sources present in the steel room environment also do interfere with LEP measurement. Since, the wholebody counting facility of RSD is located in a nuclear complex having Madras Atomic Power Stations (Two CANDU type thermal reactors), during favourable wind conditions, the interference of ^{41}Ar is common. ^{41}Ar being a gas its ingress into the counting facility is difficult to control. Special, dedicated monitoring system is a pre-requisite for identifying such interferences. Also, such monitoring system should be kept along with the lung counting system.

We thought of using the pulses resulting from the interaction of HE photons taking place in CsI portion of phoswich detector which can simultaneously provide information about such interfering radionuclides. References to selection of such HEP interaction in phoswich detector with PSD electronics is found in literature[2]. But its application to the above mentioned problems is rarely reported. Hence, we suitably configured the existing PSD electronics and connected to two MCA systems. The modification enabled us to record LEP photon spectrum in one MCA and HEP photon spectrum in another MCA, simultaneously, using the signals from a single phoswich detector with PSD electronics.

As, the HEP monitoring system using phoswich detector is established for the first time, a systematic evaluation for using it as gamma ray spectrometer is necessary. The details of the evaluation and the salient results obtained during this study are discussed here.

System description

Detector

The phoswich detector (Scionix make) based lung counting system consists dual phosphors of 203 mm dia x 3 mm thick NaI(Tl) and 203 mm dia x 50 mm thick CsI(Tl) with ultra low background 0.5 mm beryllium entrance window.

PSD electronics

The PSD, based on scintillation decay time comparison, uses the rise time difference in the signals of NaI(Tl) scintillator (250 ns) and CsI(Tl) scintillator (1100 ns) to produce a gating pulse to selectively choose / reject pulses due to the LEP interactions in NaI(Tl). The functional description, optimization and performance details of PSD are discussed elsewhere[3].

The existing PSD electronics is suitably reconfigured as shown in Figure-1. The gating pulses are feed as coincidence (C) input to Fastcomtec MCA through a linear gate and anticoincidence (AC) input to Aptec MCA. The pulses, which are to be anlaysed for spectrum, from delay amplifier are also feed as another input to Fascomtec & Aptec MCA along with the gating pulse. Many of rear panel input / output connections in the PSD modules are effectively utilized to avoid splitting of signal. This avoided using an additional set of PSD electronics modules to record the HEP spectra simultaneously.

HEP gamma ray spectrometer

Energy calibration and linearity

The energy calibration is carried out to cover an energy range from 100 keV to 3 MeV with energy calibration of 4 keV/channel. The System is found to have good energy linearity of ± 4 keV in the energy range from 100 keV to 3 MeV.

FWHM Vs Energy

FWHM at different gamma energies is measured (Table-1). The predicted FWHM value 90.15 keV for 1275 keV gamma using the fitted equation matches very well with that observed value of 89.05 keV.

Table-1 : FWHM data

Energy (keV)	FWHM (keV)	% Resolution
122	28.42	23.2
355	43.21	12.2
661	63.05	9.5
1173	86.52	7.4
1332	90.71	6.8
2614	139.05	5.3

$$\boldsymbol{Y = -0.00269 + 0.0764 * \sqrt{(X + 0.1193 * X^2)}}\ ;\ R^2 = 0.9904$$

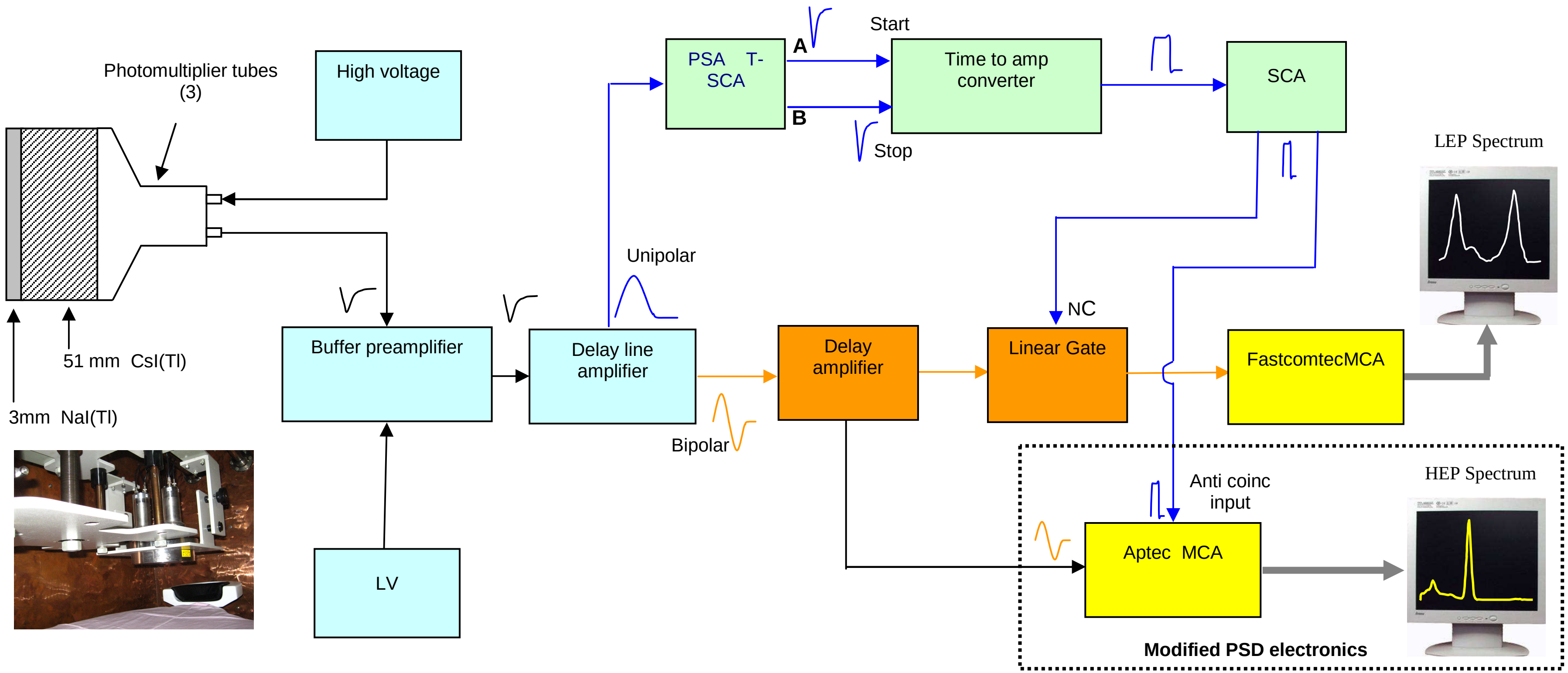


Figure-1: Phoswich PSD electronics for simultaneous recording of HEP & LEP spectrum

Efficiency calibration

Efficiency calibration with point sources at 10 cm from the detector is carried out. Efficiency curve is shown in Figure-2. For the energies from 356 keV to 1332 keV the efficiency is fitting to second order polynomial as expected. As a validation, activity of a source (^{22}Na, 1275 keV) was estimated in the same geometry using efficiency fitting parameter as 223 Bq which is within 5% of actual activity of 233 Bq. The present system has shown excellent efficiency correlation with energy.

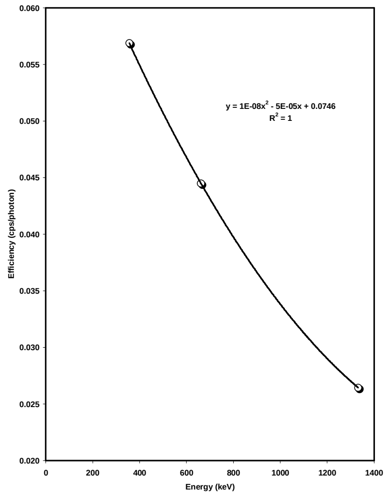


Figure-2: Point source efficiency

Performance evaluation of PSD using HE gamma emitters

The LEP & HEP spectrum obtained with ^{137}Cs source is shown in Figure-3. The LEP spectrum, where pulses corresponding to interactions in NaI detector portion are selectively accepted, the predominant peak observed at 32 keV corresponds to Ba X rays. The HEP spectrum clearly demonstrates the efficient selection of 662 keV pulses from CsI and rejection of pulses corresponding to Ba X-ray interaction in NaI, thus the purpose of added PSD electronics for simultaneous recording HEP spectrum without effecting LEP spectrum is met. Also, the spectral parameters like peak energy, FWHM, efficiency for 17 & 60 keV were reassessed after the incorporation of PSD electronics modification and found unaffected.

Applications of HEP spectrum measurement

Room background measurement

One hour background spectrum obtained inside the steel room is shown in Figure-4. Peaks at 511 keV (annihilation) and 1460 keV (^{40}K) are identified clearly. A predominant peak at 662 keV is also observed which could not be attributed to any source initially. Various sources were suspected including the presence of ^{137}Cs in the detector material. The detector material contamination was confirmed by literature survey[4,5,6] and personal communication[7] to the detector manufacturer. The manufacturer informed that the contamination detector material could be around one Bq. Using MCNP code theoretical estimation[8] of ^{137}Cs contamination was carried out. The phoswich detector was modeled with uniform distribution of ^{137}Cs in CsI portion. The estimated activity calibration factor was 0.411 cps/Bq. Based on the 662 keV ROI counts (0.57 cps) from the observed spectrum, the activity is calculated to be 1.4 Bq.

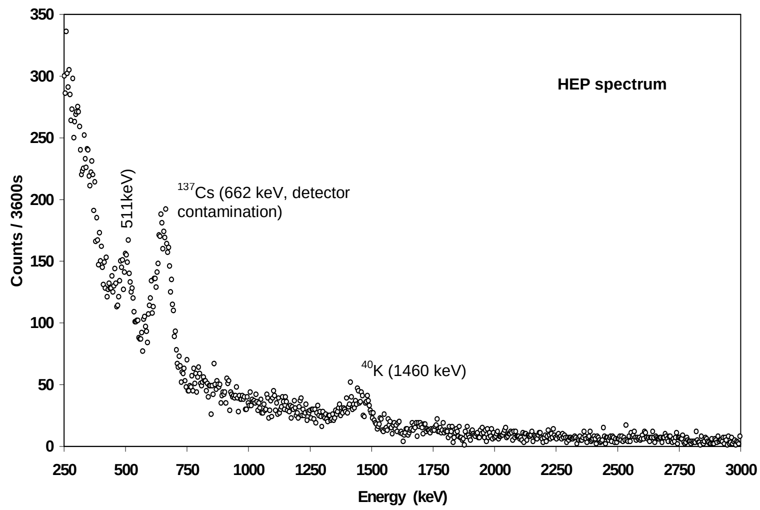
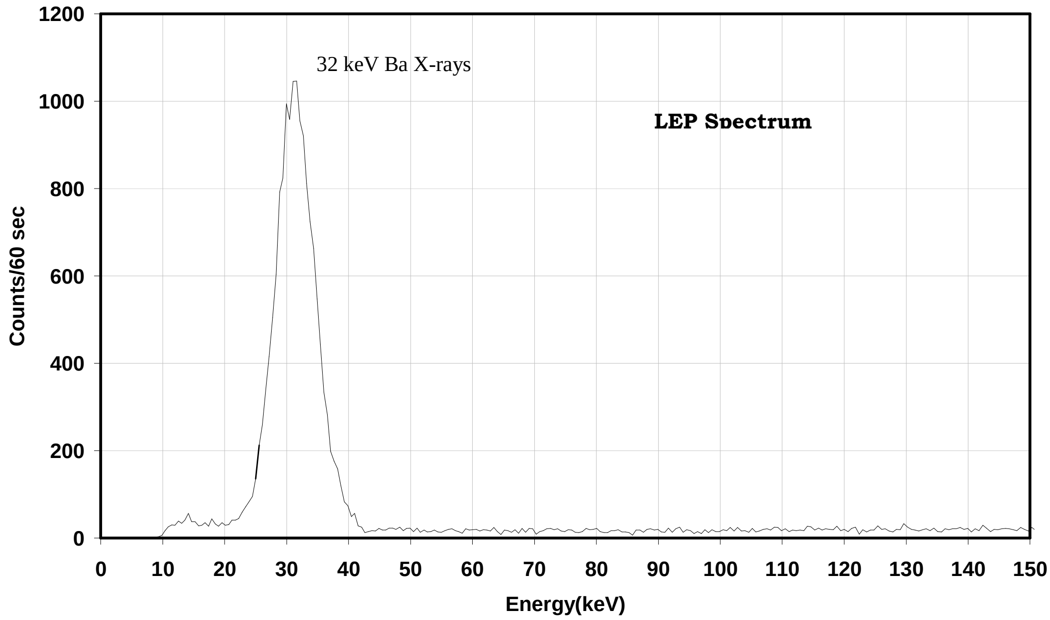


Figure-4: Room background spectrum



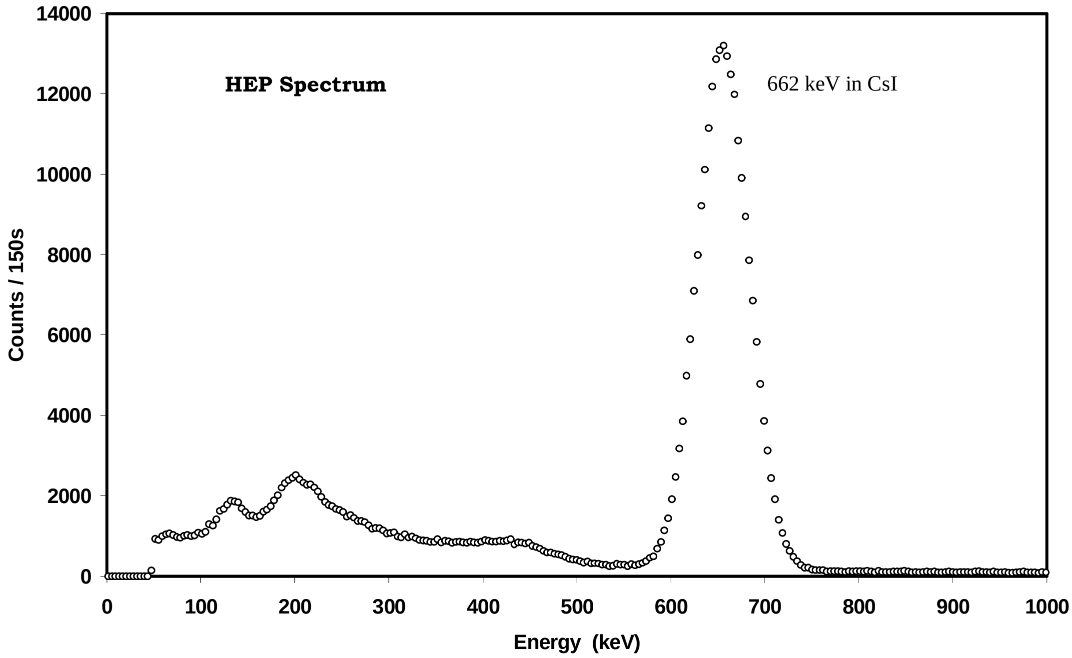


Figure-3 : Simultaneous recording of LEP & HEP spectrum with ^{137}Cs source

Interference of ^{41}Ar

Release of ^{41}Ar as gaseous effluent from nuclear power plant, interfere with low level in vivo measurements (like whole body counting, lung monitoring, etc.,) at our laboratory under favourable wind conditions. The ^{41}Ar interference increases the background counts in lower energy regions. Even inside shield room the increase in room background is significant during ^{41}Ar presence. With the new feature of simultaneous monitoring of HEP spectrum now it is possible to identify and quantify the ^{41}Ar interference (Table-2). Typical HEP spectrum obtained during a ^{41}Ar interference period is shown in Figure-5. The presence of ^{41}Ar is very evident from the predominant peak at 1293 keV. A good correlation between the increased counts in lower energy regions (17 & 60) and the ^{41}Ar interference (in 1293 keV ROI) is observed. This correlation can be used in quantifying the interference in lower energy regions.

Table-2 : ^{41}Ar interference data

ROI counts / 3600s in		
1293 keV	**17 keV**	**60 keV**
2578	971	1114
2971	988	1140
7393	1072	1289
10590	1192	1439
11467	1292	1527

The typical room background count rate in ^{41}Ar ROI is observed to be 0.5 cps. The count rate is observed to increase as high as 4 cps during ^{41}Ar interference periods. The interference depends on the release rate, wind condition and ventilation pattern in the wholebody counting room where the phoswich detector is located inside the steel room.

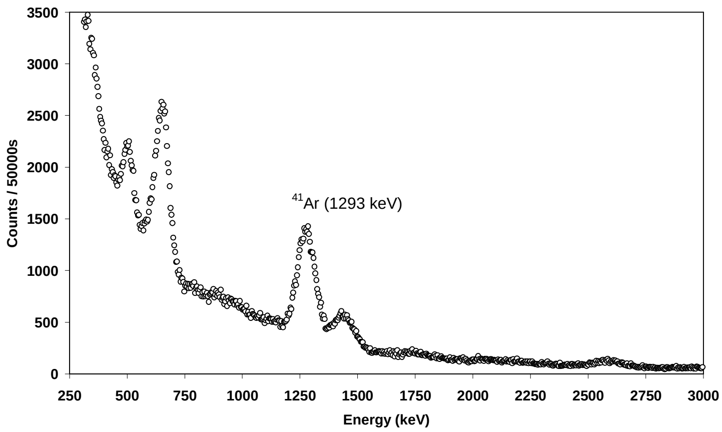


Figure-5 : HEP spectrum during ^{41}Ar interference

Feasibility study to use the HEP spectrum measurement feature for wholebody potassium estimation

The ^{40}K measurement is required for different purposes in *in vivo* monitoring. Based on the chest wall composition (fat/muscle), the calibration factor for phoswich detector is chosen for estimation of Pu and Am activity in lungs. Since the phoswich detector kept inside a low background steel room with PSD electronics has very little background counts in ^{40}K region, even small variation in ^{40}K activity results in statistically significant counts in ^{40}K region. The newly added feature of HEP spectrum recording enabled us to exploit the high sensitivity of phoswich detector for estimation of ^{40}K in the subjects. The phoswich system was calibrated using masonite cut-sheet wholebody phantom for ^{40}K estimation. The calibration factor obtained with manosite cut-sheet phantom is 4.5x10^{-4}cps/Bq of ^{40}K. The MDA works out to be 110 Bq. This corresponds to 3.5g of body potassium (31 Bq of ^{40}K = 1 g of potassium).

In the HEP spectrum obtained with different subjects, the recorded counts in ^{40}K region are well above that of steel room background. A typical HEP spectrum of a subject along with room background spectrum is shown Figure-6. The 1460 keV gamma peak is very predominant for the subjects.

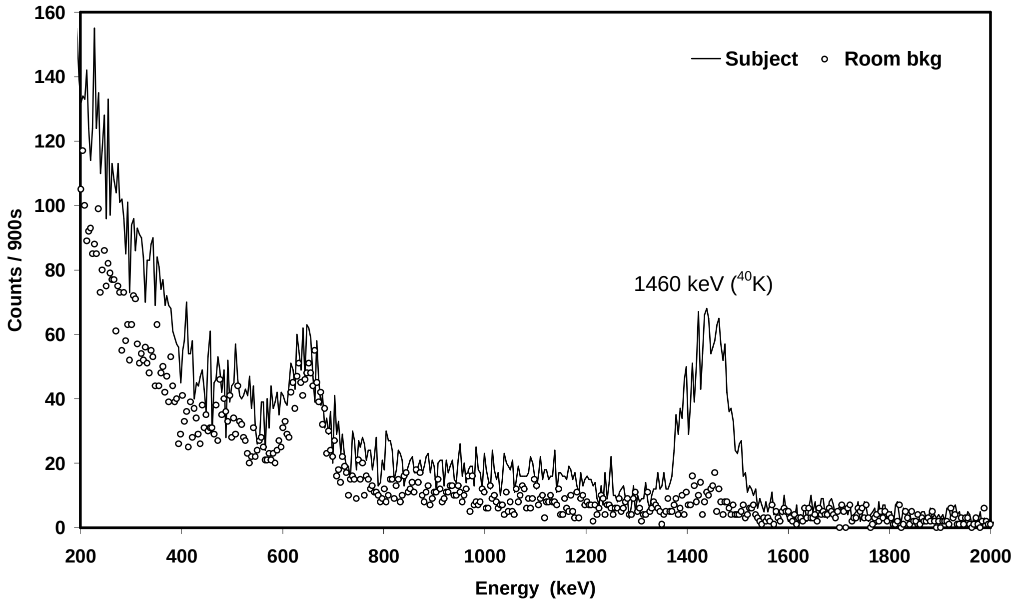


Figure-6 : HEP spectrum with subjects (^{40}K)

Conclusion

The existing PSD electronics is suitably reconfigured without adding any additional electronic modules for simultaneous recording for HE phonton spectrum from phoswich detector. Operational parameters for the reconfigured PSD electronics of phoswich are optimized. The phoswich system with reconfigured PSD has shown good energy linearity within (3 keV and a satisfactory FWHM performance in the energy range of 122 keV to 3 MeV. The efficiency calibration exercise with point source geometry demonstrated that HEP spectrum of phoswich could be used for activity estimation.

Phoswich detector has high sensitivity to ^{40}K variation in the subjects with MDA value of 110 Bq equivalent to body potassium variation of 3.5 g. This sensitivity can be exploited for estimating LBM and total body fat fraction which are required as part of lung activity estimation of LEP emitters.

During evaluation, CsI detector portion of phoswich detector is found to have presence of 1.4 Bq of ^{137}Cs.

The interference of ^{41}Ar in LEP measurements could be easily detected and quantified. Its interference in LE region was studied.

The phoswich detector with re-configured PSD electronics with feature of simultaneously recording LEP and HEP spectrum is successfully commissioned at wholebody counting facility of RSD, IGCAR and being currently used for lung monitoring. A single phoswich detector works as lung counter with additional capability to simultaneously detect any other interfering HE gamma emitters present in the subjects.

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