Assessment of the Rapiscan Secure 1000® Body Scanner for Conformance with Radiological Safety Standards

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CONTENTS

Introduction

This work was performed as fulfillment of Task Order 001 of Interagency Agreement HSTS04-06-X-CTO003 between the Transportation Security Administration (TSA) and the Food and Drug Administration (FDA)'s Center of Devices and Radiological Health (CDRH). The agreement calls for CDRH's Ionizing Radiation Measurements Laboratory to evaluate x-ray emissions and to estimate effective doses to human subjects, operators and bystanders resulting from the operation of screening equipment. The resulting doses are compared to the limits imposed by existing radiation safety standards, particularly ANSI N43.17, "Radiation Safety for Personnel Security Screening Systems Using X-rays." [1] The equipment in question is a full body scanner proposed to be used for the screening of passengers.

Summary of the results

The main aim of this work was to estimate the effective dose to subjects being screened. Thus the information needed to calculate effective dose was measured, calculated, or otherwise obtained and verified. A Monte Carlo computer program was used to calculate the effective dose for a variety of exposure conditions. The entrance skin exposure is the most important parameter for effective dose calculations. The entrance exposure for one scan was found to be about 9.6 μR at 30 cm from the surface of the front panel. The effective dose to a subject being screened varies depending on the age and size of the human subject. An adult would receive an effective dose of about 2.4 μrem per frontal scan. A small child would receive an effective dose of about 4 μrem per frontal scan. An infant would receive a dose of about 5 μrem per frontal scan. In order to be compliant with the ANSI N43.17 standard the effective dose should not exceed 10 μrem per scan at a distance of 30 cm from the "beam exit surface". The Secure 1000 was found to meet the ANSI standard requirements and recommendations relating to radiation dose to bystanders and operators. All exposure measurements outside of the primary beam, due to scatter or leakage from the cabinet, were on the order of natural background levels and far below the ANSI requirements.

Description of the screening system

The system tested was the Secure 1000 manufactured by Rapiscan Security Products, Inc., Hawthorne, CA. The system was received by CDRH for testing on 3/29/06 and had the following identification markings "Serial No.: S701201213", "Date: May 2001". The label also included the following statement: "Each scan cycle from this system produces 3 microRem of x-ray radiation emission. This value is comparable to the radiation exposure all persons receive each five minutes from naturally occurring radioactive materials in the air and soil." The system tested included a back plate and floor panel. The back plate was measured to be 153 cm wide by 242 cm high. When positioned against the floor panel the back plate surface was at approximately 89 cm from the front surface of the Secure 1000 cabinet. Figure 1 shows a picture of the system. Information obtained from the manufacturer[2] indicated that the x-ray source (b) (4) (b) manufactured by Superior X-ray Tube Company. (b) (4) (b) (4)

5 USC 552(b)(4)

Figure 1. The Secure 1000 as tested.

Instruments and methods

Testing of the system was aimed at obtaining sufficient information to be able to estimate the effective dose that would be delivered to a screening subject. Effective dose is a measure of the combined effects of the radiation insult to the various body tissues and organs as defined by the International Commission on Radiological Protection (ICRP).[3] The Monte Carlo program PCXMC[4] was used to estimate the individual organ doses and to calculate effective dose. The input information required by the PCXMC program includes 1) the x-ray tube anode angle, 2) the anode voltage, 3) the total filtration, 4) the x-ray field size, 5) the location of the field on the body, 6) the focus-to-skin distance (FSD), and 7) the entrance skin exposure. All of these parameters were measured, calculated, or verified by indirect measurements. For example, the total added filtration was verified by measurements of the half-value-layer (HVL) followed by comparison with empirical data and analytical charts of HVL vs. added filtration at the specified anode angle. The FSD used in the Monte Carlo calculations was not the actual FSD. The Monte Carlo code assumes a stationary source and a beam diverging as the inverse square of the distance from the focal spot of the x-ray tube. The FSD entered in the code was one for which the derivative of exposure with distance, assuming a stationary source, approximates the measured exposure drop-off at the actual distance.

Exposure measurements were made using a Radcal 9015 radiation monitor, serial No. 91-0097; a model 9060 electrometer, serial No. 99-0186; and a model 10X5-1800, cylindrical ionization chamber, serial No. 9946. A 1 cm^2 solid-state detector, RTI model R100B, serial No. 06144, was used where good spatial resolution was required, as in the determination of scan field size. The R100B detector was used with a RTI Barracuda system, serial No. 5030167. The ionization chambers and solid-state detector were calibrated at the CDRH X-ray Calibration Laboratory in an appropriate x-ray beam, traceable to the National Institute of Standards (NIST). Details of the calibration are included in Appendix A. Several exposure readings were made and averaged for each measurement point, typically four. The background exposure level was measured and subtracted where necessary. Environmental corrections, where necessary, were made using the laboratory's NIST-traceable reference barometer and thermometer.

The photon energy spectrum (for determination of the end-point energy and the x-ray tube kilovoltage) was obtained by means of a Canberra DSA-2000 spectrometer system using a GUL0110P high purity germanium detector. The energy scale was calibrated using the 14.1 keV and 122.1 keV gamma energies from a ^{57}Co source. Calibration results are included in Appendix A. The photon count scale was not calibrated and the spectrum was not corrected for any distorting effects. This does not affect the determination of the end-point energy.

A Technical Associate model P8-Neon survey instrument was used to localize leakage radiation. The instrument, consisting of an array of eight Geiger Muller pancake probes, was designed for quick, qualitative surveys of the shielding. The Radcal ionization chamber was used for follow-up, quantitative measurements of any leakage detected.

Half-Value-Layer

The half-value-layer (HVL) is the thickness of aluminum required to attenuate the x-ray beam to exactly one half of the exposure rate of the unattenuated beam. The higher the x-ray photon energy, the greater the penetrating power. Therefore the HVL is an indication of the effective energy of the x-rays. Knowing the HVL allows the estimation of the total aluminum-equivalent filtration, which is required by the Monte Carlo Program. The HVL was measured using high purity aluminum filters and a solid state detector under good geometry conditions (Figure 2). A 1-inch diameter, ¼-inch thick lead collimator was placed at 35 cm from the Secure 1000 front panel. The R100B solid state detector was placed at 50 cm from the front panel. The collimator and detector were placed at 90 cm from the floor and were centered horizontally on the front panel. At this height the x-ray beam is in a near horizontal position allowing full illumination of the 1-cm^2 detector. The resulting attenuation curve is shown in Figure 3. The HVL was found to be 1.1 mm Al. Empirical data obtained at the CDRH calibration laboratory shows that the total aluminum-equivalent filtration yielding this HVL at 50 kV is 1.4 mm (Figure 4). This result was used in the PCXMC program.

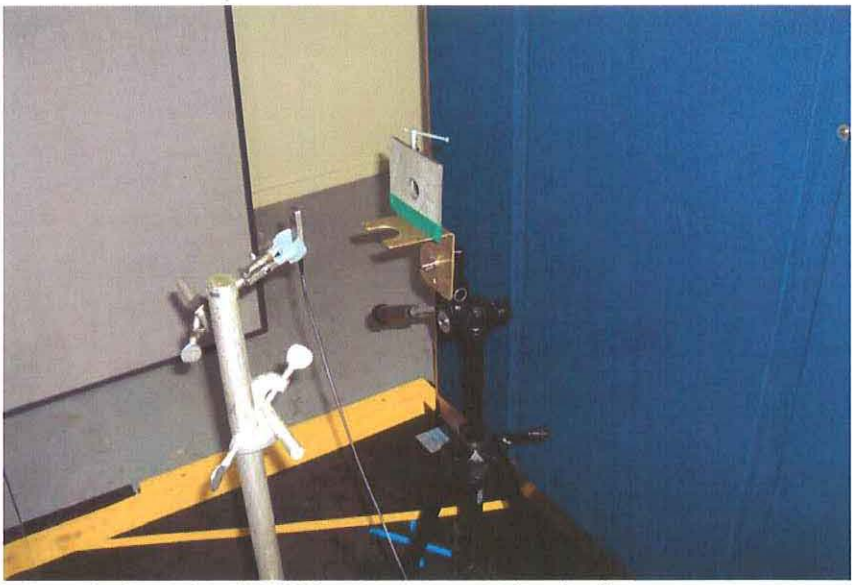


Figure 2. Setup for the HVL measurement. The aluminum attenuators were placed against the lead collimator.

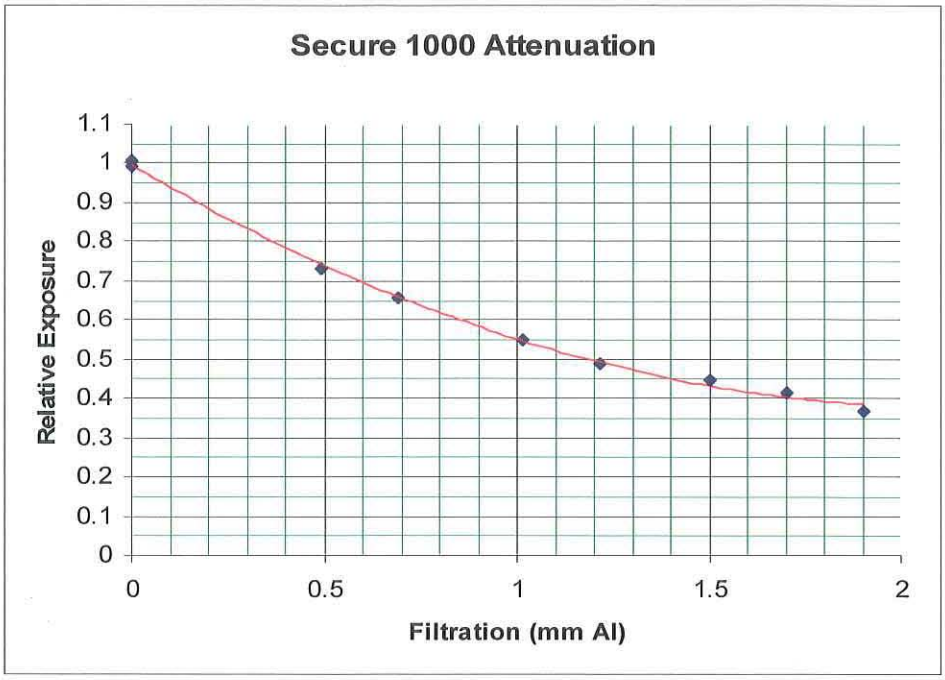


Figure 3. Attenuation curve of the x-ray beam showing a Half-Value-Layer of 1.2 mm of aluminum.

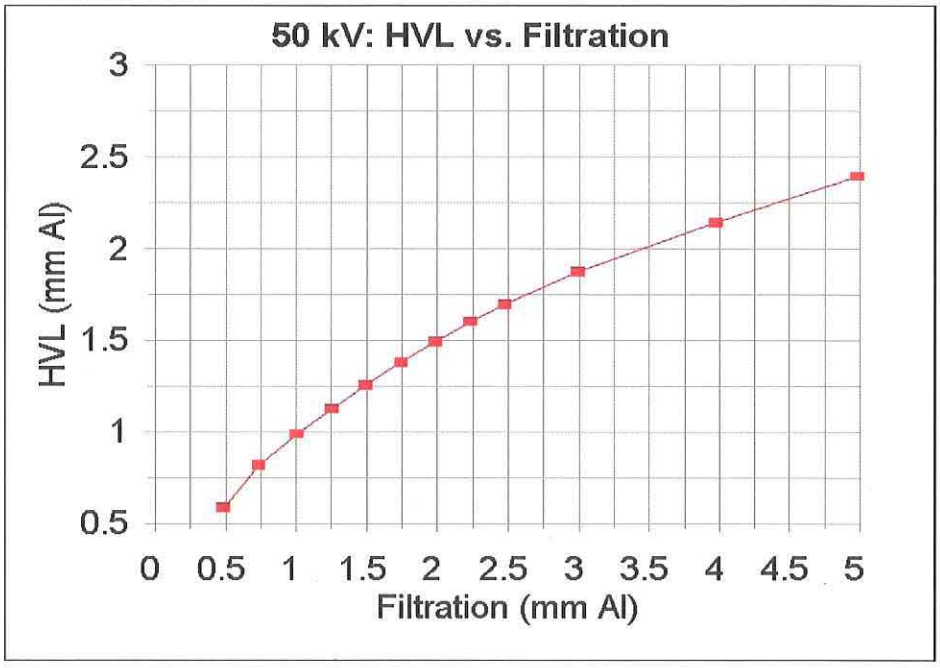
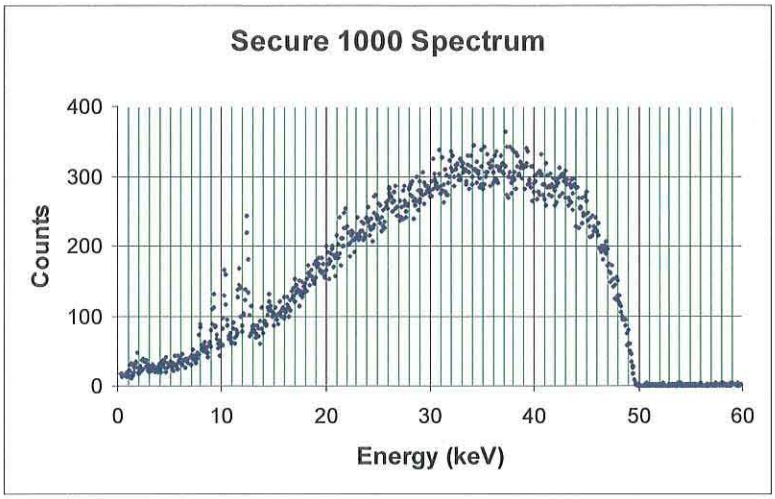


Figure 4. This chart is from the CDRH Calibration Laboratory Quality Manual. It shows measured HVL's as a function of total filtration. The data was obtained using a Philips MCN161 x-ray tube with a target angle of 22°.

Accuracy of the kV setting

The kV setting determines the effective energy of the x–ray beam and is a critical parameter for estimating the effective dose. The accuracy of the kV setting was checked by analyzing the energy spectrum of the x-ray beam. A high-purity germanium detector with a resolution of about 300 eV was used to capture the photon energy spectrum (Figure 5). The highest photon energy in keV corresponds to the accelerating potential (anode voltage) in kV. The spectrum is shown in Figure 6. The observed cutoff photon energy was 50.0 keV, indicating an anode voltage of 50 ± 0.5 kV.

Figure 5. Spectrometer setup.



(a)

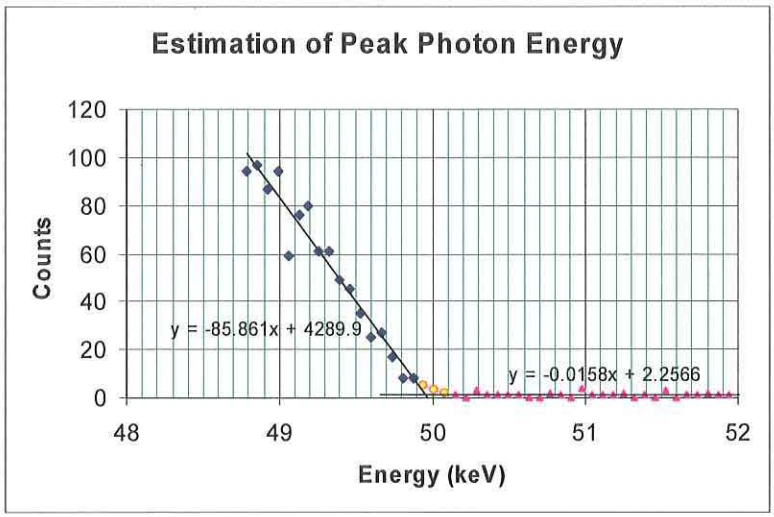
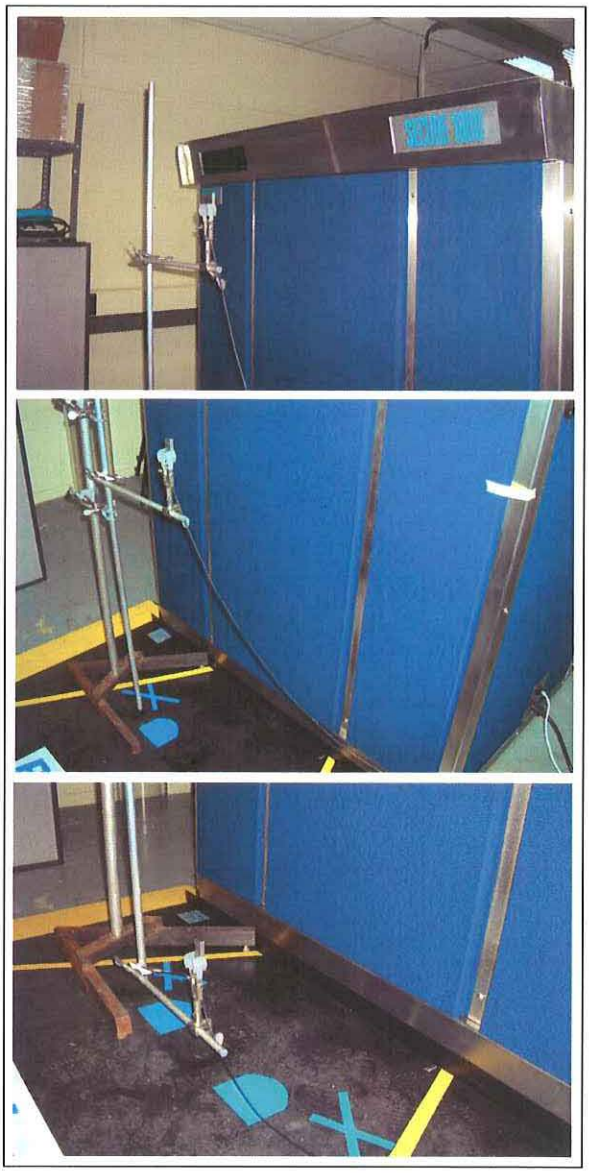


Figure 6. (a) The uncorrected photon energy spectrum obtained with a high-purity germanium detector and multichannel analyzer. (b) Detail of the peak energy channels showing an intercept of 49.95 keV (the points in yellow were not included in the linear fits).

Exposure measurements

The exposure received from a scan is the most important information needed to determine effective dose. Exposure measurements were made by scanning the 1800 cc, 10X5-1800 ion chamber. The ion chamber was centered at 30 cm from the front surface of the Secure 1000 cabinet. The ion chamber averages the exposure over its sensitive volume, which extended from about 23 to 37 cm from the front surface. Measurements were also made with a 1×1 cm solid state detector, RTI R100B, to map the exposure profile of the scan field. Both instruments were calibrated in the CDRH X-ray Calibration Laboratory at 50 kV and 1 mm Al HVL (corresponding to the NIST M50 beam quality).

Exposure profile of the scan field



The R100B detector was first used to study the exposure variation along the vertical (see photos at left) and horizontal axes of a plane parallel to the front surface and 30 cm from the surface.

The results of these measurements are shown in Figure 7 and Figure 8. The measurements near the top of the scan field yielded different readings on alternate scans. This is due to the fact that the tube does not return to the starting position after a scan. Rather, the scan motion starts either at the top or the bottom, alternating with subsequent scans (see the video attached to the electronic copy of this report). Only the higher exposure scans are represented in Figure 7 (for height > 180 cm). It appears that when the scan starts at the top, the horizontal sweeps in the first 10 to 20 cm overlap. At the very top, the exposure due to the overlap is about 2.6 times the exposure at the center of the scan area. The exposure gets progressively smaller as the tube moves downward. For most people this anomaly will be over the person's head.

Figure 7 shows that the maximum exposure (excluding the anomaly discussed) is at about 100 cm from the

floor. This is the point where the axis of the x-ray beam is in the horizontal orientation as the tube moves and rotates. The tube rotates upward above the 100 cm point and downward below this point. The 100 cm height was chosen as the exposure measuring point for the purpose of estimating effective dose.

Figure 8 shows a pronounced drop-off in exposure on either side of the center. The center of the horizontal sweep was used as the exposure measuring point for the purpose of estimating effective dose. The x-ray scan area corresponds roughly to the diagonal yellow lines on the floor (see Figure 1) and is well within the dimensions of the back plate.

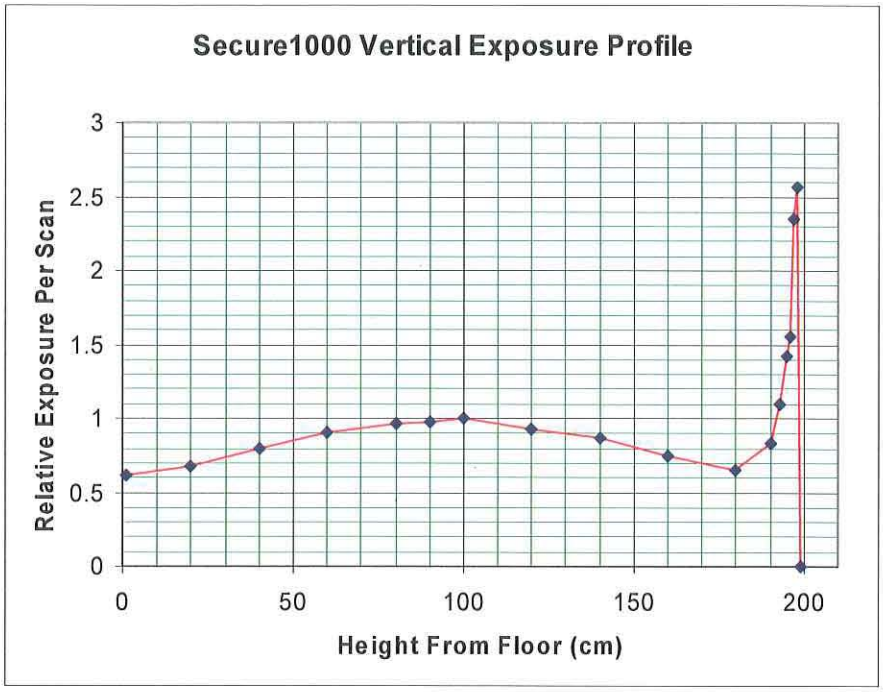


Figure 7. The relative exposure at 30 cm from the surface as a function of height, measured at the center of horizontal sweep. The peak at the far right occurs only for alternate scans.

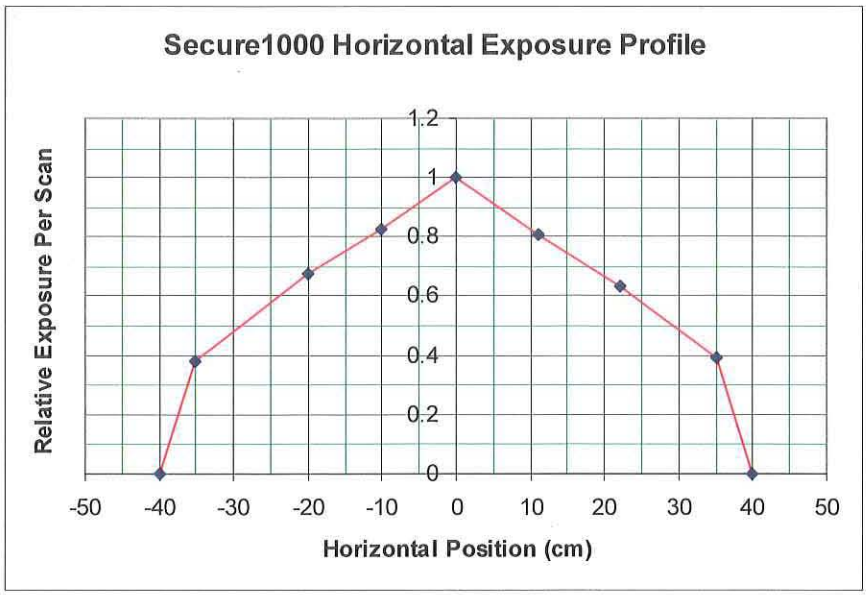


Figure 8. The relative exposure at 30 cm from the surface as a function of horizontal position, measured at center of the vertical sweep.

The exposure variation with distance was also measured using the solid state detector. Although the ANSI standard specifies a 30 cm distance, the screening subject is more likely to stand at 30 cm from the front surface to the center of the body, rather than to the skin. Figure 9 shows the exposure per scan in the center of the field at various distances between the front surface and the back plate.

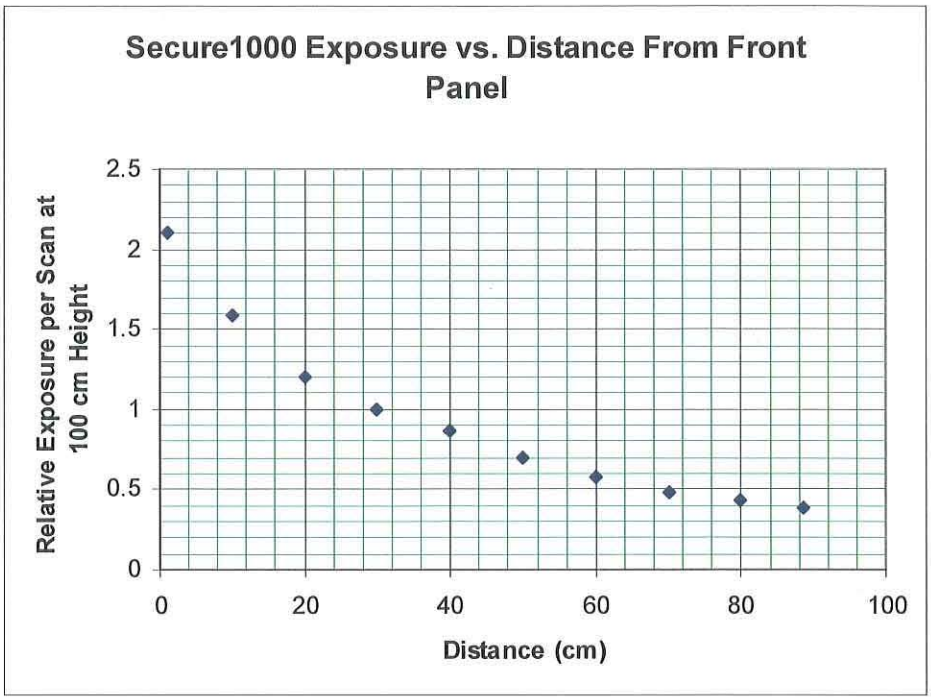


Figure 9. The relative exposure at the center of the scan as a function of distance from the surface, normalized at 30 cm.

The Monte Carlo code requires the skin entrance exposure and assumes an inverse square x-ray field divergence based on the FSD. This is true for a medical diagnostic x-ray field but not necessarily for the Secure 1000. The x-ray beam in this case is shaped by (b) (4) [redacted] In order to account for the actual exposure variation with distance, the FSD used in the Monte Carlo calculations is not the actual FSD. Rather, the FSD that (in the inverse square situation) results in the same slope as the slope of the curve of Figure 9 at 30 cm from the surface. The slope is .0165/cm and the corresponding FSD is about 121 cm.

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Exposure determination at 30 cm

The Radcal 10X5-1800 ionization chamber and a Radcal 9015 monitor were used for an accurate determination of the exposure per scan. The ion collection efficiency of the ion chamber was tested. This was done in order to dispel any rate dependence concerns under the unique exposure conditions of the Secure 1000. The ion chamber response to the Secure 1000 scans varied by only 2.3% when the bias was reduced from 300 V to 27 V. This indicates excellent collection efficiency at 300 V.

The ion chamber was placed with its center at 30 cm from the front panel surface, 100 cm from the floor, and in the center of the horizontal beam sweep (see Figure 10). The exposure from 30 scans was integrated, corrected for background, energy dependence, and environmental conditions. The resulting exposure per scan was 9.60 μR.

Figure 10. Measurement of the exposure using the 1800 cc ionization chamber.

Determination of effective dose

The PCXMC Monte Carlo program was described by Servomaa and Tapiovaara[3]. Using the methodology described above to derive all the input parameters, effective dose calculations were obtained for frontal scans of an adult, a child, and an infant. The results are given in Table 1. As stated above, the FSD used is not the true FSD. The most appropriate FSD, based on the exposure drop-off at 30 cm from the surface, is 121 cm. The field size used, based on Figure 7 and Figure 8, was 80 cm by 200 cm. The PCXMC code, which is based on medical diagnostic x-ray equipment, could not produce the field size needed when the 121 cm FSD was used. In the adult case, the largest field size obtainable at 121 cm did not cover the entire body. Consequently, 200 cm was used as the FSD for the adult case.

Table 1. Effective dose results obtained using the PCXMC Monte Carlo program.

	Entrance Exposure to Effective Dose Conversion (µrem/µR)	Effective Dose Per Frontal Scan at 30 cm (µrem)
Adult	0.246	2.36
Absorbed Dose to Uterus	0.119	1.14
Child	0.388	3.72
Infant*	0.520	4.99

*The radiation scattered from an adult holding the infant being scanned was not considered.

The input screens used for the Monte Carlo calculations and resulting output printouts are included in Appendix B.

The effective dose was also estimated using the chart in Appendix A of the N43.17 standard. According to the chart, the conversion for a frontal adult scan is about 0.27 µrem/µR, resulting in about 2.6 µrem per scan.

Dose to bystanders

The ANSI N43.17 standard requires delineation of an inspection zone outside of which the skin-entrance dose must fall below 2 mrem/hr. The standard requires the system to be shielded so as to limit radiation leakage to less than 0.25 mrem/h (skin entrance dose rate) at any point 30 cm from the outer surface. The standard also recommends that operators and workers be limited to less than 100 mrem effective dose in a twelve month period. Exposures due to leakage radiation and scatter radiation have been quantified in order to determine compliance with these requirements and recommendations of the standard.

Radiation leakage

The Secure 1000 was operated in a "burn-in" mode in order to evaluate the radiation leakage from the main cabinet and transmission through the back plate. This mode is only accessible to service personnel and provides continuous scanning until stopped. In the burn-in mode the Secure1000 performs a scan roughly every 17 seconds. During the scan cycle the x-ray tube is on about 50% of the time. A Technical Associate model P8-Neon instrument was used to localize any leakage. The Neon instrument has 8 side-to-side pancake GM detectors for a sensitive area of about 5 cm by 50 cm. 8 LED's, one for each detector, allow localization of the leakage within the sensitive area. The Secure 1000 was surveyed by holding the Neon steady at one location while the "Scan in Progress" light was illuminated, then moved to another location. The areas surveyed included the three sides of the cabinet other than the side adjacent to the inspection zone, the area over the top of the cabinet, and the outer side of the back plate. Careful attention was given to cracks around the back doors (through which light from the inside could be seen) and the four ventilation fans on the doors. No measurable leakage was detected at these locations nor behind the back plate.

Figure 11. The P8-Neon detector and the tape marking the point of highest radiation leakage.

The highest response from the Neon was in a vertical line on each side and over the top of the cabinet. The line was about 29 cm from the front panel surface and coincided roughly with the plane of the tube port (fissure between tube window and collimators). The Neon response seemed to be stronger along this line in the lower half of the cabinet (see Figure 11). Also, the leakage seemed to extend from the line to the front edge of the cabinet, being strongest at the line. This line was marked with masking tape to facilitate follow-up measurements with the Radcal 10X5-1800 ionization chamber. The ion chamber entered on the line at 30 cm from the surface and 84 cm from the floor. Five-minute background samples were taken before and after the leakage measurement. The measurements were corrected using the average background exposure rate. The results, shown in Table 2, are well within the 0.25 mrem/h limit of the ANSI standard.

Table 2. Measurement of the leakage radiation at the point of maximum survey meter response.

Time (s)	No. scans	Scan duration (s)	Net exp (μR)	Net exp/scan (μR)*	Net exp rate for scanning in burn-in mode (μR in 1 h)	Hourly exposure assuming 3 scans/m (μR in 1 h)
596	34	17.5	2.54	0.0746	15.3	13.4

*Corrected for energy response, background, and environment

Scatter radiation

The exposure due to radiation scattered from a person being scanned to the area adjacent the inspection zone was assessed. A 181 cm full body phantom was improvised to represent a screening subject. The phantom consisted of the following components: Rando phantom components of head, 23 cm. long; anthropomorphic phantom of torso, 50 cm long; Rando phantom components of abdomen, 37 cm. long; Lucite tube, 215 mm dia, 7 mm thick, 710 mm long (legs). The phantom was placed at the normal screening position. The Radcal 10X5-1800 ionization chamber was used to measure exposure at two locations: (1) directly to the side of the phantom, 30 cm from plane of front surface, 30 cm from plane of side surface, 1 m from floor; and (2) at the plane of back plate (90 cm from plane of front surface), 30 cm from plane of side surface, 1 m from floor (see Figure 12, Figure 13 and Figure 14).

The exposure at each location was integrated over 20 scans and corrected for background. The resulting exposure per scan was 0.20 μR for location (1) and 0.11 μR for location (2). For continuous scanning at the rate of 3 scans per minute, a person in location (1) would receive an exposure of 36 μR in one hour, corresponding to roughly 36 μrem of skin entrance dose. A person in location (2) would receive an exposure of about 20 μR in one hour, corresponding to roughly 20 μrem of skin entrance dose. These results are well within the 2 mR/h limit of the ANSI standard.

Figure 12. Measurement of scatter exposure, location (1). The exposure at this location was 0.20 µR/scan.

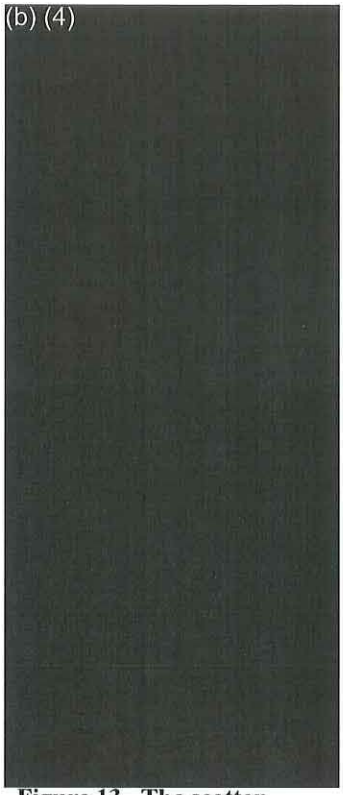

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Figure 13. The scatter phantom as imaged by the Secure 1000.

Figure 14. Measurement of scatter exposure, location (2). The exposure at this location was 0.11 µR/scan.

Concluding remarks

The unit tested was fitted with a back plate and was evaluated as assembled. The back plate may have some benefits in the formation of an image which are beyond the scope of this work. However, the back plate also acts as a radiation shield. It may be useful to consider the effect of removing this shield on the demarcation of an inspection zone as defined in the ANSI N43.17 standard and on the radiation environment in the general area. Figure 9 shows that the exposure at the back plate (about 90 cm from the front panel) is 0.4 times the exposure at 30 cm*. That means that at 90 cm the exposure per scan is just under 4 μR. At 3 scans per minute this translates to about 0.7 mrem of skin entrance dose in one hour. The standard requires the dose outside the inspection zone to be less than 2 mrem in one hour. At the 3 scans per minute rate, this occurs at about 24 cm from the front panel surface.

The purpose of this work was to evaluate the radiological safety aspects of the unit tested. Investigation of non-radiological hazards is beyond the scope of the interagency agreement. However, the agreement called for the reporting of any potential physical or electrical hazards that may have been noticed during testing. One observation made was that the supporting structure of the back plate assembly may not be sufficiently stable under some conditions. The back plate was measured at 153 cm width x 232 cm height and is estimated to weigh several hundred pounds. It was supported by steel feet, 1.9 cm (3/4 in) thick, protruding 29 cm on the outside (side away from the Secure 1000 cabinet) and 24 cm on the inside (side facing the cabinet). The outside feet were reinforced with aluminum triangular plates to prevent bending or breakage. The reinforcing plates were not added to the inside feet, presumably because they would interfere with accessibility of the inspection zone. The back plate also had a sturdy handle on each vertical edge, near the middle. The handle can be used for moving the back plate but may also be grasped by a person for balance. It is conceivable that a large person pulling on one of the handles may cause the whole assembly to fall over on the side of the shorter feet. The risk of tipping over the back plate is reduced somewhat if the metal ramps are fastened securely to the floor panel, thereby holding the feet flat on the floor underneath. Nevertheless, for the sake of stability consideration should be given to making the inside feet the same length as the outside feet. The features of the back plate assembly are shown in Figure 15 and Figure 16.

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* The RTI R100B detector used for this measurement is not expected to be sensitive to radiation scattered from the back plate into the back side of the detector, so the measurement holds in the absence of the back plate.

Figure 15. The back plate assembly showing the handle and the triangular aluminum plate mounted on the outside foot. The outside foot protrudes 29 cm behind the plate. The inside foot is covered by the aluminum ramp.

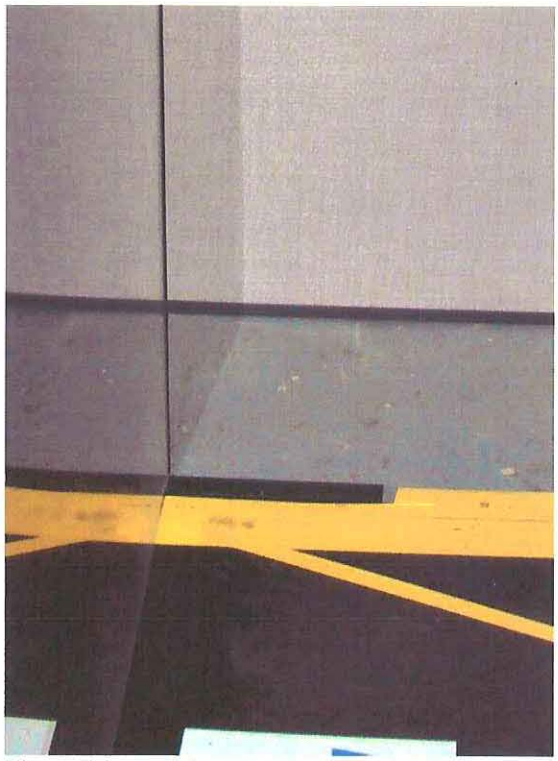


Figure 16. The 24 cm-long inside foot of the back plate can be seen on the far side of the floor panel. The aluminum ramp that attaches to the floor panel and normally covers the foot was not installed on this side.

REFERENCES

[1] American National Standards Institute. *Radiation Safety for Personnel Security Screening Systems Using x-rays*. ANSI/HPS N43.17-2002. Health Physics Society (2002).

[2] Steve Gray. Personal communication. April 17, 2006.

[3] International Commission on Radiological Protection. *1990 Recommendations of the International Commission on Radiological Protection*. Publication 60. Ann. ICRP 21. (Oxford:Pergamon) (1990).

[4] Servomaa, A. and Tapiovaara, M. *Organ dose Calculation in Medical X Ray Examinations by the Program PCXMC*. Radiation Protection Dosimetry 80, 213-219 (1998).

APPENDIX A

U.S. Food and Drug Administration
Center for Devices and Radiological Health

Report of Calibration (cont.)

Calibration: 2218-X3 PC Date: 10- 6- 5

Instrument: MDH 9015 MONITOR (MANUAL TP COR) S/N:91-0097

Chamber: MDH MODEL 10X5-1800 AUTO MODE S/N:9946

Owner Code: OHIP

Use Code: M50

Comments: COLL REMOVED

Constant Potential (kV)	Beam Intensity (mR/s)	First HVL (mm Al)	First HVL / Second HVL	Correction Factor*
50.	2.1	1.01	0.64	1.24

* The instrument readings must be multiplied by the appropriate correction factor in order to obtain the correct value of exposure or exposure rate.

Additional corrections or conditions required:

Actual Correction Factor =
Listed Correction Factor X (760/P) X (273+T)/295

where:
P is the ambient pressure in millimeters of mercury
T is the ambient temperature in degrees Celsius

Calibration performed by Frank Cerra

U.S. Food and Drug Administration
Center for Devices and Radiological Health

Report of Calibration (cont.)

Calibration: 2219-X3 Date: 10-10- 5

Instrument: RTI BARRACUDA S/N:5030167

Chamber: R100B DENTAL MODE W/3mm Al S/N:06144

Owner Code: RMB

Use Code: M50

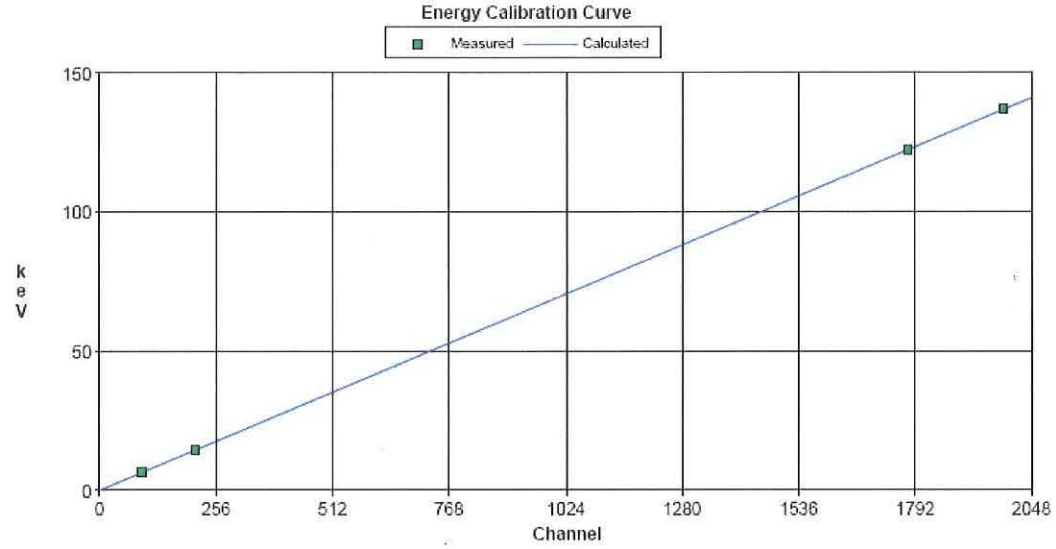
Comments:

Constant Potential (kV)	Beam Intensity (mR/s)	First HVL (mm Al)	First HVL / Second HVL	Correction Factor*
50.	5.0	1.01	0.64	1.17

* The instrument readings must be multiplied by the appropriate correction factor in order to obtain the correct value of exposure or exposure rate.

Calibration performed by Frank Cerra

Calibration of the Canberra DSA-2000 Spectrometer and GUL0110P Detector Using ^{57}Co Gamma Energies Performed on 4/22/06



Datasource: C:\GENIE2K\CAMFILES\Secure1000#1.CNF
Energy = -2.288e-003 keV + 6.871e-002*Ch
FWHM = 1.042e-001 keV + 3.696e-002*E^1/2
Lo Tail = 1.385e-001 keV + 2.384e-003*E

APPENDIX B

Assessment of the Rapiscan Secure 1000® Body Scanner
for
Conformance with Radiological Safety Standards
July 26, 2006

ADDENDUM – EXPLANATORY INFORMATION ABOUT APPENDIX B
August 13, 2010

The following information is intended for individuals familiar with radiation protection concepts, methodology and terminology. In particular the output of the PCXMC Monte Carlo program[1] in Appendix B of the CDRH / NIST[2] report needs additional explanation to be readily understood by individuals not familiar with the PCXMC program.

Organ absorbed doses and an effective dose are calculated by PCXMC and are relative to the incident air kerma value that is input for the Monte Carlo simulation. The air kerma input is labeled as "SurfDose" in the printouts in Appendix B. The program expects units of milliGray (mGy) for the air kerma ("Surf Dose") input and all subsequent organ absorbed doses are calculated in units of mGy. An exposure of 1 milliRoentgen (mR) is equivalent to an air kerma of 0.00877 milliGray (mGy). The input air kerma ("Surf Dose") listed in Appendix B for all simulations is 0.0088 mGy or 1 mR entrance skin exposure and the listed organ/tissue absorbed doses are in units of mGy, and the effective dose is in units of milliSievert (mSv). Furthermore, the results can be used as conversion factors from an entrance skin exposure measurement (mR) (air kerma of 0.0088 mGy) to an organ absorbed dose (mGy) or effective dose (mSv).

The equivalent dose to a specific organ/tissue is the absorbed dose multiplied by the appropriate radiation weighting factor. For photons the radiation weighting factor is 1. This means the results can be used as a conversion from entrance skin exposure (mR or μR) to organ equivalent dose (mSv or μSv, respectively).

The effective dose is calculated by determining the equivalent dose to each organ, applying the appropriate organ/tissue weighting factor (w_T)to each organ, and summing the weighted doses. The second to last line, labeled "Effective dose" on the output list is the conversion factor from entrance skin exposure to effective dose. The w_Ts used in the effective dose calculations are from the 1991 ICRP Report #60[3]. Subsequent w_Ts have

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[1] Servomaa, A. and Tapiovaara, M. *Organ dose Calculation in Medical X Ray Examinations by the Program PCXMC*. Radiation Protection Dosimetry 80, 213-219 (1998).

[2] CDRH / NIST *Assessment of the Rapiscan Secure 1000® Body Scanner for Conformance with Radiological Safety Standards*, July 2006

[3] ICRP–International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60. Annals of the ICRP 1991; 21 (1–3).

been published in ICRP Report #103 in 2007[4], after this work was completed. Using the updated w_Ts will result in a relatively small reduction of the effective dose.

The following are examples of how to use the results in Appendix B for systems with identical system input parameters:

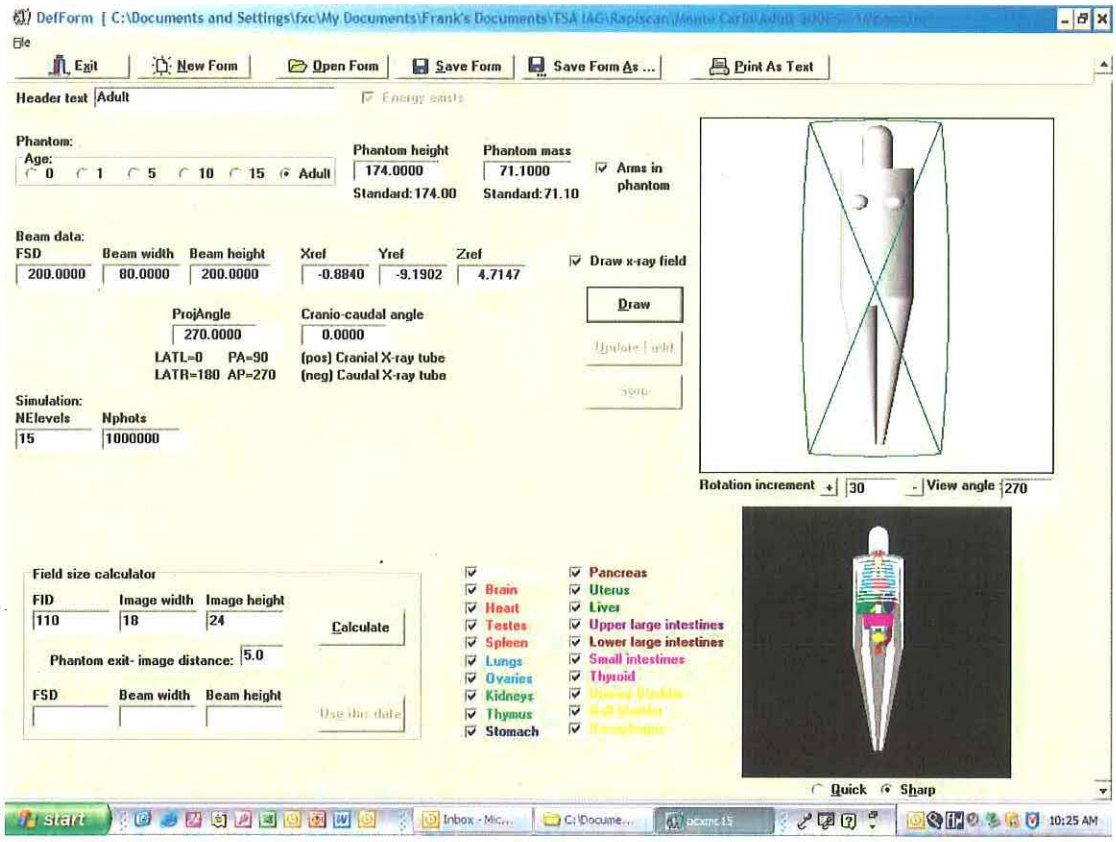
- For simplicity we will use the entrance skin exposure reported in the body of the report: 9.6 μR. (page 12)

- To determine the effective dose in Sv:
  9.6 μR × 0.00246 μSv/μR = 0.0236 μSv is the whole body effective dose from one scan.

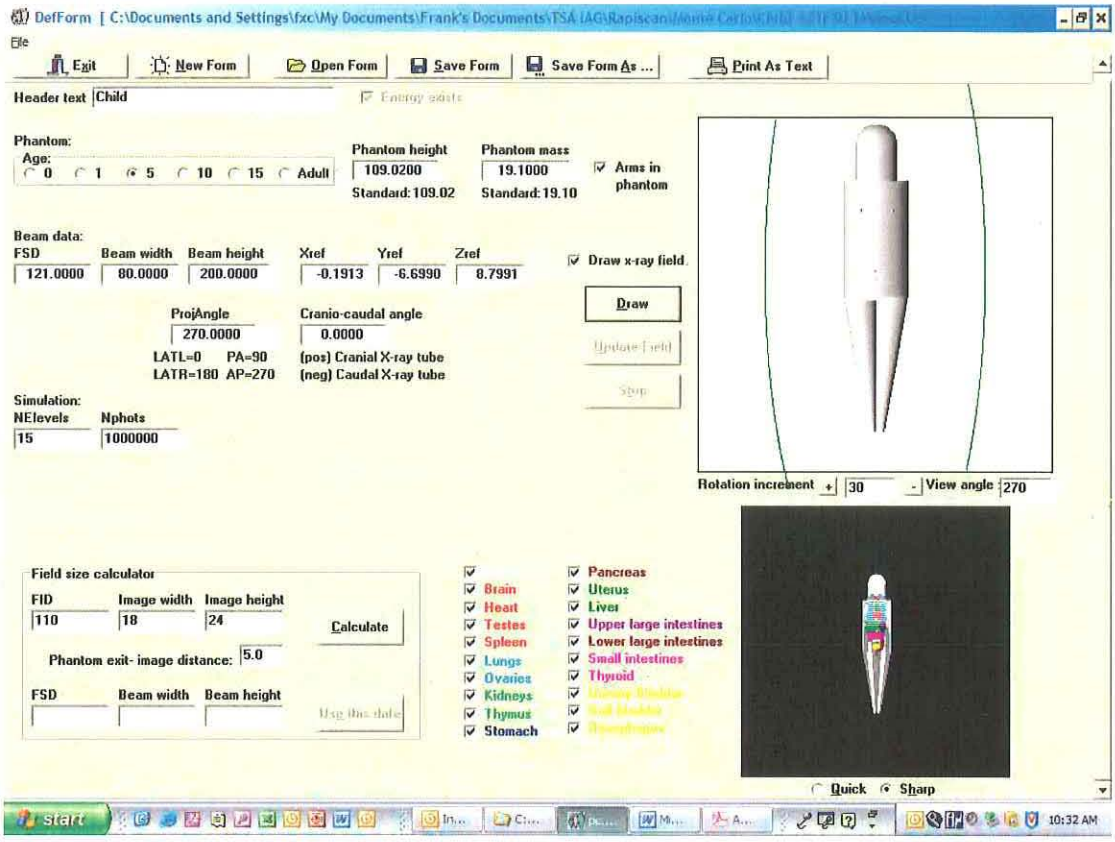
- To determine skin dose in Sv:
  9.6 μR × 0.00554 μSv/μR = 0.0532 μSv is the dose to the skin from one scan.

- To approximately determine the skin dose **if** the dose delivered was at the limit for a general-use x-ray security system of 0.25 μSv reference effective dose per screening:
  (Skin dose ÷ Effective dose) × 0.25 μSv =
  (0.0532 μSv ÷ 0.0236 μSv) × 0.25 μSv = 0.56 μSv skin dose from one screening for which the effective dose was at the dose limit of 0.25 μSv.

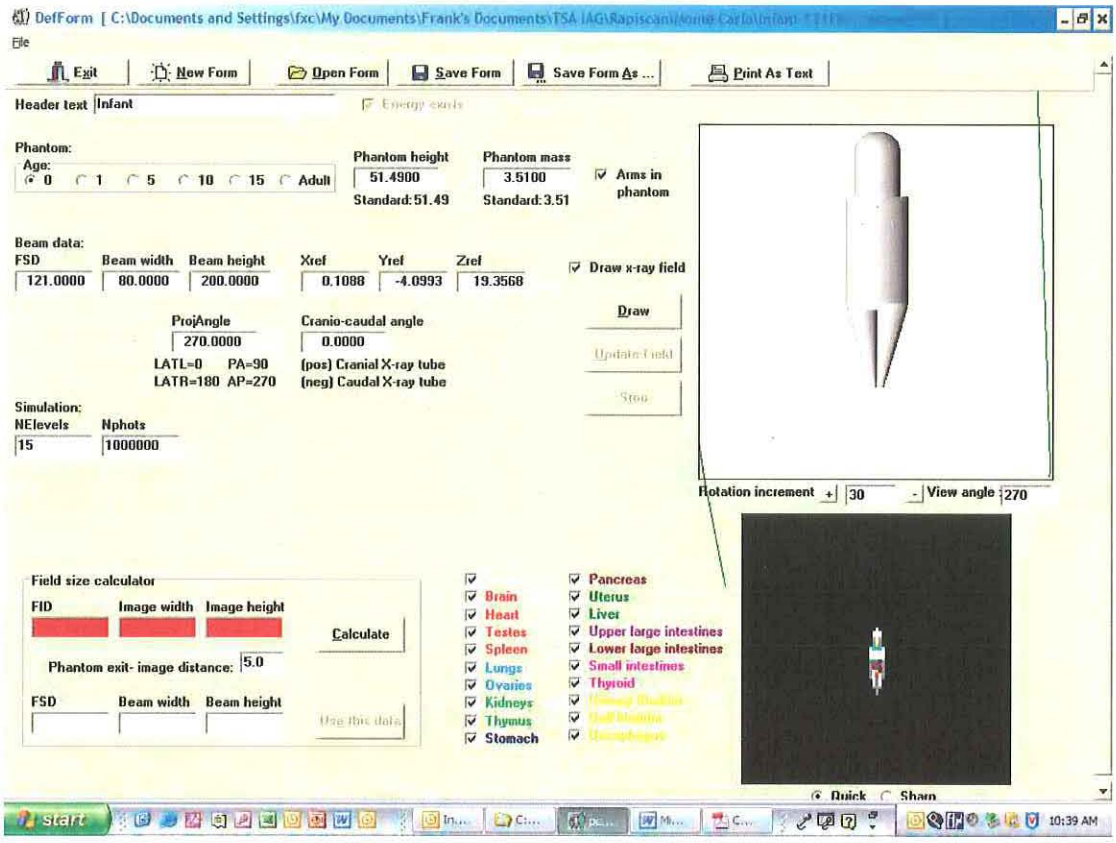
[4] ICRP–International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Annals of the ICRP 2007; 37 (2–4).



Header:		Adult
Projection:		270.0000
Obl. Angle:		0.0000
Age:		30
Length:		174.0000
Mass:		71.1000
Arms in phantom:		1
FSD:		200.0000
X-ray beam width:		80.0000
X-ray beam height		200.0000
Xfocus:		-0.8840
Yfocus:		-209.9902
Zfocus:		4.7147
NELevels:		15
NPhots:		1000000
XYscale:		1.0000
Zscale:		1.0000
X-ray tube voltage (kV):		50
Filter:		1.4 mm Al
SurfDose:		0.0088
Organ:	Dose(mGy):	Error(%):
Ovaries	0.000925	8.8
Testes	0.006832	1.8
Active bone marrow	0.000604	0.3
Skeleton	0.003273	0.3
Lungs	0.001486	0.8
Lower large intestine	0.001128	1.9
Stomach	0.002583	1.7
Liver	0.001809	0.7
Thyroid	0.004735	2.9
Oesophagus	0.000332	5.0
Breasts	0.005120	0.6
Urinary bladder	0.002985	2.2
Skin	0.005543	0.2
Adrenals	0.000213	12.5
Brain	0.000375	1.9
Kidneys	0.000199	3.2
Pancreas	0.000762	2.9
Small intestine	0.001276	0.7
Upper large intestine	0.001742	1.6
Spleen	0.000486	2.7
Thymus	0.004078	3.7
Uterus	0.001192	3.7
Remainder (muscle)	0.002303	0.1
Gall bladder	0.001773	2.8
Heart	0.002089	1.3
Total Body	0.002454	0.1
Effective dose	0.002462	0.7
Abs. fraction (%)	24.877410	



Header:		Child
Projection:		270.0000
Obl. Angle:		0.0000
Age:		5
Length:		109.0200
Mass:		19.1000
Arms in phantom:		1
FSD:		121.0000
X-ray beam width:		80.0000
X-ray beam height		200.0000
Xfocus:		-0.1913
Yfocus:		-128.4990
Zfocus:		8.7991
NELevels:		15
NPhots:		1000000
XYscale:		1.0000
Zscale:		1.0000
X-ray tube voltage (kV):		50
Filter:		1.4 mm Al
SurfDose:		0.0088
Organ:	Dose(mGy):	Error(%):
Ovaries	0.002309	14.6
Testes	0.009122	6.8
Active bone marrow	0.001200	0.4
Skeleton	0.006540	0.3
Lungs	0.002860	1.0
Lower large intestine	0.002021	3.0
Stomach	0.004234	2.0
Liver	0.003355	1.0
Thyroid	0.005243	4.8
Oesophagus	0.000776	6.4
Breasts	0.008574	8.9
Urinary bladder	0.004783	2.8
Skin	0.006916	0.6
Adrenals	0.000473	16.9
Brain	0.000729	1.3
Kidneys	0.000471	4.2
Pancreas	0.001561	4.4
Small intestine	0.002252	1.2
Upper large intestine	0.002974	2.2
Spleen	0.001004	4.2
Thymus	0.005673	3.5
Uterus	0.002442	9.6
Remainder (muscle)	0.003444	0.1
Gall bladder	0.002968	2.8
Heart	0.003685	1.8
Total Body	0.003691	0.2
Effective dose	0.003876	2.1
Abs. fraction (%)	10.051325	



Header:		Infant
Projection:		270.0000
Obl. Angle:		0.0000
Age:		0
Length:		51.4900
Mass:		3.5100
Arms in phantom:		1
FSD:		121.0000
X-ray beam width:		80.0000
X-ray beam height		200.0000
Xfocus:		0.1088
Yfocus:		-125.8993
Zfocus:		19.3568
NELevels:		15
NPhots:		1000000
XYscale:		1.0000
Zscale:		1.0000
X-ray tube voltage (kV):		50
Filter:		1.4 mm Al
SurfDose:		0.0088
Organ:	Dose(mGy):	Error(%):
Ovaries	0.004887	20.2
Testes	0.011608	8.3
Active bone marrow	0.002410	0.7
Skeleton	0.011252	0.6
Lungs	0.004228	1.9
Lower large intestine	0.003636	5.2
Stomach	0.005467	5.2
Liver	0.005116	1.3
Thyroid	0.009291	9.9
Oesophagus	0.002399	10.7
Breasts	0.000577	30.5
Urinary bladder	0.006701	6.8
Skin	0.007755	0.9
Adrenals	0.001012	8.7
Brain	0.002381	1.2
Kidneys	0.001106	6.3
Pancreas	0.002931	11.4
Small intestine	0.003728	2.3
Upper large intestine	0.004455	5.4
Spleen	0.002078	7.0
Thymus	0.007904	3.8
Uterus	0.003784	6.4
Remainder (muscle)	0.004565	0.4
Gall bladder	0.003922	6.4
Heart	0.005672	2.4
Total Body	0.005141	0.3
Effective dose	0.005201	3.0
Abs. fraction (%)	2.572894	