# THE ACCUSCAN-II VERTICAL SCANNING GERMANIUM WHOLE BODY COUNTER

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***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.

# THE ACCUSCAN-II VERTICAL SCANNING GERMANIUM WHOLE BODY COUNTER

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ABSTRACT

The ACCUSCAN-II is manufactured by Canberra Industries, and represents a new generation of WBC systems. One or two Germanium detectors are used for precise nuclide identification. The detectors scan the total body and can accurately quantify radioactive material anywhere in the body. The shield is a full 4" thick steel weighs about 9000 lbs. The subject can be counted standing for full body scans, or seated for longer counting times over limited portions of the body. Optional electronics generate a count rate vs. body-position profile as an aid to interpretation of the dose implications of the count. Typical LLDs are 5-10 nCi for a 5 minute total body count and 0.5 - 0.7 nCi for a 5 minute lung screening count.

The system is available in several variations. The manual version is an inexpensive system intended for universities, hospitals and small industrial facilities. The automatic system includes a computer and runs ABACOS Body Burden Software, and is ideal for facilities with large numbers of people to count and where automated analysis of the data is desirable.

## INTRODUCTION

Since the introduction of the photomultiplier tube in the 1950's, NaI(TI) detectors have been the dominant detector in Whole Body Counting systems. Today, however, Germanium detectors have become a very attractive alternative, and are indeed superior in some applications. For low energy applications (Plutonium at 17 keV, Uranium at 63, 93, and 186 keV) Germanium detectors have better detection limits, fewer false positives, and have a comparable total system cost. At intermediate energies (300-2000 keV), where most in-vivo counting is performed, NaI detectors still have better sensitivity, but for many situations, the improved energy resolution makes Germanium detectors a better option.

## BACKGROUND

Canberra is the largest supplier of Whole Body Counting systems in the world. The Canberra (Masse'-Bolton) chair counter has had the most total units sold, but few have occurred in the past several years. This counter uses a 3" X 3" NaI detector in a 50 cm-arc geometry viewing the trunk of the body, or the detector can be collimated to view the lung, or the GI only. There is a separate detector for the thyroid.

The FASTSCAN was developed in 1982 by Canberra to fulfill a need of the nuclear power industry for a very sensitive and very fast W8C system. This counter still had to have full spectroscopic capabilities. The FASTSCAN is not merely a screening WBC system. It is fully diagnostic. The MDA is approximately 3 nCi Co-60, with only a one-minute count. The computerized automatic counting and analysis system results in a very easy to operate system, with high quality results that are easily defendable before a regulatory agency or in a court of law. For a few cases, however, the simplicity of the FASTSCAN makes complex uptakes more complicated to resolve.

The ACCUSCAN Counter is a fixed detector counter with a moving subject. The total body scan, linear geometry, and ability to do posterior and anterior counts make this counter one of the most accurate systems commercially available. The availability of an activity vs. position profile helps define the organ of location of internal deposition, and thus better determine the actual dose.

Canberra also manufactures a specialty WBC for the detection of low energy nuclides in the lung (Plutonium, Uranium). This counter uses 4-8 Germanium detectors placed on the lung. The subject is enclosed in a large steel shield, typically 6" thick. Counting times are typically 30 minutes to one hour. These techniques are necessary due to the very low MPLB or ALI of non-transportable transuranics in the lung. Germanium detectors offer somewhat lower MDA over the more efficient NaI detectors, because of their lower background in the peak area. Their prime advantage, however, is the reliability of the data. A peak can be clearly seen to be (or not to be) present. The Germanium detectors are essential when the same subject has simultaneous depositions of higher energy radionuclides (e.g. Cs-137).

## ACCUSCAN-II

The ACCUSCAN-II was designed to fulfill the needs of two types of customers. Nearly all nuclear power plants require two WBC systems for redundancy. One of these counters should be the FASTSCAN, for rapid processing of the vast majority of the workers who have little internal deposition, or have uptakes that are simple to interpret. The second counter should be designed to more easily interpret these few, but very important situations where uptakes do exist. The ACCUSCAN-II was designed as a complimentary tool to be used in conjunction with the high throughput FASTSCAN. Although the FASTSCAN has been the most popular counter in recent years at US nuclear power plants, and has spawned several lookalikes from competitors, it does have two weaknesses: the poor energy resolution of NaI, and the poor positional resolution of two large linear detectors.

The ACCUSCAN-II uses one or two germanium detectors (Figure 1). The inherently superior energy resolution makes it easy to separate isotopes that are difficult to resolve with NaI detectors, and to quickly identify new or unusual nuclides. The detectors also scan during the count. As the detector moves, a positional spectrum is acquired simultaneously with the energy spectrum. This positional spectrum will aid the user to determine the organ of location, or reduce the interference from external contamination, as an aid to more accurate dose determinations. A third advantage of germanium detectors is their wide dynamic range. This is especially important in emergency situations where large internal depositions or contamination (e.g. one MPBB of Cs-137) will render high sensitivity NaI counters useless.

For facilities that only need one WBC system, the ACCUSCAN-II is a perfect choice. It can be operated in a high sensitivity mode, with the subject's lung (or thyroid, GI etc.) in contact with a non-moving detector for maximum sensitivity. Subjects can be quickly screened this way. When activity is found worth investigating further, the subject can be recounted in the total body scan mode for better accuracy and to determine the precise source location.

The ACCUSCAN-II is available as an inexpensive manually operated model using the internal calculation abilities of an MCA. An intermediate model adds a computer and the ABACOS software. The top of the line model replaces the manually operated motor drive unit with a computer controlled stepping motor, and adds the simultaneous positional spectra feature. All of the models are available with one or two detectors. The second detector adds more efficiency, of course, but also adds redundancy.

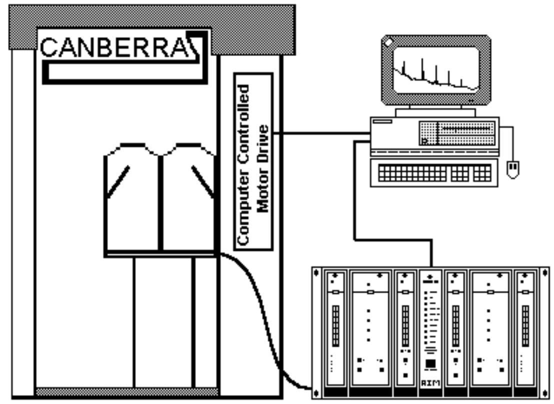



FIGURE 1 - ACCUSCAN-II with Dual HPGE Detectors

**COUNTING GEOMETRY**

The choice of the counting geometry was made after carefully studying our experiences with chair geometries, linear scanning geometries, current and future regulations, and the necessary factors in the WBC result as a legal record.

There are four basic 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)<br>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)<br>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.

Counters with these high geometric errors are difficult to defend, both professionally for result interpretation, but most importantly in legal or regulatory makers. Furthermore, counters that only see parts of the body, and not the total body, have a difficult time quantifying systemically distributed nuclides (radio-cesium) and will totally miss radioactivity outside the field of view of the detectors. Linear geometry counters do not suffer from these problems.

Future regulatory trends also favor the well-designed linear geometry counter. ANSI N13.30 Performance Criteria for Radiobioassay, now in final approval stage, requires WBC facilities to perform an error assessment of their counter, and to utilize *all* uncertainties of the system (not just counting statistics) in reporting MDA of the system. ICRP 26 and 30 as implemented in the proposed 10CFR20 utilize the ALI (Annual Limit of Intake) as the primary method of determining compliance for internal exposure. Inhalation uptakes are the most common. During the first several days following an inhalation, the radioactivity is rapidly translocating between the upper respiratory track, lung, and GI. Under these conditions, results from organ-specific counters will be very difficult to interpret. However, since fecal elimination is usually delayed for several days, total body counts from well-designed counters will accurately represent the uptake, which allows easy determination of intake. Comparison of intake to the ALI determines compliance and allows easy prospective dose estimation.

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 – ABACOS SOFTWARE**

The program used for ACCUSCAN-II is the same ABACOS software used for Canberra's FASTCAN. This is a library driven peak search program, which is essential for short count time germanium spectra containing low count peaks that are commonly on a zero count background.

ABACOS also uses a unique background erosion technique. In the past, most background subtraction algorithms have concentrated on locating minima in the spectrum, rejecting some of them on the basis of certain criteria, and approximating the background by some type of interpolation between the remaining minima. In order to locate the minima accurately, smoothing of the spectral data was usually performed. This had the undesirable side effect of raising the minima values and broadening the effective detector resolution, thus distorting the data. In addition, most of the criteria used to reject false minima were sensitive to the counting rate and the slope of the background. The background subtraction technique used in ABACOS is invariant with respect to counting rates and the slope of background.

After the estimated background has been subtracted from the original data, an iterative least-squares fitting technique is used to determine the net areas of significant spectral peaks, as directed by a library containing the peaks from the isotopes of interest. The program also corrects the peak areas from interference effects from other nearby peaks. This unique library driven peak search technique of ABACOS avoids problems associated with low count spectra. All sizes of peaks are reliably found, and very few false positives are found. Activities are calculated from the peak areas and 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 statistical 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 the percent statistical uncertainty at the confidence level (one sigma, two sigma, etc.) specified by the system manager during the counter setup procedure. The quoted statistical uncertainty includes the uncertainty associated with the detector efficiency calibration. Results are available in either conventional units (Ci) or SI units (Bq).

ABACOS provides the user with multiple libraries. Each special application or detector-shield combination can have a library with all of the parameters uniquely tailored for that application. Each library contains switches to easily enable or disable an entire nuclide, or a single peak. Thus a rarely found peak can be only "activated" when there is reason to suspect that it is present. The library also contains all parameters necessary to calculate MPC-hr, % MPOB, organ dose according to ICRP-2 methodology, or committed effective dose equivalent according to ICRP-30.

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 spectrum, a least-square fit of energy versus 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). In addition, the relationship between energy and the widths of spectral peaks is also determined.

In ABACOS, a detector efficiency calibration is performed using a phantom containing a single NBS traceable mixed gamma source of known activity. A pulse height spectrum is collected and analyzed, then the detection efficiency is calculated for each gamma ray. The efficiency values are then used to calculate an efficiency versus energy curve using a least-squares fitting process. The coefficients of such a curve are then saved on a disk as a calibration file for use in subsequent analysis. The efficiency calibration need only be done once, unless the detector or the detector geometry is changed.

An essential part of any operational counting system is protection of data. In addition to the operating system passwords, each of the sensitive areas of ABACOS are protected with different user selectable passwords.

To provide a legally defensible document, all data associated with the analysis is automatically stored on disk. Reanalysis of data does not erase old data. The hardcopy reports contain all data or references to data necessary to allow an independent observer to confirm that the results are correct.

Each time one of the three QA count-types is done, approximately 25 separate parameters are stored in the QA file. This file can be easily printed or plotted (using ABACOS commands) for a historical trending analy*sis* of system performance.

**ACCUSCAN-II COMPONENTS**

The ACCUSCAN-II was derived from a combination of the best elements of our successful FASTSCAN, ACCUSCAN and CHAIR WBC systems. The shield is a full 4" of laminar steel around the subject and 2" lead around the detectors. It is a complete 4 pi shadow shield and can be used in elevated background areas. There is an optional cryostat design that includes external lead shielding between the detector and the dewar. The shield weighs about 9000 lbs. (4000 kg), but is in small enough components to allow manual assembly.

The subject can be counted standing (for full body scans), or seated (for longer count times of a limited portion of the body). When standing, counts can be done from the front and then from the back to achieve the maximum accuracy and independence of source location. The subject can stand or sit against the back wall for best accuracy, or can lean against the detector in a high sensitivity mode. Figure 2 shows these various ways the ACCUSCAN-II can be used.

The ACCUSCAN-II is available in three basic versions (Figure 3). Model 2280A is the most basic and least expensive. It has the full complete shielding, an adjustable speed motor drive for the detector, a 25% relative efficiency detector, and a multi-channel analyzer (MCA). The MCA is used to find peaks, determine their energy, determine their identity, and to determine net peak area. This is an ideal system for those facilities that have few people to count, or limited funds. As needs change, the system can be upgraded.

Model 2280B includes a computer and the ABACOS software. It is delivered as a turnkey system, with phantoms, sources, factory calibration, all parameters in the software loaded, and is ready to count.

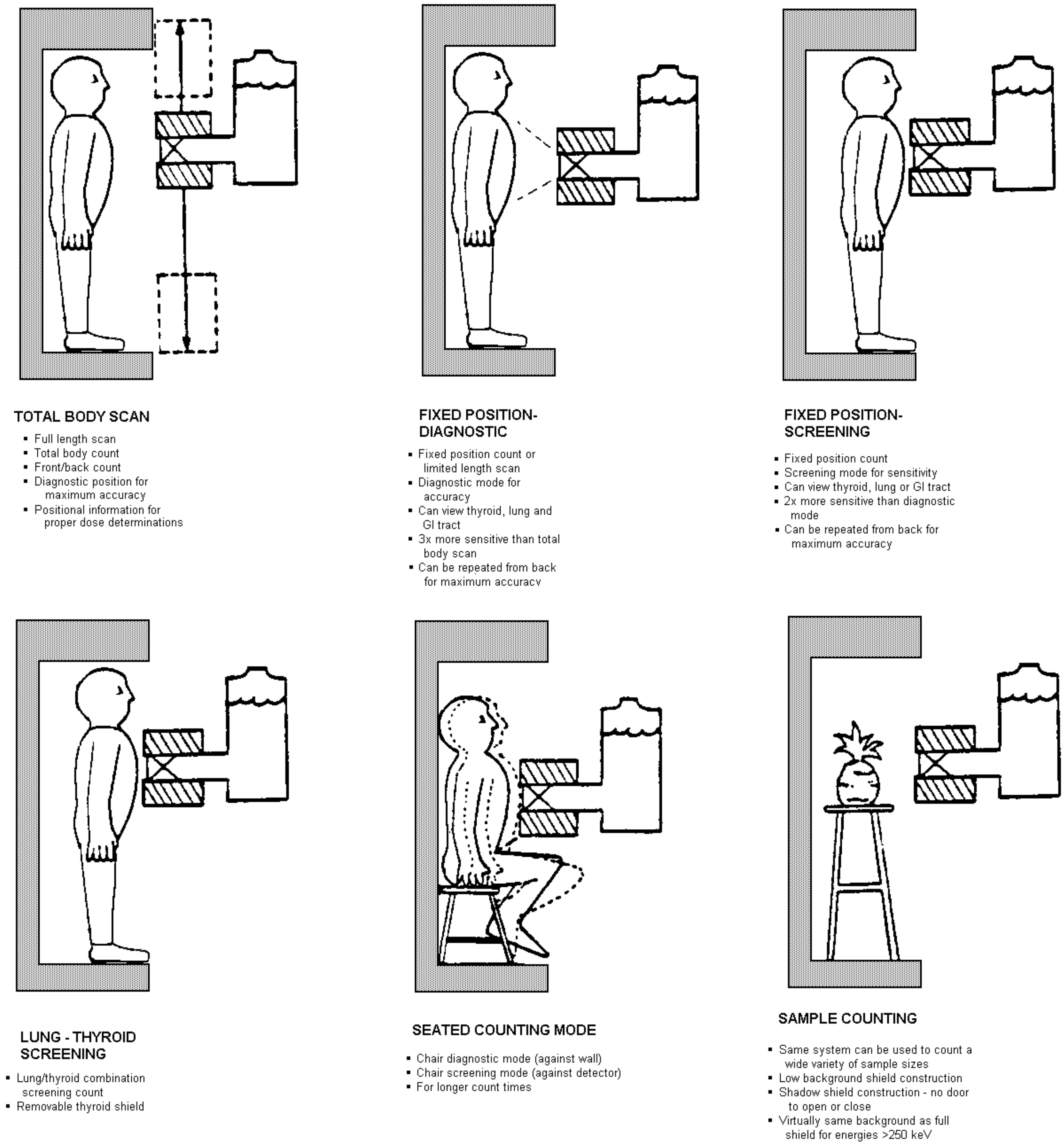
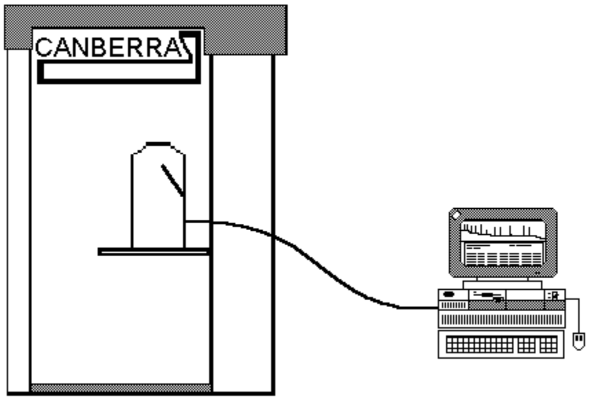



FIGURE 2 – VARIOUS COUNTING GEOMETRIES OF THE ACCUSCAN-II

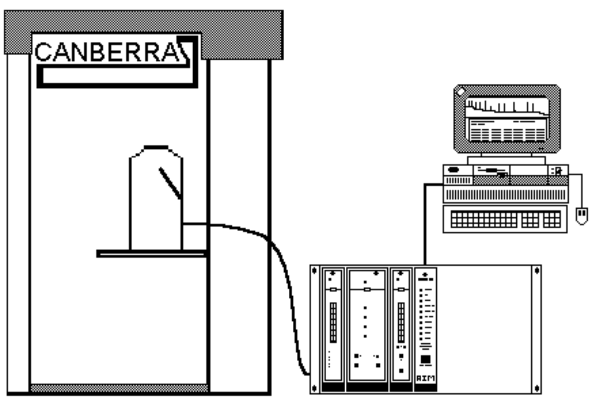
## BASIC GERMANIUM WBC




Germanium detector, 25% relative efficiency
**Full 4π** shielding
4" steel in back, 2" lead around detector
Motor positioning mechanism
Fixed position mode and scanning mode
Computer based MCA
Options available
Calibration phantom, sources and sample counting stand
Factory calibration
On-site installation

**IDEAL FOR:**
- Universities of facilities with multi-isotope inventory
- Facilities with few people to count
- Low budget operations that don't want to sacrifice quality
- Facilities that are expected to grow later

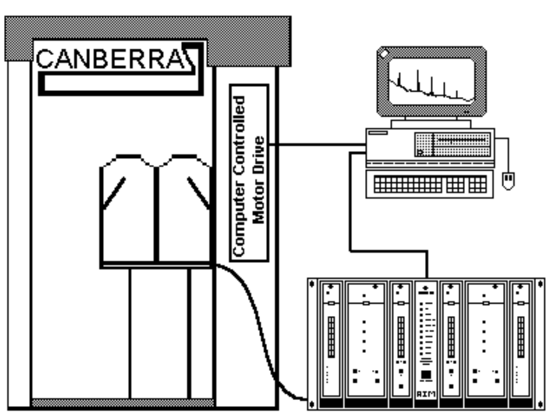
## COMPUTER BASED GERMANIUM WBC




Germanium detector, 25% relative efficiency
Full 4π shielding
4" steel in back, 2" lead around detector
Motor positioning mechanism
Fixed position mode and scanning mode
Computer based MCA
ABACOS Body Burden Software
Factory Calibration, source and documentation
Options available
Calibration phantom and sample counting stand

**IDEAL FOR:**
- Facilities demanding immediate automated data analysis and print-out
- Facilities needing the best legally defensible records (spectra storage, hard-copy results, QA records).
- Facilities with a Fastscan or Chair system, that have the potential for complex cases to evaluate.

## FULLY AUTOMATIC SINGLE OR DUAL GERMANIUM WBC




One or two Germanium detectors, 25% relative efficiency each
Full 4π shielding
Computer driven automatic motor drive
Fixed position mode and scanning mode
Computer / Network based MCA
ABACOS Body Burden Software
Simultaneous activity vs. position display
Factory Calibration, source and documentation
Options available
Calibration phantom and sample counting stand

**IDEAL FOR:**
- Facilities demanding maximum sensitivity and minimum MDA in shortest time
- Facilities needing full automation, minimum training and skill for data interpretation.
- Facilities with maximum potential for complex nuclides and unusual body distributions.

FIGURE 3 – THREE DIFFERENT MODELS OF ACCUSCAN-II

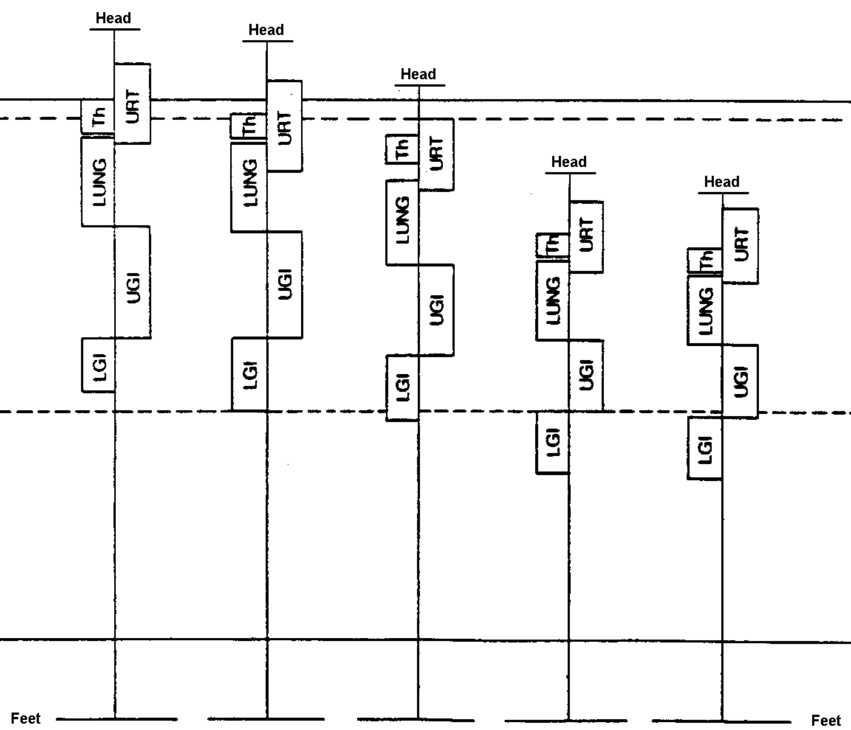
The 2280-G2K (or 2280-ESP) is a fully automatic system. The scan drive is by means of a computer driven programmable stepping motor. With the added multi-channel scaling (MCS) capability, a spectrum containing total counts vs. position is stored in a portion of the MCA memory and displayed. This occurs automatically and simultaneously with the energy spectrum acquisition and display. The information derived from the positional display is useful to properly determine the organ of deposition, which is necessary to correctly calculate dose.

The 2280 optionally includes a second Germanium detector. This increases efficiency, reduces the LLD or the count time, and increases reliability through redundant components.
For the computer-based systems, operation with ABACOS is extremely simple for the pre-configured routine counting conditions. It is also very flexible when using the special operations mode. Extensive error checking is used to reduce operator-input mistakes.

**PERFORMANCE RESULTS**
The excellent efficiency response of the ACCUSCAN-II to various subject sizes and source distributions is shown in Table 2. This table shows the location of expected radioactivity in internal depositions. The middle figure represents standard man, and shows the height of the common organs of reference. The two figures on the left represent tall US males, (95th and 99th percentile) and short US females (5th and 1st percentile). The relative efficiency of the FASTSCAN and ACCUSCAN-II counters is shown on the extreme right hand columns. While the FASTSCAN is adequate for most of the subjects to be measured, and can be made more accurate by elevating the short individuals, the ACCUSCAN-II has a much larger flat efficiency response region. This is important for systemic burdens and depositions in other areas outside the torso of the body.

TABLE 2 – EFFICIENCIES OF ACCUSCAN-II AND FASTSCAN vs. SUBJECT HEIGHT

| HEIGHT (in.) | 99 PERCENTILE MALE | 95 PERCENTILE MALE | 50 PERCENTILE MALE | 5 PERCENTILE FEMALE | 1 PERCENTILE FEMALE | TYPICAL PERCENT EFFICIENCY FASTSCAN | TYPICAL PERCENT EFFICIENCY ACCUSCAN-II |
|---|---|---|---|---|---|---|---|




| HEIGHT (in.) | FASTSCAN | ACCUSCAN-II |
|---|---|---|
| 76 | 38 | 60 |
| 74 | 46 | 67 |
| 72 | 53 | 72 |
| 70 | 60 | 78 |
| 68 | 70 | 83 |
| 66 | 78 | 88 |
| 64 | 86 | 92 |
| 62 | 90 | 95 |
| 60 | 94 | 98 |
| 58 | 102 | 101 |
| 56 | 104 | 103 |
| 54 | 103 | 105 |
| 52 | 102 | 107 |
| 50 | 101 | 109 |
| 48 | 100 | 109 |
| 46 | 101 | 109 |
| 44 | 102 | 109 |
| 42 | 103 | 109 |
| 40 | 104 | 109 |
| 38 | 103 | 109 |
| 36 | 98 | 109 |
| 34 | 87 | 109 |
| 32 | 83 | 109 |
| 30 | 78 | 109 |
| 28 | 62 | 109 |
| 26 | 52 | 108 |
| 24 | 38 | 107 |
| 22 | 34 | 106 |
| 20 | 31 | 104 |
| 18 | 22 | 101 |
| 16 | 18 | 98 |
| 14 | 13 | 95 |
| 12 | 11 | 92 |
| 10 | 10 | 87 |
| 08 | 8 | 86 |
| 06 | 6 | 80 |
| 04 | 5 | 75 |
| 02 | 5 | 64 |
| 00 | 5 | 52 |