AN INVESTIGATION INTO THE USEFULNESS OF THE ISOCS MATHEMATICAL EFFICIENCY CALIBRATION FOR LARGE RECTANGULAR 3”x5”x16” NAI DETECTORS

Frazier L. Bronson CHP
Canberra Industries, Inc.
800 Research Parkway, Meriden, CT 06450 USA

Valery Atrashkevich Ph.D.
Verdansky Institute of Geochemistry and Analytical Chemistry
Moscow, Russia

ABSTRACT

Large NaI detectors are commonly used in gamma measurement systems where nuclide identification and quantification is desired. These systems are used to measure people, soil, drums, boxes, animals, and other things. For quantification, an efficiency calibration must be performed, which becomes increasingly difficult as the sources become large and complicated. Mathematical techniques can be quite useful here, if they are easy enough to use, and accurate enough for the application. A series of experiments was performed to show how accurately the efficiency of large (3”x5”x16”) rectangular NaI detectors can be computed with techniques that could be implemented within the commercially available ISOCS mathematical efficiency calibration software. This software assumes that the detector response function is cylindrically symmetric, which certainly isn’t the case here. But, perhaps it is good enough for the applications for which these large rectangular detectors are commonly used.

A series of mathematical experiments was performed comparing a normal 3”x5”x16” NaI detector with an optimized cylindrical NaI detector. The comparison was done at three different energies: 100 keV, 500 keV and 2000 keV. The first test was done at 172 points from 1 cm to 10 m distance and radially out to 100 meters. The second test was done for a series of discs, and the third test was done for a series of lines. The final test was done to simulate a person standing in a common whole body counter.

The tests revealed that if 20% accuracy is acceptable, most normal counting situations can be adequately calibrated using this equivalent detector.

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INTRODUCTION

Large NaI detectors are frequently used for high efficiency measurements of low levels of gamma emitting radioactivity. The most common sizes of these detectors are 4”x4”x16” and 3”x5”x16”. The 4x4 detector was the initial replacement for large multi-tube cylindrical detectors, and is commonly used for geological surveys, while the 3x5 detector is normally used in Canberra systems, as it is similar in cost and background, but approximately 25% higher in efficiency. At Canberra, our most common use of these large rectangular detectors is in our Whole Body Counting systems. The FASTSCAN counter uses two of them, the ACCUSCAN scanning bed counter can use up to four, and we have also built special *in vivo* counters using up to 32 of them. Animal counters also used these large detectors as well as counting systems for waste in drums, boxes, and trucks. These detectors are also commonly used to survey large volumes of soil or building debris in D&D and ER projects. This is commonly done *in situ* with fixed or moving detectors, on conveyors with the sample moving passed a fixed detector, or with the sample in large containers e.g. trucks. There is also much interest in use of arrays of these large NaI detectors for Homeland Security portal monitors for pedestrians and vehicles.

Large detectors are more sensitive than smaller detectors, and better able to detect small levels of radioactivity. Traditionally large area gamma detectors have been plastic scintillators. The advantage of NaI as compared to plastic scintillators is that gamma spectroscopy can be performed to identify and to quantify the radionuclides from the item or area being measured. But, before this can be done, the system has to be calibrated for efficiency as a function of gamma energy.

The normal way to perform efficiency calibrations is to construct a calibration source that is the same physical size, and constructed in a radiologically identical manner to properly simulate the item being measured. Then, a known amount of radioactivity is distributed in the same manner as it will be in the item to be measured. This must be done for a wide range of energies to establish a calibration curve. For small water samples in a laboratory this is relatively simple. But, as the samples get larger, or if they are not liquid, the task becomes more complicated, more expensive, more time consuming, and less accurate. For these situations mathematical efficiency calibrations are especially attractive.

The code MCNP (Monte Carlo Neutron-Particle) is widely available for evaluating radiation transport phenomenon. Canberra has previously shown that MCNP, when properly applied, can create gamma spectroscopy efficiency calibrations that are accurate to 5%[1]. But creating these models takes quite a bit of time and experience, and running the computations takes much computer time, especially for large samples at far distances. Computer time can be hours or even days.

The Canberra ISOCS (*In Situ* Object Calibration Software) mathematical efficiency calibration software was developed to simplify and speed up this efficiency calibration process[2]. It is capable of calibration accuracy in the 5-10% range[3]. It was developed originally for Ge detectors but has been extended to NaI detectors. A critical assumption in this calibration software is that the detector is a right circular cylinder, and therefore that the radiation response is radially symmetric about the detector axis. This, of course, is not true for these rectangular detectors. But perhaps the ISOCS calibration technique is still good enough to be useful for calibrations of adequate quality in a limited spatial region around the detector.

This investigation was designed to answer that question. We know from extensive testing that the ISOCS software can produce results that are within 2% agreement of the MCNP results, for the specific shapes that are allowed within the various ISOCS templates. Therefore, if this investigation done using MCNP shows acceptable agreement, then so should the ISOCS process.

What does "good agreement" mean? A value of ±20% was subjectively chosen. Gamma spectroscopy using NaI detectors is not nearly so easy as with high resolution Ge detectors. Because of the much poorer peak resolution of NaI, errors in determining the net peak area from other peaks in the spectrum can easily occur. While laboratory users measuring simple spectra can get results better than 20%, it is difficult with multiple nuclides in the spectra (e.g. background containing radium, thorium, potassium), and also at low levels as typically are encountered for the applications with these large detectors.

METHOD USED

The first step was to create an MCNP model of the reference 3"x5"x16" NaI detector, and then a model of an "equivalent" cylindrical detector. The rectangular detector was modeled using the known dimensions and materials of the real detector. The cylindrical detector was modeled using the same exterior protection materials outside of the NaI, however the diameter and thickness of the NaI were optimized to best match the efficiency of the rectangular detector for a thin source that is 2 m diameter and 1 m from the front face of the detector. This matching was done by iteratively varying the diameter and thickness, each time evaluating the agreement between the cylindrical and rectangular detector. The energies used were 100, 500, and 2000 keV. When the process was stopped, the agreement was within 1% at all energies for a cylinder that is 26.3 cm diameter and 6.9 cm thick. Figure 1 shows the geometry and the results graphically.

POINT SOURCES

The next experiment was to use MCNP to compute the efficiency for both the equivalent cylinder and the 3"x5"x16" rectangular NaI at 50 different point locations in front of the detector. These were all placed in radial symmetry in one quadrant about the axis of the cylindrical detector. Points were placed in planes located at 1 cm, 10 cm, 1 m and 10 m from the front face of the detector. They were placed at 0 degrees (parallel to the 16" dimension], 17°, 34°, 54°, 72°, and 90°. They extended radially 10 meters for the 1 cm and 10 cm distances, and 100 meters for the 1 m and 10 m distances. There were 42 points on each of the six radials; at each of these points the efficiency was computed for both detectors at 100 keV, 500 keV, and 2000 keV. An analysis of the data showed that as long as these small sources are greater than 10 cm away from the face of the detector, and within a 90 degree subtended solid angle radiating out from a 40 cm diameter plane on the face of the detector (this encompasses all of the 3"x5"x16" detector), then the cylindrical model was within 20% of the rectangular efficiency for nearly every location. Since that is where a user would typically place a source, this was quite encouraging. If the source is outside this area, the worst case error is a factor of 2. Figure 2 shows a selected portion of this data graphically. The best agreement was at 17° and the worst is at 0° and 90°.

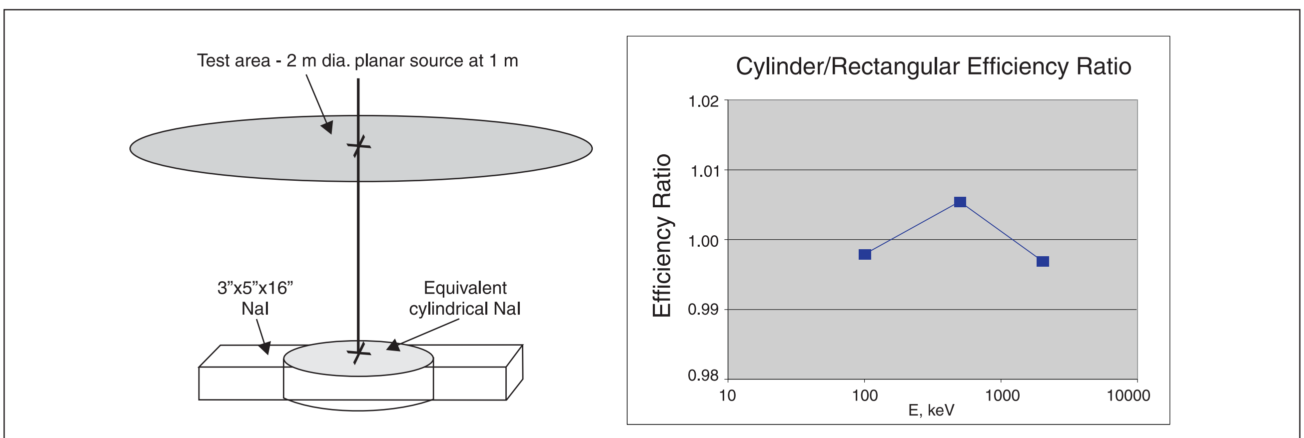


Figure 1.
The optimization geometry for developing the equivalent-sized cylinder that best matches the efficiency of the 3"x5"x16" NaI detector. The graph at the right shows the ratio of cylindrical to rectangular efficiency.

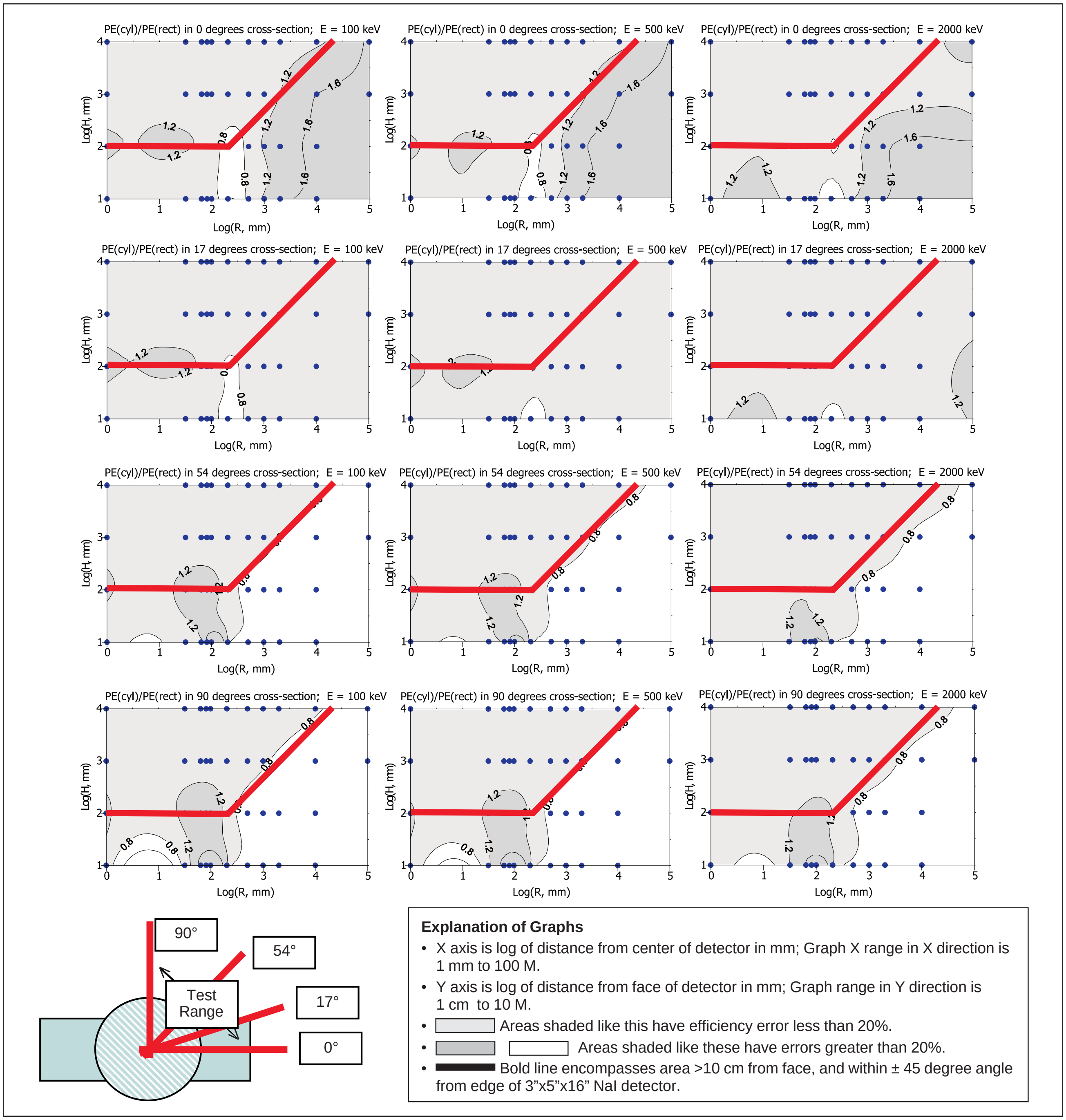
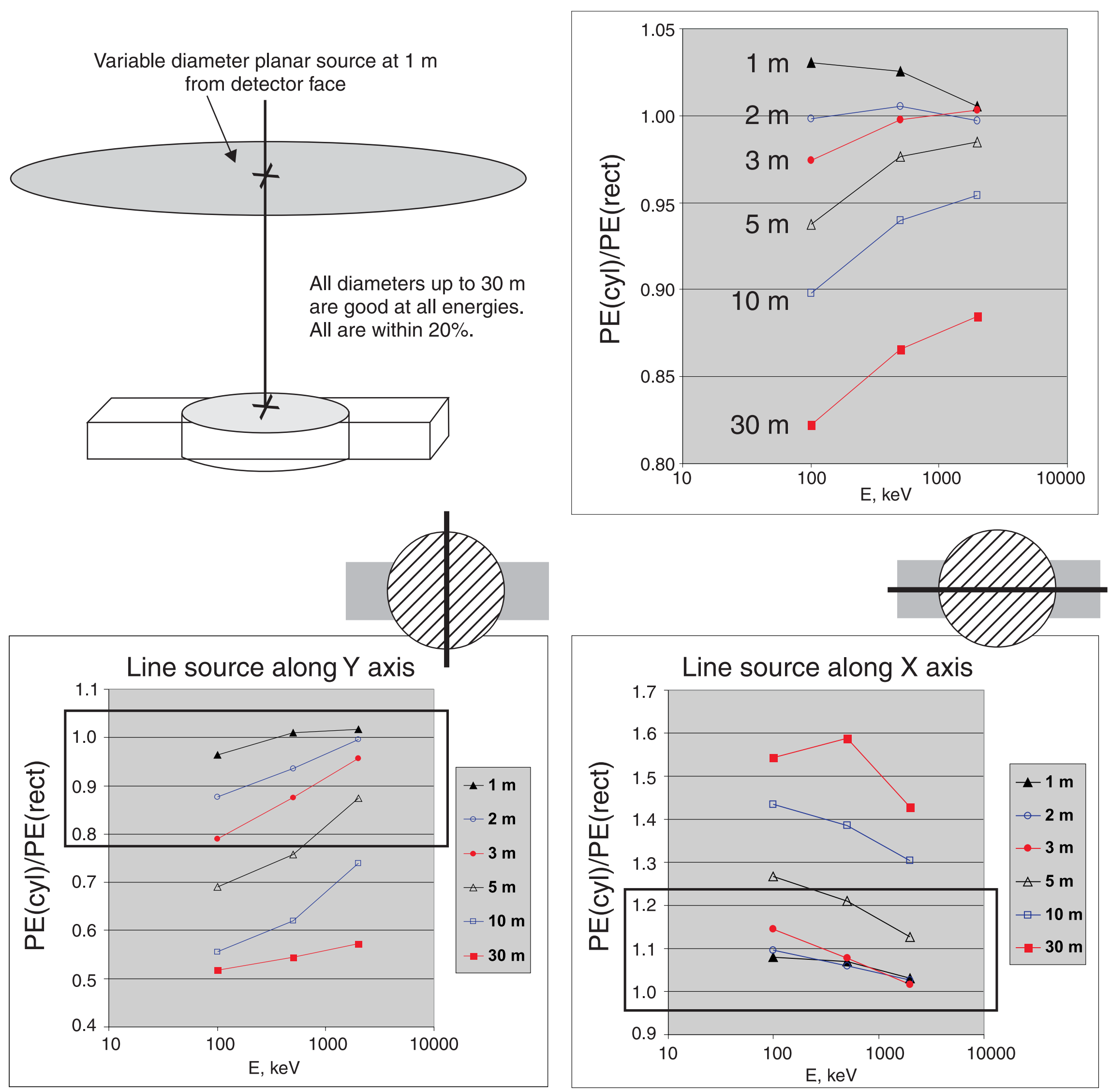


Figure 2.
The point source test geometry and results.

CIRCULAR AND LINEAR SOURCES

Further computations were done to show calibration accuracy for non-point sources. A series of circular planes was the next test. This geometry is a common one for soil surveys. The planes were at 1 m from the detector face, and the diameter was varied from 1 m to 30 m. For cylindrical sources at 1 m, the accuracy of calibrations with the equivalent cylindrical detector is always within 20% for all source diameters. Based upon the point source response, it is expected that this relationship also holds true for circular planes at further distances, but this was not tested. Figure 3, upper section, shows this geometry and the data graphically.

The next test was for linear sources. Linear sources might be representative of a person standing, a pipe, sources moving on a conveyor, or a moving car or train. A distance of 1 m from the face of the detector was used, and the line length was varied from 1 m to 30 m. The line was positioned at 0° and 90°. These are the two worst case situations, all intermediate angles will have better agreement. The accuracy is within 20% for all three energies, as long as the source length is less than 3 m. In all cases the error was worse at 100 keV than the other two energies. Based upon the point source data, it is speculated, but not tested, that as the line source is moved further away from the detector, the length that is within 20% accuracy will increase approximately proportionally. Figure 3, lower section, shows this geometry and data graphically.



Good for lines up to about 4 m at 0 and 90 degrees.

These are worst case orientations – other angles better.

Figure 3.
Geometry and results for circular planar source (upper portion) and for linear source (lower portion).

WHOLE BODY COUNTER

The last test was to simulate the Canberra FASTSCAN Whole Body Counter. This counter is used in most of the US Nuclear Power Plants, and many other places. This counter has two 3”x5”x16” NaI detectors in a vertical linear array. The person stands next to the detectors, with his back about 40 cm away from the face of the detector. For expediency, a simplistic model of a person was created with MCNP. That model had two cylinders stacked, where the masses of the cylinders in approximate standard-man proportions. The radioactivity was distributed uniformly, simulating a systemic uptake, e.g. ^{137}Cs.

The detectors were also positioned in the model at approximately the same locations as in the instrument. Since the spectra are summed, the efficiencies from the two detectors were summed here. The agreement was very good – within 5% for all three energies, as shown in Figure 4.

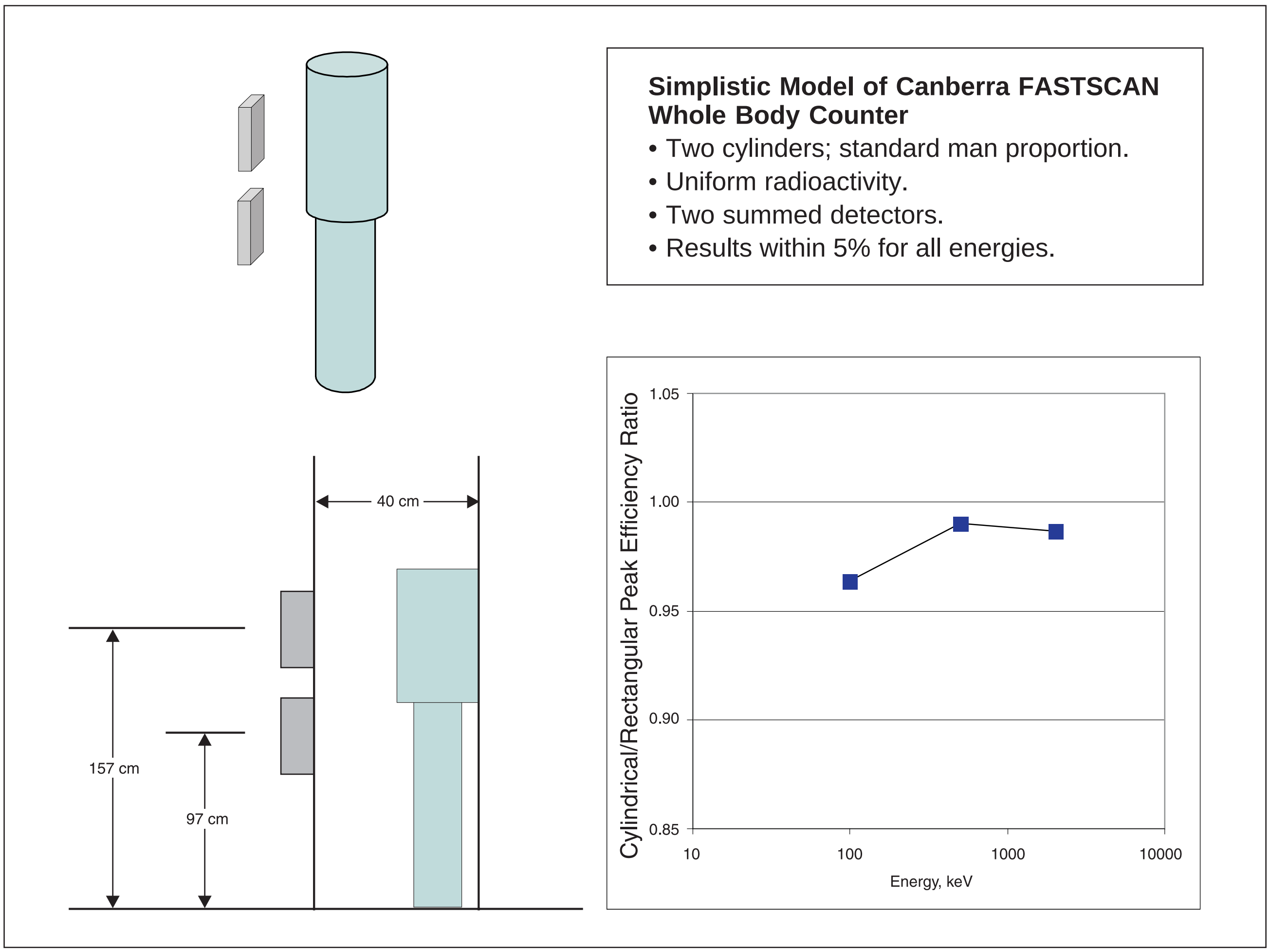


Figure 4.
Simulation of the FASTSCAN Whole Body Counter.

CONCLUSION

A series of tests has been done that show that a properly proportioned cylinder can be shown to have an efficiency approximately equal to a commonly used rectangular NaI detector. This approximation holds true for all small sources located further than 10 cm from the detector, and within ±45 degrees of a line perpendicular from the face of the detector. This equivalency holds true for all circular planar sources out to at least 30 m in diameter. This equivalency holds true for all line sources up to 3 m in length. This equivalency is true for a simplistic representation of a person in a common Whole Body Counter. Sources within these spatial parameters can be calibrated to within 20% of the correct value. Sources outside these spatial regions can be worse, but not more than a factor of 2 different than the correct efficiency.

Since we know that the ISOCS method accurately reproduces the MCNP results for the 20 different shapes that are defined as templates in the software, we know that an ISOCS model using the same cylindrical equivalent detector as used here will give similar results. The ISOCS method allows efficiency calibrations within seconds, instead of the very long MCNP computations times (hours-days). Consequently, this method should be practical for design of proposed systems, and reasonably accurate calibrations of large sources, such as waste containers, *in situ* soil measurements, moving cars and trucks, soil on conveyors, and even people.

REFERENCES

1. F. L. BRONSON AND L. WANG, "Validation of the MCNP Monte Carlo Code for Germanium Detector Gamma Efficiency Calibrations", Proceedings of Waste Management '96, Tucson, AZ, Feb. 1996.
2. F. L. BRONSON, "ISOCS, an *In Situ* System and Portable Gamma Spectroscopy Lab that can be Taken to the Accident Site", Proceedings of the ANS 7th Topical Meeting on Emergency Preparedness and Planning, Sept. 1999, Santa Fe, NM.
3. R. VENKATARAMAN, F. BRONSON, V. ATRASHKEVICH, B.M YOUNG, and M. FIELD, "Validation of *In Situ* Object Calibration System (ISOCS) Mathematical Efficiency Calibration Software", Nuclear Instruments and Methods in Physics Research (A), 422 (1999), pp 450-454.