- FASTSCAN -

A COMPUTERIZED, ANTHROPOMETRICALLY DESIGNED, HIGH THROUGHPUT, WHOLE BODY COUNTER FOR THE NUCLEAR INDUSTRY.

F.L. Bronson
L.F. Booth
D.C. Richards
Radiation Management Corporation / Canberra Industries, Inc.
Northbrook, Illinois

Editors note:

The following documents are more than 10 years old, and represent the original design philosophy of the Canberra Fastscan and Accuscan Whole Body Counters. Since these documents were originally published, Canberra linear geometry Whole Body Counters have become the de facto standard in US and worldwide nuclear power plants. While some portions of the text are dated material, the documents contain WBC information that has not fundamentally changed over the years.

Canberra has continually updated the Fastscan and Accuscan products over the years, utilizing the latest technological advances in computer processing and taking advantage of Canberra's pioneering progress in nuclear spectroscopy. References in the documents pertaining to the limitations of computer memory, disk size, processing power are clearly no longer a factor. Menu driven software has given way to graphical user interfaces (GUIs). Stand-alone Multi-channel Analyzers (MCAs) are now PC card based or networked modules. Manually adjusted amplifiers, high voltage power supplies and analog-to-digital converters (ADCs) are now controlled by computer.

The original ABACOS software has undergone several generations of change: ABACOS-II, ABACOS-PC, ABACOS-PLUS, ABACOS-GPC and the current generation of Windows 9x/NT based software, *ABACOS-2000*. Advances in the ABACOS algorithms have improved NaI and Ge spectrum performance, providing more accurate and faster data results. Canberra's latest development – the AutoScan – brings ATM-like convenience to the WBC world, providing whole body counts on demand with out the need for a count room operator.

In the years ahead, Canberra will continue to improve and enhance its Whole Body Counter product line as new advances are introduced.

- FASTSCAN -

A COMPUTERIZED, ANTHROPOMETRICALLY DESIGNED, HIGH THROUGHPUT, WHOLE BODY COUNTER FOR THE NUCLEAR INDUSTRY.

F.L. Bronson
L.F. Booth
D.C. Richards
Radiation Management Corporation / Canberra Industries, Inc.
Northbrook, Illinois

ABSTRACT

In the past ten years, the use of whole body counters in nuclear power plants has grown significantly. The average counting load is now 2000 - 5000 counts per year at a typical multi-unit station. This paper reports the results of our evaluation as to the desirable characteristics of a whole body counting system and the performance of the FASTSCAN counter.

FASTSCAN is a linear geometry counter, designed to accurately measure inhaled or ingested radioactivity in subjects covering 99% of the size range of the working population (both male and female). Its sensitivity is such that a typical MDL is less than 5 nCi of Cs-137 or Co-60 in a one-minute count. There are no moving parts to break or slow down the subject's entrance and exit.

The software performs complete nuclide identification and quantification. It uses peak searching and detection techniques to allow for the identification and calculation of unexpected nuclides and to allow the user to quickly perform his own efficiency calibrations.

The operator interacts with a menu-driven program, which is easy to understand by a technician, but flexible enough to allow a wide variety of special procedures by the sophisticated user. The program is also designed to allow it to be easily modified for customer-specific data collection formats and report generation formats.

DESIGN PHILOSOPHY OF THE FASTSCAN COUNTER

Nuclear power plants represent the largest single group of users of whole body counters in the United States. There are approximately 60 nuclear power sites in the United States, and based upon recent surveys, each performs between 500 and 10,000 counts per year at each site, for an estimated 100,000 counts per year. Canberra presented seminars at many of these sites for the purpose of presenting information about the current techniques and state-of-the-art of whole body counters, and soliciting ideas from the users about their desires and needs.

The result of this user survey was quite clear; but contained two, somewhat opposing desires: count people quicker, but don't sacrifice any quality of results to do it.

Although there are occasions of real or suspected uptakes at power plants, almost all counts are taken to document for the record that there is no internal deposition of radioactive material. Our experience indicates that the average activity per count is only 2.4 nCi Co-60, the most radiologically significant nuclide. In the entire U.S. nuclear power plant history, we have not observed or heard of a single case of regulatory overexposure due to internal deposition. Nevertheless, it is important that all counts maintain a high degree of quality, even if there are no positive or significant results. Internal plant auditors, industry review groups, and NRC inspectors are demanding, more so today than in the past, that all aspects of a radiation protection program meet high quality standards. Even more important is an increasing trend of lawsuits by radiation workers (or just plain workers) at nuclear facilities. Because of the large expense in defending these (radiologically insignificant) cases, and because of the lengthy period of several to tens of years between the dosimetry record (whole body count) and the litigation, it is important that a well documented and easy to interpret record exist of the count, even if there is no activity found.

These restraints dictated two conditions in the design of FASTSCAN in order to maintain the quality of results. A linear counting geometry was chosen over others where the detectors are very close to the body. Also, the data are completely analyzed with the same comprehensive spectral analysis program used in our other counters.

COUNTING GEOMETRY

There are basically four geometries used in commercial whole body counters. Table 1, Estimate of Whole Body Counter Errors, represents the conclusions from a study to estimate the errors involved in whole body counting. Although calibrations with phantoms can be made quite accurately, when counting real people, the exact location of the source, or organ containing the source, is rarely known, which leads to the major source of uncertainty.

Table 1. Estimate of Whole Body Counting Errors

Source of Error	Close Geometry Chair	50 cm Arc Chair	Linear Geometry	2 m Arc Geometry
Depth Geometry	75	30	25 (S) 3 (P&S)	3
Lateral Geometry	30	5	5	1
Longitudinal Geometry	20	10	2	2
Weight and Height	20	15	5	5
Source Calibration	5	5	5	5
Average Error	85%	35%	30% (S) 17% (P&S)	8%

P= PRONE S=SUPINE

The close geometry column represents those counters where the detector is in contact with the subject. The 50-cm arc chair represents a geometry where by the detector is at an approximate 50 cm distance from the trunk and thighs. The linear geometry represents those counters with a single stationary detector and a moving subject or a stationary subject with a moving detector or several stationary or moving detectors along an axis parallel to the longitudinal axis of the subject. The 2-meter arc column is added for comparison to represent what can be accomplished under research laboratory conditions. The arc geometry, where the subject is bent in a 2-m radius arc and counted both prone and supine, is clearly the most accurate method of assay, but suffers from a lack of sensitivity compared to other geometries.

The data are from published literature, laboratory measurements and mathematical calculations, and represent the estimated 95% CL error for sources of 300-1500 keV distributed in the expected locations of the lung or GI tract. As would be expected, those geometries where the detector is the closest have the largest errors, when the source location is unknown or not constant. The linear geometry and 50-cm arc geometry yield much better, but comparable results. However, the linear geometry counter allows the subject to rotate 180 degrees. If a second count is taken and the results averaged, as is done in the 2-m arc counters, then this largest source of inaccuracy can be dramatically reduced.

In light water nuclear power plants (like most other facilities), the dominant source of internal exposure is from inhalation of slowly transportable nuclides. Also, the industry trend is towards frequent counting, counting quickly after known or suspected exposures, or termination counting of the transient workers on their last day of work. All of these conditions result in counts that still contain material other than that uniformly distributed in the long-term lung compartment as is commonly assumed.

For these reasons, the linear geometry was chosen, as it gives the most accurate results, especially in the real world where the source location is not precisely known.

ANALYTICAL TECHNIQUE

The second choice to be made in the design process was the analytical technique to be used for spectral analysis. There are two basic program types used for NaI gamma spectroscopy; those that look at peaks and those that look at shape of either the total or partial spectra. The most elegant of the spectral shape programs, and the one RMC has been using for the past 7 years is based upon ALPHA-M, developed at ORNL. It is also used by the Health and Safety Lab (HASL) in a slightly modified format called WLSQ. This analysis assumes that the identity of all possible nuclides in the sample is known, and that all of these nuclides are included in the library. The library consists of the complete spectrum of a known standard quantity of each of the potential nuclides in the sample, counted in the same geometry as expected in the person. For analysis of an unknown spectrum, the computer builds a composite spectrum using various linear combinations of fractions of the standard spectra, such that this computer constructed spectrum "best" represents the unknown spectrum. The definition of "best" is when the sum of the squares of the channel-by-channel differences between the unknown and computer constructed spectra is minimized.

When a standard spectrum can be created for all possible unknowns, and when the maximum amount of information (lowest MDL) must be obtained from the spectra, this technique is the one of choice, e.g. for uranium lung counting. However, for activation and fission product counting, the calibration conditions impose significant penalties. The calibration process involves creating complex (people shaped) phantoms for each nuclide. Some of these nuclides are hard to obtain, or have short half-lives. In addition, every nuclide in the subject must have a calibration spectrum even if it is not of interest. As a result, the calibration process takes about one week to perform. These spectral-shape analysis programs also are complex, and either takes time to analyze (typically 5-10 minutes) or a computer large enough to run FORTRAN programs where the run time can be 1-2 minutes. In order to perform a quicker analysis, other analysis programs use only limited portions of the spectrum, and only analyze the spectrum against a few standards. While this is quicker (approximately 5 seconds in one case) the program has very limited ability to correctly analyze spectra which have gain shifts, and which contain nuclides other than the few it is looking for.

Because of these problems, the method of choice for FASTSCAN is a spectral peak analysis program, and makes use of the fact that a pulse-height spectrum produced by scintillation (or solid-state) defectors consists of a series of peaks superimposed on an underlying continuum. The analytical routines used for FASTSCAN are derived from those used by Canberra in their software product GAMMA-M which has been rewritten and adapted for the new whole body counting product. It is now called ABACOS. The calibration process derives coefficients of equations to represent energy (keV vs. channel), peak shape (FWHM vs. keV) and efficiency (counts/gamma vs. keV). This means that the actual nuclides of interest need not be used for calibration. Only nuclides with enough peaks to adequately define the equations need to be included in the calibration spectrum.

The analysis method used in ABACOS is a modified peak analysis technique that determines the areas of photo-peaks in the sample spectrum after the underlying continuum background has been numerically removed. This technique is more geometry independent than that used in ALPHA-M and does not require the establishment of a library of reference spectra. The method resolves multiple overlapping peaks, and can compensate for small changes in detector gain. Earlier attempts at using peak analysis techniques with NaI spectra encountered serious problems with the large continuum background and relatively poorly defined peaks encountered in such spectra, particularly when attempting to measure environmental level activities.

A different method of treating the continuum background is used. The photopeaks are systematically eroded until they subside into the continuum. The resulting "background spectrum" is then subtracted from the original spectrum. The advantages that this method enjoys over the two methods described above are: 1) it allows faster analysis than is possible with complex fitting functions, and 2) it is accurate under more situations then simply attempting to locate "true minima" in a spectrum.

The last major consideration in the design phase was the counting speed. Counters at power plants are heavily used a small amount of time, and largely unused most of the time. However, it is these peak counting loads to which the system must be capable of responding. This is not merely the counting time to achieve a specific MDL, as some systems claim, or analysis time for an arbitrarily high MDL, as others use, but should be correctly defined as the number of workers that can be logged, counted, analyzed, and recorded per hour at a specified (but reasonable) level of sensitivity.

The design goals chosen were that the system should be able to detect ~10 nCi of Co 60 in a subject containing a normal amount of K 40 (120 nCi), with a counting time of one minute, and a total system throughput of 30-40 people per hour. Additionally, the system should completely analyze and store all spectra, and without adjustments or moving parts be able to accurately analyze early and systemic inhalation depositions for all subject sizes.

A one-minute minimum counting interval was chosen as it represents the minimum operator time to enter essential information about the count. Co-60 was chosen as it represents the dominant source of effective committed dose equivalent at nuclear power plants, and 5-10 nCi represents about ½-1% of an MPLB, and a sufficient safety margin over the action criteria within ANSI N343-1978, Internal Dosimetry for Mixed Fission and Activation Products.

FASTSCAN SHIELD AND COUNTING SYSTEM

The FASTSCAN uses two large NaI (Tl) detectors, configured in a linear array on a common vertical axis. The detectors are each 4"X 4"X 16", (for a total of about 100 lbs. of NaI) and are each viewed by a single photo-multiplier tube. Resolution for each detector is less then 8.5% (typically 8.0%). The subject stands inside a shield and on an axis parallel with the detectors. Figure 1 shows the FASTSCAN counter in the foreground and the detector in the background.

The detectors are totally shielded in all straight-line directions by 4" of specially selected low background steel. The steel thickness is equivalent to 2-½" of lead for shielding. The shield weights 10,000 lbs. and is thus more effective in elevated or varying backgrounds than thinner or non-4 pi shields. The shield, however, is constructed in a laminar fashion out of ½" thick plates, and disassembles into a 1500 lb. piece, an 800 lb. piece, and a number of pieces less than 200 lbs. With two men and a small lift truck, the FASTSCAN can be easily transported to most any location and assembled within a day. When assembled, the counter occupies floor space of only 4'X 3', and is less than 7' tall.

The exterior of the shield is aesthetically covered by sheet metal. The interior of the shield is covered with a molded plastic liner. The subject is reproducibly positioned at the centerline of the detectors by locators molded within the plastic liner. The liner and floor covering are replaceable in the event of contamination.

The vertical detector placement and interior shield dimensions were chosen based upon anthropometric data of the working population (Panero, 1979). The population was considered to consist of both adult males and females. Dimensions were taken directly, were applicable. Others were mathematically extrapolated. Table 2, Anthropometric Data, contains a summary of the data. For some data (height, weight) complete data were given for 99, 95, 50, 5 and 1 percentile distribution points. For others, only 95th and 5th percentile values were given, and mathematical extrapolations were made. To estimate the locations of the internal organs, the proportions of Synder-MIRD Mathematical Phantom (Snyder, 1969) were used, where available, to calculate the various height distributions.

Table 2. Anthropometric Data

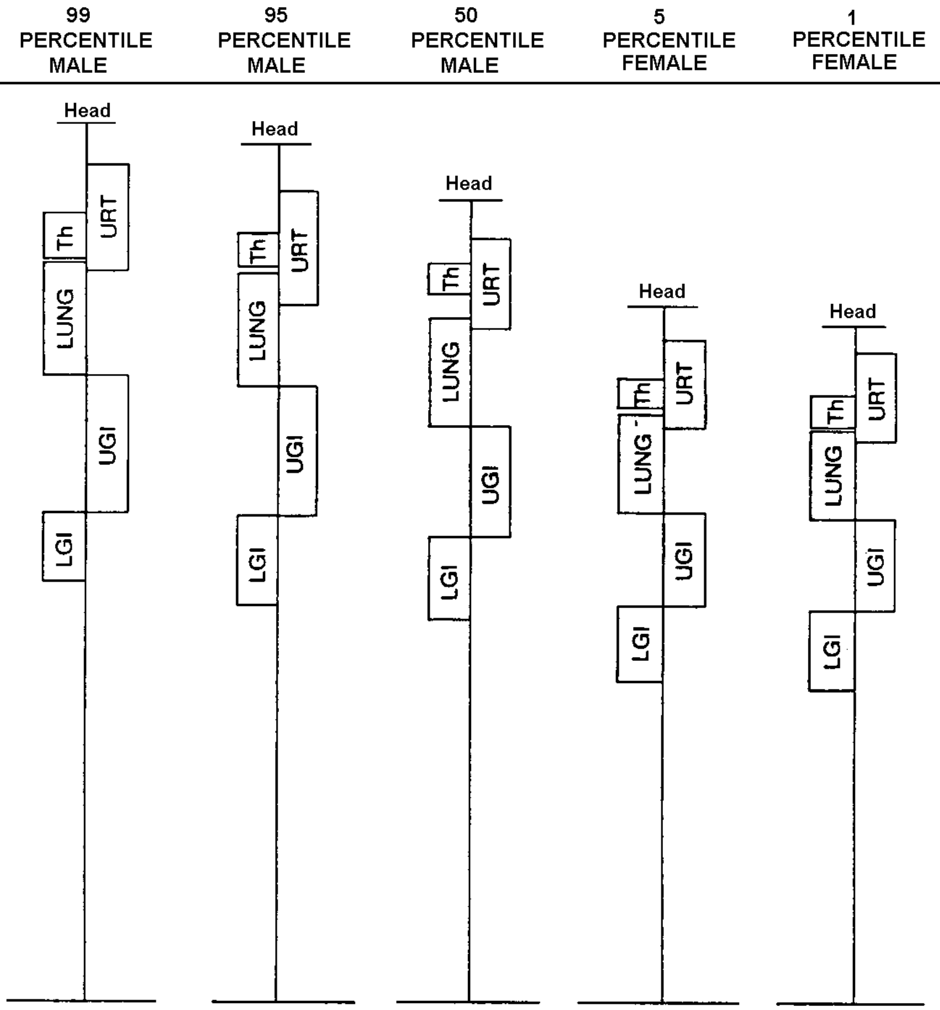
PERCENTILE		99 MALE	95 FEMALE	50 MALE	5 FEMALE	1 FEMALE	HEIGHT FRACTION
WEIGHT (lbs.)		241	212	166	104	93	
HEIGHT (inches)		74.6	72.8	68.3	59.0	57.1	
MAXIMUM DEPTH		13.7	13.0	----	10.1	----	
MAXIMUM BREADTH		23.9	22.8	----	18.8	----	
UPPER RESPIRATORY TRACT	(eye) Top	70.7	68.6	64.9	56.3	54.2	.95
	(shoulder) Bottom	62.0	61.3	56.7	48.3	47.4	.83
	Center	66.4	64.9	60.8	52.3	50.8	.89
THYROID	Top	66.4	64.8	60.8	52.5	50.8	.89
	Bottom	64.0	62.6	58.7	50.7	49.1	.86
	Center	65.2	63.7	59.8	51.6	50.0	.88
LUNG	Top	63.4	61.9	58.1	50.1	48.5	.85
	Bottom	53.0	51.7	48.5	41.9	40.5	.71
	Center	58.2	56.8	53.3,	46.0	44.5	.78
UPPER GI	Top	53.0	51.7	48.5	41.9	40.5	.71
	Bottom	42.0	40.8	38.3	33.0	32.0	.56
	Center	47.5	46.2	43.4	37.4	36.2	.64
LOWER GI	Top	42.0	41.0	38.0	33.0	32.0	.56
	Bottom	36.0	33.5	31.4	27.1	26.3	.46
	Center	38.0	37.2	34.7	30.1	29.2	.51

Since the upper respiratory tract was not defined with the MIRD phantom, it was estimated to go from the eyes (top of N-P region) to the shoulders (T-B region). The GI region includes the stomach, small intestines, transverse colon, and upper large intestine. The lower GI region consists of the lower large intestine and the bladder. The last column is merely the ratio of the height of the organ to the height of the man.

Since the counting in this device will be frequent, counting would typically occur immediately after an inhalation.

For fresh inhalations, one cannot merely assume the material is in the lung. There is very significant translocation within the first 5 days following an inhalation (or ingestion) of nuclides. Therefore, any assumption as to where the material is at any particular time will likely be wrong. We have therefore designed a system with a flat efficiency response, over the range of likely subject sizes. Table 3, Efficiency of FASTSCAN vs. Subject Height, summarizes the results.

Table 3. Efficiencies of FASTSCAN vs. Subject Height



HEIGHT (in.)	TYPICAL PERCENT EFFICIENCY
76	38
74	46
72	53
70	60
68	70
66	78
64	86
62	90
60	94
58	102
56	104
54	103
52	102
50	101
48	100
46	101
44	102
42	103
40	104
38	103
36	98
34	87
32	83
30	78
28	62
26	52
24	38
22	34
20	31
18	22
16	18
14	13
12	11
10	10
08	8
06	6
04	5
02	5
00 Feet	5

The FASTSCAN has a flat (within +5-15%) response from the thyroid of the 95 percentile (male) worker to the lower GI of the 1 percentile (female) worker. This is done without raising or lowering the subject, eliminating a time consuming task requiring moving parts. At the extreme end of the range, the efficiency drops to 60% at the top of the nasal region of the tallest 99 percentile (male) worker and to 53% for the bottom of the bladder of the shortest 1 percentile (female) worker. Of course these errors can be reduced for those extreme examples by merely raising or lowering the subject. Nuclides which have a total body distribution (K-40, Cs-134, Cs-137) and therefore have some material outside the constant efficiency range of the counter, still have enough of the body in the field of view that those results are only 80% of the central body efficiency. A correction factor for those nuclides is contained within the library.

Since FASTSCAN employs multiple detectors, the fraction of counts in each defector can be useful in differentiating internal from external contamination. These ratios can be compared to what would be expected for legitimate long-term internal depositions, as a function of organ location for that subject's height. Likewise, multiple counts with and without hands in front of the detector, and with the subject facing both towards and away from the detector are also valuable clues. The best and most foolproof method is the simplest. Have the subject change clothes, and/or take a shower, and then compare results. Because of the speed of FASTSCAN, this is now practical. As a side benefit, the difference in sequential count values, and the types of nuclides found, provide a good data base for feedback to the Health Physicist, about effectiveness of the plant's contamination control procedures.

ELECTRONICS AND COMPUTER SYSTEM

The electronics and computer are straightforward. The two NaI (Tl) detectors are biased by a single or several Canberra high voltage power supplies. Each detector signal goes through a pre-amplifier and an amplifier. The signals are routed into an appropriate multi-channel analyzer. Each spectrum is accumulated at a nominal gain of 4 keV/channel, and occupies 512 channels of acquisition memory. The MCA need not be located near the computer.

The typical computer is a PC-style computer, as well as DEC based products. These systems are capable of running several FASTSCAN (or other) whole body counters.

ABACOS SOFTWARE

The entire ABACOS suite of products are based upon the technical algorithms of ABACOS and GAMMA-M, which have been used in whole body counting and NaI gamma analysis systems worldwide. ABACOS is written in an extremely easy to follow menu-oriented format. For routine operation of the FASTSCAN counter, the operator selects the count type number (i.e. routine, new hire, termination, calibration check, background check, etc.). The count then begins and the corresponding demographics menu is displayed on the screen. The operator then fills in the appropriate answers (e.g. name, height, weight, social security number, job code and general comments). After that, the process proceeds automatically. When the count is completed, the spectra (from both detectors) are transferred from the MCA to the computer, and the routine operations menu is displayed again. The results will print out in moments with no further operator intervention. The system is now ready to start another count. The report can also be displayed on the screen, if desired, or just written to the disk and not printed at all.

For special situations, all of these functions which are chained together in the routine operations, can be performed separately. There are about 20 different menus for those tasks (start, stop, transfer, analyze, print etc.).

The program has three other functional areas: Library, Calibration, and System Edit. These areas are all password protected, to prevent the unauthorized user from entering. The library menus allow display and editing of elements of the library, the activation of different libraries and the creation of new libraries. Each library can have up to 150 nuclides. Each nuclide has defined with it a series of basic information specific to that nuclide (physical half-life, effective half-life, critical organ, dose calculation parameters, reporting parameters, etc.) plus information defining up to 30 gamma energies per nuclide (gamma abundance, how the peak is to be used, etc.). At any one time, a maximum of 64 peaks can be used. This, however, is well beyond the resolution ability of a NaI detector.

Two different libraries are commonly used. One contains information about nuclides used during the calibration process, and the other nuclides that potentially can be in the subject. Each nuclide is associated with a key indicating whether it has been "selected for analysis". In this manner, the main library can contain data about all of the potential nuclides, most of which may only rarely be encountered, but only "select" those likely to be seen in commonly occurring situations. If an unusual nuclide should be present, it will generate an unidentified peak. The analyst can then enter the library, add the appropriate nuclide to the routine analysis list merely by answering one question, and reanalyze the already accumulated spectrum. About 15 screens relate to the various library functions.

The calibration functions contain about 10 more menu screens. Two separate and independent calibrations are performed: one covering energy, the other for efficiency. The detector energy calibration procedure has been made as simple as possible. For a complete energy calibration, at least three distinct gamma ray energies are needed. After collecting and analyzing the calibration spectra, a least squares fit of energy vs. peak location is made to a second or third degree polynomial. (A third degree polynomial will be used if six or more calibration peaks are used.) At least a second-degree polynomial is needed to accurately take into account the inherent nonlinearity of NaI detectors. In addition, a relation between energy and the widths of spectral peaks is also determined.

For WBC systems, efficiency calibration is performed using a phantom containing NBS traceable sources of known activities. A pulse height spectrum is collected and analyzed, then the detection efficiency calculated at each gamma peak. The efficiency values are then used to calculate a second order efficiency versus energy curve using a least-squares fitting process. The coefficients of this curve are then saved on a disk as a calibration file for use in subsequent analysis. The efficiency calibration need only be done once for each separate geometry and not repeated unless the detector geometry is changed.

The largest number of screens (about 40) is for system definition functions. These parameters are used to define the type of computer, analyzer, ADCs, file labels, input devices, output devices, report styles, and analysis parameters. Except for a few cases, these menu screens never need to be accessed unless there is a hardware change. Those functions requiring occasional access allow changing of routine count times, setting result warning flag values, selecting report type and changing passwords.

The background due to Compton interactions within the detector and collimator is corrected by an erosion technique before analysis. After the estimated background has been subtracted from the original data, an iterative least-squares fitting technique is used to determine the areas of statistically significant spectral peaks corresponding to the library of gamma energies. Activities are then calculated from peak areas and the previously determined detector efficiency data. Activities present in the environmental background may be optionally subtracted from the measured subject activities. Note that background activities, rather than raw background spectra, are subtracted. This improves the accuracy of the result, and is insensitive to shifts in the detector energy calibration that can occur between the time background and subject spectra are accumulated. A report is then generated listing the isotopes present, their activities, and percent statistical uncertainty at the 95% confidence level. The statistical uncertainty includes the uncertainty associated with the detector efficiency calibration.

SUMMARY OF SYSTEM PERFORMANCE

The system throughput is one person every 2 minutes using a 60-second counting interval. This means that approximately 30 people can be processed in an hour. The one minute count time is a practical minimum, since it takes an operator that long to enter the necessary demographic data.

For a one-minute count time, typical Minimum Detectable Activities (MDAs) have been measured and are typically 3 nCi Co-60 and 4 nCi Cs-137. These MDAs are calculated based upon the activity equivalent to 3 times the square root of the number of counts within the area of the spectra where a peak would be if it were present. The spectra contain a normal amount of K-40 in a person, but no other nuclides. These results were confirmed by repetitive one-minute counts on a source containing 4 nCi Cs-137 and 3.5 nCi Co-60. Both nuclides were detected on all eight counts, with an average reported 95% CL error of 75% for Cs-137 and 55% for Co 60.

REFERENCES

Panero, J. and Zelnick, M. 1979. *Human Dimension and Interior Space.* Whitney Library of Design, New York.

Snyder, W.S., et. al. August 1969. "Estimates of Absorbed Fractions for Monoenergetic Photon Sources Uniformly Distributed in Various Organs of a Heterogeneous Phantom", Medical Intemal Radiation Dose Committee (MIRD), J. *Nuc. Med.* Supplement 3, Pamphlet 5.