Routine analysis of humans for plutonium lung burdens is accomplished with two phoswich low-energy gamma detectors. The analysis of data from each detector provides the spectroscopist with a total of eight parameters. These parameters are normalized and displayed as an octagonal histogram overlayed against the historical analyses of uncontaminated humans similar in body geometry, i.e., weight, height, and chest thickness. Subjects containing lung burdens of plutonium within 1σ (one standard deviation) of the historical average yield data which are displayed on a color graphics terminal as a green octagon. Analyses which yield values greater than 1σ above the historical average produce a distorted yellow, orange, or red display. Thus, through color and pattern recognition, the analyst may see at a glance if the current data statistically indicate human contamination.

Introduction

The U.S. Environmental Protection Agency in Las Vegas operates a phoswich lung counting facility in support of nuclear testing at the Nevada Test Site. Various programs require routine phoswich counting of a number of the offsite residents and Laboratory employees. In addition, special analyses are performed on individuals suspected of contamination from radioactive spills, power reactor exposures, or medical accidents. A description of the facility and summary of results through 1980 was published by Patzer and Kaye (1982)[1].

The laboratory is located underground in a concrete room with 61 cm thick walls, ceiling, and floor for shielding purposes. The room is covered by 122 cm of earth. Its counting system consists of two NaI(Tl)/CsI crystals (phoswich), each 127 mm x 50.8 mm, mounted in a 4 m x 3 m x 3 m shield of pre-1939 steel to provide a low background. Each crystal produces proportional pulses which are amplified, digitized, and stored as multichannel spectra by a Nuclear Data 6700 (ND 6700) computer-based gamma spectrometer.

The phoswich system is used to detect plutonium lung burdens in human subjects. This requires the analysis of multichannel spectra in the 10 to 120 KeV energy region. Because of the relatively
low gamma energies involved, radiation attenuation in the human chest greatly reduces the sensitivity of the measurement. In fact, the minimum detectable activity for a routine analysis is on the order of one permissible lung burden (one nanocurie for an average size human). Even at this level, spectral peaks are very difficult, at best, to detect. Therefore, visual inspection of each spectrum for actual peaks produced from subjects containing full lung burdens may be a very subtle and subjective task for the spectroscopist.

**Phoswich Spectra:** Figure 1 is an example of a typical 256 channel phoswich spectrum. The four energy regions of interest are marked by vertical lines. Region 1, 13 to 24 keV, is an energy band centered at 18.5 keV where plutonium emissions are detected. Region 3, 50 to 70 keV (centered at 60 keV) is for detecting americium-241, a plutonium daughter. Region 4, 80 to 102 keV is used to determine the ambient radiation levels of the subject undergoing analysis (Compton scattering mostly from K-40). Region 2, 8 to 120 keV is used to determine the sum of emissions in the entire energy band of interest.

In a typical analysis, each of these regions is integrated to yield a net value above background and in cases of obvious contamination (Figure 2), Regions 1 and 3 are much larger than Region 4. However, persons with trace contamination levels on the order of one permissible lung burden produce spectra similar to Figure 1 where the contaminant peaks may be overshadowed by random counting noise. Figure 1 is in fact an actual spectrum produced by counting a phantom with one permissible lung burden for the normal counting time (2,000 seconds). Since it is impossible to determine contamination conclusively from observation of spectra similar to Figure 1, we needed a new method of analysis and display.

Our solution was to first construct a data base separated by sex (the data are sexually bimodal) of all lung analyses performed historically by the system. The elements of the data base contain the net sums of counts in each energy region of interest for each detector, producing a total of 8 data points per person. Using Region 4 as an independent variable, we performed linear fits to all data points for the following relationships: Region 1 vs. 4, Region 2 vs. 4, Region 3 vs. 4, and Regions 1 plus 2 plus 3 vs. 4. In addition, we performed hyperbolic fits on the data for each relationship to determine the variance as a function of Region 4. When a new spectrum is acquired these four relationships are determined for each lung and compared statistically to the historically derived mean and standard deviation for each. These statistical relationships are then plotted on a color-graphics computer terminal for visual interpretation. If a spectrum produces parametric data which are statistical outliers, this fact becomes very apparent when the data are plotted in direct relation to normalized lines representing the historical mean and standard deviations of the entire data base. Through this method, a spectroscopist need not require the presence of a well-defined visible peak in the actual spectral display in order to suspect the presence of plutonium contamination.

**The Color Display:** The manner in which these relationships are displayed is important. Figure 3 shows a histogram display of eight spectral parameters. The line at $Y=0$ is the normalized mean for each parameter. In this way the new data, plotted as rectangles of a histogram, depict how data from that particular

![Figure 2. Phoswich spectrum of phantom containing 100 x lung burden of plutonium.](image)
Figure 3. Histogram of statistical analysis

Figure 4. Octagonal histogram of statistical analyses.
parameter measured up to the historical data. If the data are close to the mean, then the bar is green; if the data are greater than one standard deviation (one sigma) above the mean, it is yellow; two sigma, orange; and three sigma, red. On the other end, the bars go from green to blue as the data fall below the historical mean.

Instead of using a standard histogram display as in Figure 3, we decided to display these same data as an octagonal histogram (Figure 4) to provide a more distinct contrast. Here the solid octagonal line (at 0 o) is again the normalized mean and the radius of each pie shape is a measure of how that particular parameter compares statistically to the historical data. Figure 4 is a presentation of exactly the same data presented in Figure 3.

The octagon is such a basic shape that any change can be perceived very easily. Therefore, small deviations from the normalized mean produce distortions in the octagonal shape which are easily detected visually. As the data become more statistically positive, the total area of the pie shapes also increases quadratically. To amplify this, each pie shape also changes color from green to red as the pie shapes become larger.

This produces a large "Red-Flag" effect for a statistical outlier which can be seen easily even at a distance. In fact it is fairly obvious by examination of this figure that Region 3 from the left lung (60 keV region) is statistically more than 2 o above the mean, indicating the necessity for further examination. This "orange" pie shape is expected since the data analyzed was derived by counting our phantom with one permissible lung burden of plutonium.

By using this statistical method and display, the spectroscopist has no need to actually identify plutonium peaks in a raw spectral display to suspect low-level contamination. The simple interpretation of the processed data displayed as a color-coded octagonal histogram provides an observationally simpler, quicker, and more sensitive screening device for triggering more comprehensive analyses in the event of actual contamination.

Reference