URANIUM/PLUTONIUM LUNG COUNTER USING MULTIPLE GERMANIUM DETECTORS

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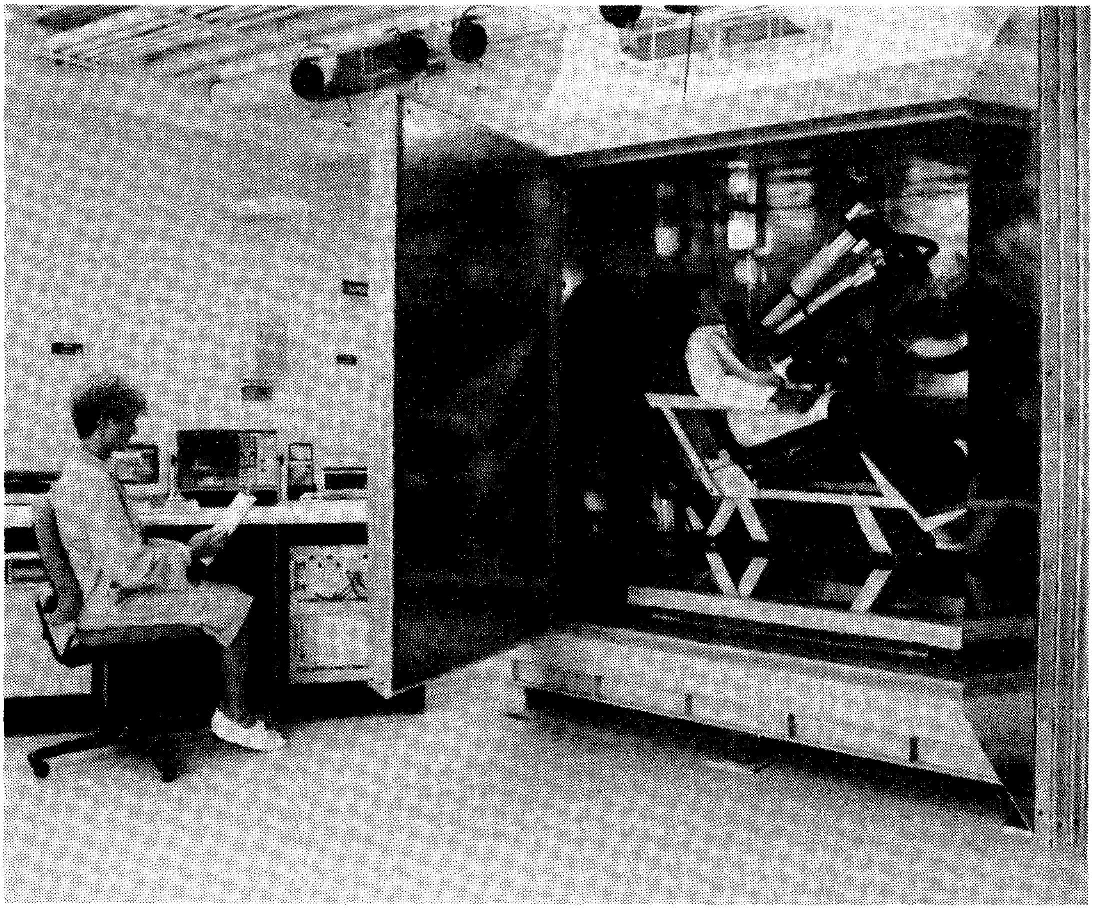
INTRODUCTION

The accurate measurement of the lung deposition of Actinides such as Uranium, Plutonium, and Americium is a critical need of the facilities dealing with these materials. Traditionally, NaI/CsI phoswich detectors have been used; however, in recent years extensive progress has been made using high purity germanium detectors. Their main advantages are a more positive identification of radionuclides, somewhat greater sensitivity, and less interference from higher energy gamma rays. While the phoswich detectors have higher efficiency, the much higher resolution of the germanium detector provides better photopeak-to-background ratios and a better background correction capability. The detection of U/Pu/Am is particularly a problem where there are concurrent depositions of higher energy nuclides (e.g. ^{137}Cs from Chernobyl, or ^{60}Co from reactor maintenance). The environmental ^{137}Cs from Chernobyl has essentially made phoswich detectors useless for plutonium on workers in Europe.

The move from the concept of using germanium detectors in a research facility to using them on a working system in a production environment, however, required a unique mechanical design for the detector and cryostat, special software, as well as a sophisticated approach to the shielding of the subject. This system incorporates the experience gained in designing, manufacturing and operating nearly 100 WBC systems, including six previous U/Pu Lung Burden systems. The result is a complete, turnkey system specifically tailored to the measurement and analysis of U/Pu lung burdens on a routine basis. The system recommended consists of a steel shield, 4 to 8 Intrinsic Germanium detectors and associated electronics, a multichannel pulse height analyzer, a DEC computer system for data analysis, and Canberra's proven ABACOS-II software.



SHIELD

The shield is 6" thick, and is constructed of certified low background steel, from a source that insures the absence of ^{60}Co. Lead is an undesirable material for low background shields. All lead (even so-called old, virgin, or low background lead) has radium and thorium, which have peaks that interfere with the very low level of U/Pu measurements to be made.

The conventional Pb/Cd/Cu liner is not beneficial in U/Pu lung systems where the detectors are in contact with the subject (a low Z material). This extra expense can be avoided. It is beneficial, however, to add a thin graded-Z liner around the portion of the detectors not in contact with the subject (sides and back). This lowers the background about 15%.

The typical shield has inside dimensions of 6' wide, 6' tall, × 4' deep; other sizes are available. If desired, the shield can be built from stacking interlocking modules, allowing assembly inside an existing structure.

The interior of the shield is covered with a low background wall lining and floor covering. The interior is lighted, ventilated, has an intercom, a music system and has a closed circuit TV camera to view the subject.

DETECTORS

The detectors are Canberra's LEGe type, a design now copied by other manufacturers. This is a low profile coaxial detector, with better resolution and background performance characteristics than planar detectors of comparable size. The recommended size is 20 cm^2 area, and 20 mm thick. The detector thickness is optimized for the minimum MDA of nuclides from 60-200 keV. Both 4, 6, and 8 detector configurations are available.

The detectors are mounted in Canberra's newly designed multi-attitude cryostat, the ACT-I. The ACT-I is a unique low background configuration designed for maximum density detector arrays. The small (2.75") diameter endcap and the 3.5" diameter cryostat are critical in obtaining the maximum efficiency from an array of detectors on the chest of a subject. All materials are selected or tested for low background, resulting in a background spectrum virtually free of peaks from contaminants in the detector package. The rear mounted preamplifier keeps cables away from the subject's face, and the printed circuit board away from the detector. The ACT-I is only 28" long, allowing smaller shield size than longer designs. The detector can rotate to 180 degrees without LN spillage on the subject, an important safety consideration. The holding time is 24 hours.

Important to the maintenance of the low background performance of the LEGe detector is separating and shielding radio-sensitive items (detector) from other potentially radioactive items (dewar, subject). Internal tungsten or lead shields are not desirable because of additional cooldown times, and because of the inherent radioactivity of tungsten. For low level counting they typically increase the background. Canberra's unique Remote Detector Chamber (RDC) allows a removable external detector shield to be placed surrounding the detector, thus shielding the detector from the cryostat, the preamplifier, and the scattered radiation background environment. With the RDC, the expense of a Pb/Cd/Cu graded lining on the inside of the shield can be avoided. The Canberra RDC allows shielding to be placed around the sides and back of the detector element, thereby using a much smaller amount of material.

SUBJECT-DETECTOR POSITIONING MECHANISM AND LIQUID NITROGEN FILL SYSTEM

The subject is seated in a semi-reclining position in a chair geometry. This geometry is the optimum for minimum chest wall thickness (especially females and large males) and also is more comfortable than fully reclined. The detectors slide out of the way, and the chair slides out of the shield for easy subject loading. The chair mass is minimized to avoid background contribution. All components used for the subject-detector positioning mechanism are tested and chosen for minimal radioactivity. When a subject containing only ^{40}K is counted for 60 minutes, no peaks interfering with Pu/U/Am will be statistically present (greater than the LLD).

A simple, (and therefore quite reliable) LN_2 filling system is supplied. This system is automatically enabled by means of a programmable timed controller system. There is also a manual fill capability. Typically, the programmer would be set to fill at times when the system is not being used (e.g. 6 AM) Each detector has a detector temperature monitor with visual indicator and audible alarm, and a bias disable circuit to remove HV if the detectors warm up.

ELECTRONICS

The electronics consist of independent bias supplies and amplifiers for each detector. The amplifier contains an ultra-fine gain control to allow precise matching of the detector spectra. Each detector's spectrum is stored separately in the MCA.

To provide the ability to function if the computer is inoperative, an independent standalone MCA is provided (the Canberra Series 35 PLUS, with 8192 channels of memory). Other MCAs are available offering more channels of memory (to 64 K) and/or color display.

The MCA is controlled by either a DEC MicroPDP-11 RSX based computer system (least expensive) or, the recommended MicroVAX-II VMS based computer system (faster, more future expansion).

SOFTWARE

The key element to transform a group of detectors inside a shield to a complete successfully operating WBC system capable of performing in a production environment is the software program. The software must efficiently convert the spectra into a well documented, reliable, legally defensible record. ABACOS-II has been designed specifically for the unique and demanding purpose of spectral analysis for whole body counting. It is menu driven and therefore very easy to learn and to operate. All operator responses are checked for validity, to minimize incorrect data entries. After starting the count, and answering the demographic entries, the entire sequence of STOP/TRANSFER/ANALYZE/REPORT is automatically performed by ABACOS-II. Because of the program structure, a new count can start after the transfer task is complete. The analysis and reporting tasks operate in parallel with the next acquisition.

The system can be pre-configured by the whole body counting manager in a wide variety of ways. All spectra can be analyzed and reported separately, or as a single summed analysis of all detectors, or as two analyses of two detector groups each (left and right lungs). Even if the system is pre-configured for a certain standard set of conditions (library, efficiency, energy range of analysis, detectors to be summed), these conditions can be easily changed on a case-by-case basis for further reanalysis of the same spectra, without recounting.

A drawback of most programs for analysis of low intensity peaks has been the peak search routine. It is a well recognized problem that searching for small peaks in low-count spectra is a difficult task. Sometimes the peak search routine is too sensitive, and finds many false positive peaks. Reducing the sensitivity to false positives also makes the false negatives increase, so that peaks near the calculated MDA will not reliably be found. Canberra has solved this problem by implementing a unique library-driven peak search in ABACOS-II. This technique truly allows near-MDA peaks to be reliably found, even if they are only a few counts in area or on a zero-count background. Furthermore, this technique still allows corrections for interferences from adjacent peaks or from the underlying Compton continuum.

A critical element in an *in vivo* measurement system is Quality Assurance. ABACOS-II has an internal QA program that automatically tracks three types of QA counts (check sources, blanks, and duplicates). Each of these count types has user-adjustable predetermined limits of acceptance. If any of the results is outside its limits, then the operator is notified immediately. Twenty-five different parameters are tracked, and can have high and low warning levels. The results of the QA program can be printed out in a tabular form, and/or plotted on the printer for quick visual review.

To prevent unauthorized changes in parameters, data, or reports, there are six different user definable passwords within ABACOS-II. Each password protects a separate function, and can therefore be distributed to different user levels. ABACOS-II can print out the MDAs (user selectable) for peaks and/or nuclides searched for, but not found. The definition of MDA is also user definable (e.g. 1 sigma, 3 sigma, 4.66 sigma) and allows the use of the 2.71 constant to account for low-count statistics. ABACOS-II also provides spectral and efficiency plots from the computer. The CIMPA plotting package is used by ABACOS-II, and is optionally available, along with the necessary hardware.

PERFORMANCE

The LLD for a 4 detector system has been calculated as the activity equivalent to $2.71 + 4.66\,(BKG)^{1/2}$. Background is from a 30 minute count of standard size person (23 mm chest wall thickness) containing only ^{40}K. When comparing different systems, care should be exercised to assure a consistent definition of the LLD. More detectors, longer count times, less ^{40}K, thinner chest wall, ignoring the 2.71 factor, and different confidence level will all generate lower LLDs.

	^{239}Pu	^{241}Am	^{234}Th	^{235}U
LLD	75 nCi	0.10 nCi	1.0 nCi	0.10 nCi