STUDIES ON IN VIVO CALIBRATION OF A PLUTONIUM LUNG MONITOR

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ABSTRACT

A phoswich assembly comprising a 20 cm x 3 mm NaI(Tl) primary detector and 20 cm x 5 cm CsI(Tl) secondary detector has been installed in the large steel room at BARC, Trombay for monitoring of chest burdens of plutonium and other transuranic elements. A special pulse-shape discrimination (PSD) circuit along with a multiplexer enables simultaneous and independent recording of pulses due to interactions of low and high-energy photons with the NaI(Tl) and CsI(Tl) layers respectively of the detector. The background of the primary detector in the 12 - 25 KeV energy band has been reduced by an order of magnitude at a loss in counting efficiency of 12-14%. To derive the counting efficiency for chest burdens of Pu-239, an in vivo calibration procedure is adopted. For this purpose, healthy volunteers inhale 'mock-Pu' aerosol consisting of polydisperse (AMAD 1 μm, σ_g = 1.8) polystyrene particles labelled with a mixture of Cr-51 and Pd-103. Cr-51 serves as a marker for the precise estimation of Pd-103 contents from which the calibration factor appropriate for chest burdens of Pu-239 is derived. The counting efficiencies for a subject-detector geometry and subject posture selected for routine monitoring are presented and discussed. The effects on the counting efficiency due to mode of breathing (nose/mouth), resulting in changes in deposition of the inhaled aerosol, are also investigated.

Phoswich Detector System

At Trombay a 20 cm dia phoswich detector (Quartz et Silice type Scintiflex 203YBE3) has been installed inside a large steel room (20 cm mild steel with no graded-Z lining) for monitoring lung depositions of insoluble Pu dust. Fig.1 shows the schematic diagram of the electronics system used for the detector. This system is essentially same as the one described by us in an earlier publication(1); however, a few additional options have been introduced to achieve further reduction of background in the low energy bands. In addition, to facilitate the simultaneous and independent recording of information about low-energy and high-energy gamma interactions on a single 400 channel pulse-height analyzer, we have incorporated a two input multiplexer which aids in selecting either half of analyzer's memory depending upon the origin of signal pulse (Fig.1).

By pulse shape discrimination (PSD) alone we were able to reduce the background in (12-25 KeV) energy band to 10 cpm, i.e. by a factor of more than 5 in comparison to a thin NaI(Tl) detector; the loss in genuine signal was 10-12%. With the PSD operating, the background in low energies ($<$ 25 KeV) was still higher than expected. Cosmic ray interactions showing saturated pulses were observed to cause electronic artifacts in the form of bleed off monopolar pulses occurring after a lag of about 100 μsec or so, whose rise-times were similar to those of NaI(Tl) pulses. Electronic elimination of such pulses, not rejected by rise-time discrimination, was carried out by options B & E shown in Fig.1. Option E is essentially an overload rejection and inhibits the output of spectrometry pulses for about 300 μsec, the moment any saturated pulse is detected. Option B serves to limit the energy band desired. Though the combined effect of these measures was a reduction in the background (12-25 KeV energy band) by more than 1 cpm, the shape of the low energy pulse-height spectrum appeared to show some unrejected components.

Experimental evidence indicated that the PSD perhaps did not reject some noise pulses, having rise-times similar to those of NaI(Tl) pulses. We have not yet been able to identify the source of such noise pulses but their presence has been established beyond doubt since when, in addition to all other options the output of the last dynode of phototube is operated in coincidence with that of the anode, the low energy background (12-25 KeV) is reduced by a factor of almost 2 (Option C in Fig.1). This results in further signal loss; however, when the time window for NaI(Tl) in the PSD channel is widened to compensate for signal loss, the overall reduction in background observed is similar.

Finally, another option D has been incorporated to substantiate PSD criterion by inserting CsI(Tl) output in anticoincidence to the spectrometry signal. Thus the phoswich detector at Trombay has been in operation with the measures of PSD, overload rejection and energy band restriction, last dynode coincidence and PSD substantiation. The overall loss of the genuine signal for low-level counting has been adjusted to 12-14%; PSD alone accounts for 8%. The resultant background in (12-25 KeV) region is 4-5 cpm; almost an order of magnitude less than expected from a thin NaI(Tl) per se. The shape of the background spectrum does not seem to indicate the anomaly observed earlier as is clear from Fig.2 which also shows the effects of incorporated options.

In Vivo Calibration

The inadequacy of in vitro calibration methods for assessment of low energy x-ray emitters in lungs is well recognised.[1,2] While some effort is being made to improve chest phantoms to make them more realistic, we believe that simulation of radioactive aerosol distribution within the lung and that of human posture would still remain as uncertain factors, although the extent of uncertainty may be known. We prefer in vivo calibration of the system, involving inhalation of 'mock-Pu' by human volunteers. The mock-Pu used in the present studies is polydisperse polystyrene aerosol (AMAD = 1.0 μm; σ_g = 2.0) labelled with Pd-103 (20.2 KeV) and Cr-51 (323 KeV). The technique of aerosol generation and inhalation by human volunteers are same as those described by us earlier.[1] Three more volunteers inhaled dual (Pd-Cr) labelled aerosols by nose. In order to ascertain the effects of the mode of breathing, two volunteers inhaled by mouth aerosols labelled with Cr-51 only. Normal breathing patterns were maintained as far as possible. The maximum amounts of each of these radionuclides deposited in lungs and subjected to long-term elimination were less than 1 μCi in most cases.

Measurements & Results

The measurement techniques were essentially the same as those described by us earlier.[1] From chest contents of Cr-51, measured by Cs(Tl) secondary detector of phoswich and Cr-51/Pd-103 ratios, estimates of Pd-103 lung contents were obtained. The counting efficiencies E(count per photon emitted by Pd-103 in lungs) were calculated from the observed counting rates from subjects in (12-30 KeV) energy band covering the 20 KeV photopeak. Since our earlier data[1] had been adjusted to 8% signal loss as a result of phoswich operation, the present data have also been adjusted to the same loss. For mouth breathers who inhaled aerosol labelled with Cr-51 only, supine and prone measurements on the chest were carried out for more than 30 days. In addition, ultrasonic measurements of chest wall thickness (CWT) were carried out for 60 Indian subjects in arms by side posture and the data fitted by a least square straightline as a function of W (Kg)/H (cm) ratio which yielded the regression equation.[3]

$$CWT\ (cm) = 0.812 + 3.75\ (W/H);\quad \sigma = 0.19\ cm$$

This equation was used to get CWTs of the subjects in earlier experiments.

The results from the present series are similar to those obtained in our first experiment.[1] Fig.3 shows the correlations of counting efficiencies for Pd-103 and Pu-239 in lungs with CWT of the subject in arms by side posture, the single phoswich being placed centrally over the chest. As was expected, better correlation was obtained with CWT than with chest circumference. The method of converting Pd-103 counting efficiency to that for Pu-239 in lungs is the same as reported earlier.[1] Fig.3 shows also the variations of the corresponding limits of detection for Pu-239 in lungs with CWT. These results which predict 0.76 and 0.62 cm as half-value thickness of tissue for Pd-103 and U_L x-rays respectively are given for the counting geometry used at Trombay for routine monitoring of chest burdens of Pu. The results have been normalised to the same ratio of counts in Cr-51 photopeak from front to back.

The results from the two mouth breathers indicate similar biological half-lives for clearance from lungs as in the case of nose breathers. It appears that in general the pattern of activity deposition in lungs is similar, as is indicated by the ratio of Cr-51 photopeak from front and back in the case of nose and mouth breathers.

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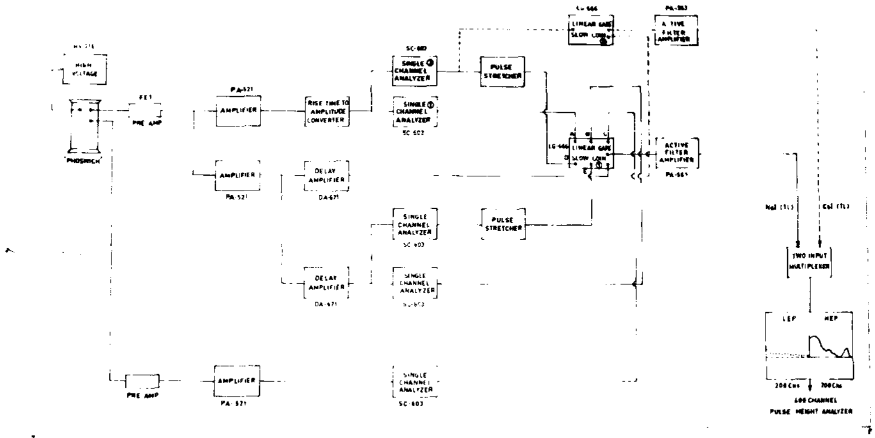

Fig.1 SCHEMATIC DIAGRAM OF ELECTRONICS FOR PHOSWICH DETECTOR

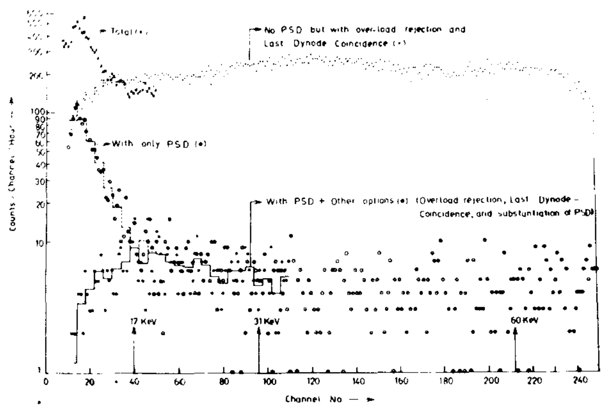

Fig.2 Low energy background spectra from phoswich inside Trombay steel room under different operating conditions. Histograms depict 5 point averages

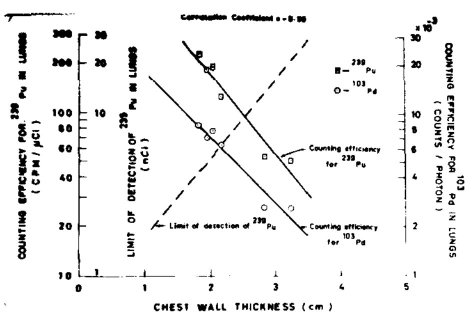

Fig.3 Correlations of counting efficiencies for Pd-103 and Pu-239 in lungs with chest wall thickness (CWT) of subjects in arms by side posture