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TREATMENT OF THE X AND γ RAYS LUNG MONITORING SPECTRA OBTAINED BY USING HP-Ge DETECTORS IN CASE OF EXPOSURES TO URANIUM

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INTRODUCTION

X and gamma whole body counting examinations make it possible, when focusing to an organ, to determine the retention of radioelement. The critical organ when performing the radiotoxicological monitoring of personnel exposed to non-transferable compounds of uranium is the lung. This is true for both natural and enriched uranium because of their biological inertia and of the very high ionising power of their alpha radiation. *In vivo,* X and gamma spectrometry take advantage of the low excretion rate of these compounds to allow the quantification of the pulmonary retention of the inhaled products. These examinations are based on the analysis of the X and gamma radiation emitted by the radioelements retained in the lung and the ensuing quantification of their activity.
HyperPure coaxial Germanium detectors (HP-Ge) are used because of detection features which are specific to uranium. In the 10 keV to 400 keV energy range, these detectors combine low electronic background, satisfactory energy resolution and a high peak/background ratio. Their detection limits depend on spectrum treatment performance and on the modelling of the morphological parameters of the rib cage. For various reasons, the estimation of radioactive contamination in the lungs of a human being poses a delicate spectrometry problem: activity levels are low, a significant proportion of the radiation emitted is absorbed by the rib cage and counting time is limited for practical reasons as well as because of the equipment background effect. Consequently, for most of the spectra, the 185 keV ^{235}U absorption peak does not clearly stand out of the average level of spurious counter pulses. It is therefore difficult to affirm whether or not a peak exists, and in case of contamination, it is, *a fortiori,* difficult to estimate the number of pulses emitted by the radioelement at that energy level during the measurement operation.
The aim of our study, which calls into question both acquisition conditions and interpretation methods, is to improve the efficiency of these measurements.

MATERIALS AND METHODS

1 - The whole body counting equipment

The system consists of four LOAX detectors movable and adjustable on a rail. The coaxial N-type low background detectors are made with high purity germanium. The energy detection range extends from 3 keV to 3 MeV and covers the isotopic energies required for medical assessment in Pierrelatte facilities. Two detectors are placed along the body axis above each lung to cover as much lung area as possible. The absolute efficiency of the measuring system is calibrated with a Livermore phantom. Two background measurements are performed every day. The background measurements are made on an empty shield, the counting time being the same as for the monitoring measurements. The calculations, which take into account the morphological parameters of the worker, are made using automatic spectral analysis, peak search and specific area. The results are analysed using the sum of the counts given by the four detectors, once the background of the room has been subtracted.

2 - The method adopted

The starting point for this study was a critical appraisal of the measurement principles. It is clear that, before looking at spectrum interpretation problems, a certain number of questions need to be asked: Do the four spectra need to be summed or should they, on the contrary, be treated separately ? Can the backgrounds really be exploited ? If so, what counting time should be allotted for them ? Should lung acquisition time be increased, or can it be reduced ?

In replying to these questions, an important consideration is to take into account all the available information: the resolution of the detector, for example, is a useful piece of information since it indicates what form the eventual peaks will have. The second stage involves the analysis of the spectra. Basing ourselves, respectively, on statistical test theory and evaluation theory, we propose a method of diagnosis and a peak quantification algorithm. A computer programme written in Turbo-Pascal has been developed in order to implement the corresponding algorithms.

3 - Modelling

A whole body counting spectrum cannot be considered to be a series of regular peaks, even if the background is totally abstracted. Adjusting a Gaussian function to a peak is not a trivial affair, because the peak is the result of random phenomena. As such, in comparison with the "ideal" Gaussian function, it may contain discrepancies of varying importance.

Peak formation modelling is a random phenomenon when we consider that the number of counts that the detector - which is submitted to a certain apparent activity over a given period - shows in each of its channels obeys a Poisson distribution in which the average is equal to the product of the following numbers:

➪ the apparent activity (activity x percentage of non-absorbed photons x solid detector angle fraction)
➪ the counting time
➪ the fraction of the theoretical Gaussian area intercepted by the channel

Throughout this study, to simplify the calculations, we have taken the numbers of pulses received in each channel as being independent random two-by-two variables. The probability of a spectrum corresponding to a given source can be calculated, thanks to this approximation, from the probabilities of the number of counts that each channel can receive.

RESULTS

1 - The background

Physical modelling of the background has to be ruled out, because there are too many possible explanations for the spurious counts. The study will accordingly be statistical, based on a two-hour long background measurement on an empty cell. Subtracting the background does not bias the measurement. However, for low counting rates, the relative error may not be negligible.

2 - Do the treatments have to be separated ?

The argument advanced to justify the summing of the four spectra is that, for cases of low contamination, it appears to be necessary to add up the spectral information. This argument holds for peak presence searches, but it is not valid in the cases where the peak area has to be quantified. Figure 1 shows the magnitude of a spectrum corresponding to a level of activity close to the equipment detection limit.

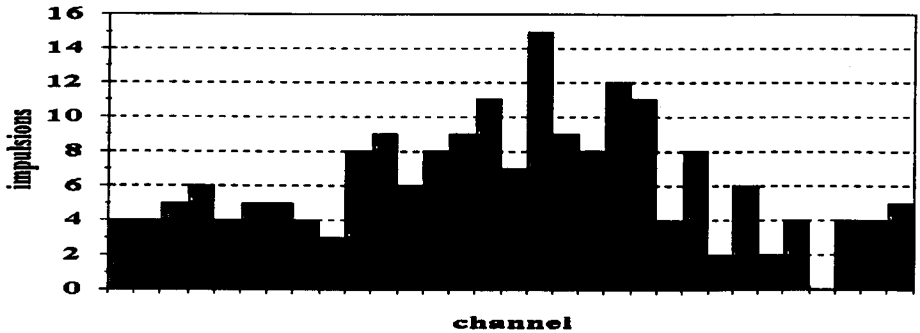

Figure 1: spectrum obtained by summing up the counts of the interest areas for a slightly contaminated worker

The peak obeys a Poisson law where the average is proportional to the resolution of the detector. Separate quantitative treatment also shows up the distribution of the contamination in the lungs.

Table 1 summarises the distribution in terms of the spectral information provided by each detector during measurement on workers whose results were higher than the detection limit. Examinations need to be studied detector by detector.

Table 1: Distribution of the areas measured on real cases in function of the detectors

detector	1	2	3	4
% of the area cover by each detector	24.2	25.4	24.2	26.2

3 - Estimating the presence of internal contamination

This analysis falls within the scope of statistical test theory. Two multiple hypotheses can be posited: the presence of spurious pulses only, or the simultaneous presence of spurious pulses and photonic uranium isotope emission. Since the numbers of pulses counted in each channel are considered to be independent variables, test theory enables us to show the existence of an unbiased, convergent Uniformly Most Powerful test, with an acceptance region corresponding to a 5 % type I error.

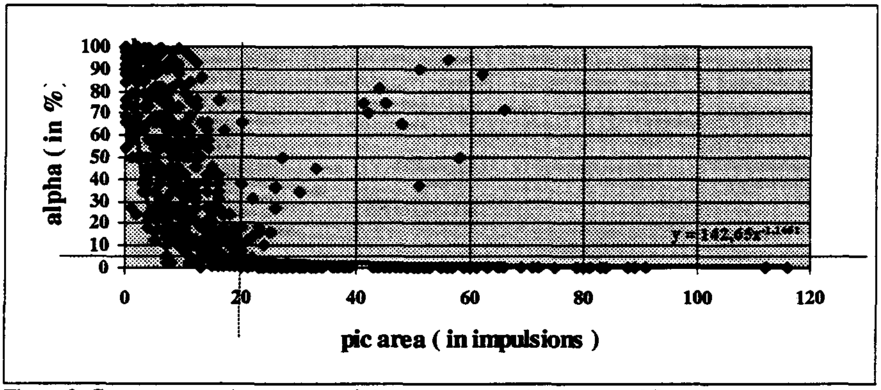

Figure 2: Curve representing the sum-of-the-detectors area in function of first-species hazard (α)

Figure 2 shows four distinct zones.

Negative results : weak area (less than 20 pulses), α between 5% and 100%

Positive results : area with more than 20 pulses, α less than 5%

Results with interferences : weak area and α less than 5%, or area with more than 20 pulses and α between 5% and 100%

CONCLUSIONS

A lung monitoring counting spectrum can be described as a random phenomenon. Channel-by-channel Poisson-type modelling was verified for cases of pure background. When carrying out spectral analysis for qualitative research, one must work with the sum of the detectors. The quantification must be calculated detector by detector. Statistical tests make it possible to certify that one or several peaks are really present in the organism.

The calculations are currently made with automatic spectral analysis, peak search, specific area, statistics and probability of the real presence of analytic photo peak taking into account the morphological parameters of the worker. The results are analysed detector by detector, with and without the background of the room. Detection limits obtained in Pierrelatte in monitoring measurement conditions were assessed for variable tissues covering the range of subjects to be examined. For each subject , the calculations are made taking into account the equivalent tissue thicknesses derived from individual morphological parameters.

This method makes it possible to quantify lung activities with a detection limit of 3.9 Bq (^{235}U; thirty minutes counting time ; reference man parameters) and to monitor exposure to the different compounds of uranium.