BABYSCAN: a whole body counter for small children in Fukushima

Ryugo S Hayano¹, Shunji Yamanaka², Frazier L Bronson³, Babatunde Oginni³ and Isamu Muramatsu⁴

¹ Department of Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
² Department of Mechanical and Biofunctional Systems, Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
³ Canberra Industries, Inc., 800 Research Parkway, Meriden, CT 06450, USA
⁴ Canberra Japan KK, 4-19-8 Asakusabashi, Taito-ku, Tokyo 111-0053, Japan

E-mail: hayano@phys.s.u-tokyo.ac.jp

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Abstract
BABYSCAN, a whole body counter for small children with a detection limit for ¹³⁷Cs of better than 50 Bq/body, was developed, and the first unit has been installed at a hospital in Fukushima, to help families with small children who are very much concerned about internal exposures. The design principles, implementation details and the initial operating experience are described.

Keywords: Fukushima Dai-ichi accident, radioactive caesium, whole-body counting, radiological protection

1. Introduction

The Fukushima Dai-ichi NPP accident [1] contaminated the soil of densely-populated regions of Fukushima Prefecture with radioactive caesium, which poses risks of internal (and external) exposures to the residents. If we apply the knowledge of post-Chernobyl accident studies [2], internal exposures in excess of several mSv y⁻¹ would be expected to be frequent in Fukushima.

Extensive whole-body-counter surveys of 21 785 residents in highly-affected Fukushima municipalities, however, showed that their actual internal exposure levels are much lower than estimated [3]; in 2012–2013, the ¹³⁷Cs detection percentages (the detection limit being ~300 Bq/body) are about 1% for adults, and practically 0% for children (age 6–15). These results are consistent with those of many other measurements and studies conducted.
so far in Fukushima, e.g., dose assessment [4–7], rice inspection [8], foodstuff screening and
duplicate-portion studies [9].

Nevertheless, there continue to be many residents, families with small children in particu-
lar, who are very much concerned about internal exposures. This is in part due to the fact the
whole body counters currently being used in Fukushima, such as the FASTSCAN [10], are
designed for radiation workers, who are adults. Children have been successfully measured
previously at Chernobyl, and in Fukushima Prefecture, by having them stand on a small stool
to get their bodies into the detection zone. While this is suitable to measure larger uptakes in
larger children, it is not optimum for measuring small children ($\lesssim$4 y), and is not suitable for
infants or children who cannot stand.

Scientifically, it is sufficient to measure parents, but worried parents strongly request to
have their babies measured. We therefore launched a project in the spring of 2013\(^5\) to develop
a whole body counter for small children called a ‘BABYSCAN’, and have installed the first
unit at the Hirata Central Hospital in Fukushima Prefecture in December 2013. The design
principles, implementation and the initial operating experience are reported.

2. BABYSCAN requirements

About 80% of some 60 whole body counters currently installed in Fukushima Prefecture are
Canberra’s FASTSCAN. A subject stands for two minutes in a shielding box made of iron,
which houses two $7.6 \times 12.7 \times 40.6$ cm sodium iodide (NaI) gamma-ray detectors. The detec-
tion limit for radioactive caesium is about 250–300 Bq/body (both for $^{134}$Cs and $^{137}$Cs), which
is nearly independent of height and/or weight of the adult subject (flat within $\sim \pm 15\%$).

This detection limit is however too high for reliably measuring small children, since the
biological half-life of radioactive caesium in children ($\sim 13$ d for 1 year old, $\sim 30$ d for 5 year
old) is much shorter than that in adults ($\sim 110$ d) [11, 12]. As a result, children’s internal con-
tamination is harder to detect.

For example, if an adult ingested 3 Bq of $^{137}$Cs every day, the body burden would reach an
equilibrium plateau of $\sim 400$ Bq/body [12]. This can be detected by the FASTSCAN. If on the
other hand a 1-year-old child ingested the same amount, the resultant body burden would be $\sim 60$
Bq/body. Therefore, the whole body counters for babies must have a much lower detection limit.

Our goal was to achieve a detection limit of $<50$ Bq/body for $^{134,137}$Cs. In order to realize
this high sensitivity, the BABYSCAN must be ergonomically designed so that a small child
can stay still for several minutes, without feeling afraid of confinement.

From the beginning, it was recognized that the BABYSCAN’s design must be reassuring
to parents, and that in addition to being a measurement device, it would be expected to play
an important role as a communication tool to facilitate interactions between medical staff and
residents.

3. BABYSCAN details

The BABYSCAN’s design principles and technologies were derived from those of FASTSCAN,
but in order to realize higher sensitivity, there are some crucial differences.

As shown in figure 1, the subject lies down inside the measurement chamber of BABYSCAN,
as opposed to standing as in the case of FASTSCAN. A child can either lie on the bed supine
(on their back and face up) or prone (on their stomach, face down). During development, we

\(^5\) FB gave the first proposal to Japan Atomic Energy Agency (JAEA) in spring 2012. Independently, RH received a
request to make such a device from the Hirata Central Hospital, also in spring 2012.
discovered that older children’s posture tends to be more stable in the prone position, as shown in the right-hand panel of figure 1. Small babies, however, tend to prefer the supine position, and are more comfortable when they can also see their mother’s face through the opening. Both positions are OK, as they have essentially the same efficiency.

There are four NaI detectors (7.6 × 12.7 × 40.6 cm each), arranged in a two-by-two geometry, installed in an iron-shielded compartment placed above the subject. The bottom of the NaI compartment has a window facing the subject, made of a carbon-honeycomb plate measuring 28 cm × 86 cm. The detectors are close to each other, therefore the area of the NaI group of detectors is approximately 26 cm × 82 cm. This is similar to the size of a small child, thereby achieving a high gamma-ray detection efficiency.

The detection efficiency can be further optimized by using a height-adjustable bed. The distance from the bed surface to the bottom of the NaI detector is either 20 cm, 25 cm or 30 cm. The left panel of figure 1 shows a 20 cm bed with a harness used for measuring small babies, while the right panel shows a child lying on a 25 cm bed. The bed is pulled out when a child enters/leaves the measurement chamber, and it is pushed in during the measurement.

The size of the measurement chamber is 30 cm (H) × 80 cm (W) × 140 cm (L), and the bed is 40 cm (W) × 120 cm (L). These dimensions limit the maximum height of the subject to be about 130 cm.

The measurement chamber and the detector compartment are surrounded by 10 cm-thick iron shielding as shown in the left panel of figure 1. The shielding at bottom has an additional 5 cm of iron and the front has an additional 3 cm of iron. The size of the opening through which the subject enters the measurement chamber is 44 cm (W) at the top and 32 cm (W) at the bottom. This reflects an optimum balance between ease of use and maximum shielding of background radiation.

This iron structure is covered by an ergonomically designed plastic cover. The exterior surface of BABYSCAN is covered by smooth curved panels (made of glass-fiber reinforced plastic (GFRP)) colored with natural white for its gentle appearance. In order to provide a cozy space for children, the interior surface is also covered by organic surface (made of carbon-fiber reinforced plastic (CFRP), so as to avoid the radium, thorium, and 40K background from the glass in GFRP), colored by light blue which looks like being made of soft materials. These panels are precisely assembled to eliminate the possibility of injuring baby’s skin by their gaps or edges.

All the materials used to manufacture BABYSCAN, including the bed and the tablet computer, were tested for natural radioactivity using a germanium detector prior to assembly. Materials known previously to be problematic were avoided. The approximate criteria for
acceptance was when any radioactivity in the component would not cause a detectable peak in the background of the BABYSCAN detectors with a subject in place, when the subject is counted ten times longer than normal, i.e. 30–40 min. No artificial nuclides were detected, but occasionally, low levels of natural radioactivity were detected.

Table 1 summarizes the BABYSCAN parameters.

4. BABYSCAN calibration

The BABYSCAN was calibrated using a Monte Carlo N-Particle Transport Code (MCNPX version 2.7.0) [13] for a wide variety of weight and height combinations for each of the three bed-height positions. These calibrations were validated with (1) a 4-year-old ANSI BOMAB phantom containing 290 kBq of $^{152}$Eu (made by Japan Isotope Association), and (2) 2-year-old and 6-year-old ‘universal’ phantoms, respectively containing 3113 Bq and 6225 Bq of $^{137}$Cs (made by STC RADEK, St. Petersburg), for three different bed heights.

In the ‘universal’ phantom, polyethylene blocks and $^{137}$Cs-containing rods are combined to make six different age and anthropometric types. We used 2- and 6-year-old phantoms to further check the BABYSCAN calibration, and also to compare the BABYSCAN’s characteristics with those of FASTSCAN.

Table 2 shows the results of these validation measurements at the $^{137}$Cs energy range for the three phantoms, using different bed heights.

Figure 2 shows the spectra of the 6-year-old phantom (6226 Bq of $^{137}$Cs) measured with the BABYSCAN (4 min, shown in black) and the FASTSCAN (2 min, shown in grey); they are installed in the same room of the hospital.

The $^{137}$Cs peak count of BABYSCAN is about 8 times larger as compared to the FASTSCAN. From the increase in the number of detectors ($\times 2$) and in the measurement time ($\times 2$), one would naively expect an increase of factor 4; the extra factor of 2 comes from the
closer subject–detector distance than in the FASTSCAN, and because the detectors are closer
to each other than in the FASTSCAN detector geometry.

The Cs-region background count of BABYSCAN is about 3.5 times higher than that of
FASTSCAN, which is 13% smaller than the factor 4 expected from the differences in both the
number of detectors and the measurement time. This 13% background reduction (despite a
rather large opening at the top) is the result of the increased shielding.

5. Initial operating experience of the BABYSCAN

The first BABYSCAN unit, installed at the Hirata Central Hospital in Fukushima Prefecture,
started operation on 2 December 2013. We here demonstrate its performance based on the data
of first 100 subjects, whose age distribution (minimum 3.8 months old, maximum 10 years
old, mean 4.2 years old) is shown in figure 3, and their anthropometric parameters are plotted
in figure 4 (minimum weight 6.5 kg, maximum weight 31.3 kg, mean 16.1 kg, minimum

![Figure 2. Comparison of the $^{137}$Cs 6-year-old phantom spectra. Black: BABYSCAN
4 min, grey: FASTSCAN 2 min.](image)

![Figure 3. Age distribution of the subjects.](image)
Radiocaesium was not detected in any of the 100 subjects, and the mothers were happy to learn the test results. Nevertheless, as expected, $^{40}$K was detected in all subjects. Typical gamma-ray energy spectra are presented in figure 5; the spectra shown in black dots were taken with subjects (4 min), and those in grey dots were taken without subject (measured for 5 h, normalized to 4 min). The background-subtracted spectra are shown in open circles.

Figure 6 shows the distribution of the $^{40}$K activity (Bq/body) versus the weight of the subject. The data shown in open circles/filled circles/open squares were measured with the

height 60.0 cm, maximum height 133.3 cm, mean 98.2 cm). This study was approved by the Ethics Committee of the University of Tokyo.
The data points show a linear correlation between the weight and the amount of $^{40}$K in the body, with a slope of $50.7 \pm 0.9$ Bq kg$^{-1}$. This is consistent with the known amount of $^{40}$K in human body.

The data shown in figure 6 indicates that $^{40}$K activities as low as 300 Bq were reliably detected, and accurately measured. One can use this information, to estimate the amount of $^{137}$Cs that can be reliably measured. The gamma yield of $^{137}$Cs is 85% while the gamma yield of $^{40}$K is only 10%. The $^{137}$Cs background (counts per keV) is 3 times the background of $^{40}$K, but the detector full width at half maximum (FWHM) for $^{137}$Cs is 0.6 times that of the $^{40}$K. The efficiency at $^{137}$Cs energies is 1.4 times larger than at $^{40}$K. These combine to convert a reliably measured 300 Bq $^{40}$K value into an estimated 35 Bq $^{137}$Cs value that should be reliably measured, all other things being equal. This is consistent with the calculated $^{137}$Cs MDA described in the next paragraph.

The minimum detectable activity (MDA) [14]$^6$ for $^{137}$Cs (Bq/body), calculated for each subject, is plotted in figure 7 against weight (kg). Here again, data taken with 20 cm/25 cm/30 cm bed. The data points show a linear correlation between the weight and the amount of $^{40}$K in the body, with a slope of $50.7 \pm 0.9$ Bq kg$^{-1}$. This is consistent with the known amount of $^{40}$K in human body.

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$^6$The MDA used here is the standard Currie lower limit of detection, where there is a 5% chance of Type 1 error, a 5% chance of a Type 2 error: [14].
20 cm/25 cm/30 cm beds are shown in open circles/filled circles/open squares. As the bed-to-detector distance decreases, the solid angle increases and hence the MDA decreases. This plot clearly shows that our initial goal of achieving a detection limit lower than 50 Bq/body has been met.

6. Conclusion

BABYSCAN, a whole body counter for small children was developed, and the first unit has been installed at a hospital in Fukushima. The radiocaesium detection limit of BABYSCAN is better than 50 Bq/body, which has been realized by a careful ergonomic design, optimized detector geometry and reinforced shielding. Even with this low detection limit, radiocaesium was not detected in any of the first 100 Fukushima children, while, as expected, $^{40}$K was detected in all subjects. The results of larger-scale measurements with the BABYSCAN will be reported in our forthcoming publications.

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