Larry Hudson
Jack Glover
Ronnie Minniti

National Institute of Standards & Technology

USA

23 October 2012

Dosimetry For Air Travelers

Timeline for the Development of X-Ray Backscatter Standards – Whole Body Imaging in Aviation Security

Radiation Safety:

ANSI/HPS N43.17-2009

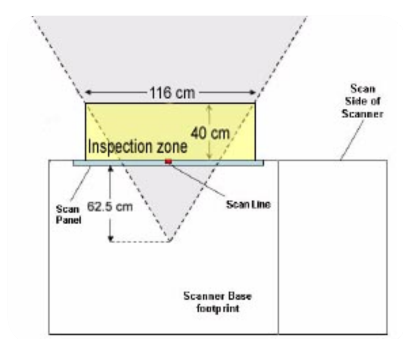
Radiation Safety for Personnel Security Screening Systems Using X-Ray or Gamma Radiation

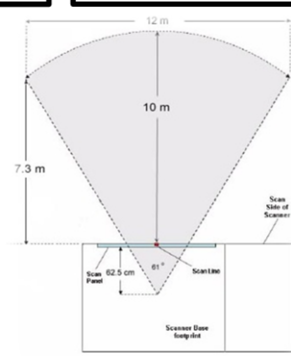
2006 2008 2010

5/11/06
Kickoff

12/9/08
(PINS) Work Item

8/19/09 (Approved)
Published





Technical Performance (Image Quality):

ANSI-IEEE N42.47-2010

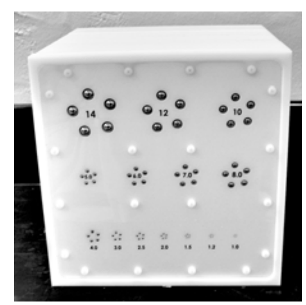
American National Standard for Measuring the Imaging Performance of X-Ray and Gamma-Ray Systems for Security Screening of Humans

2006 2008 2010

5/10/06
Kickoff

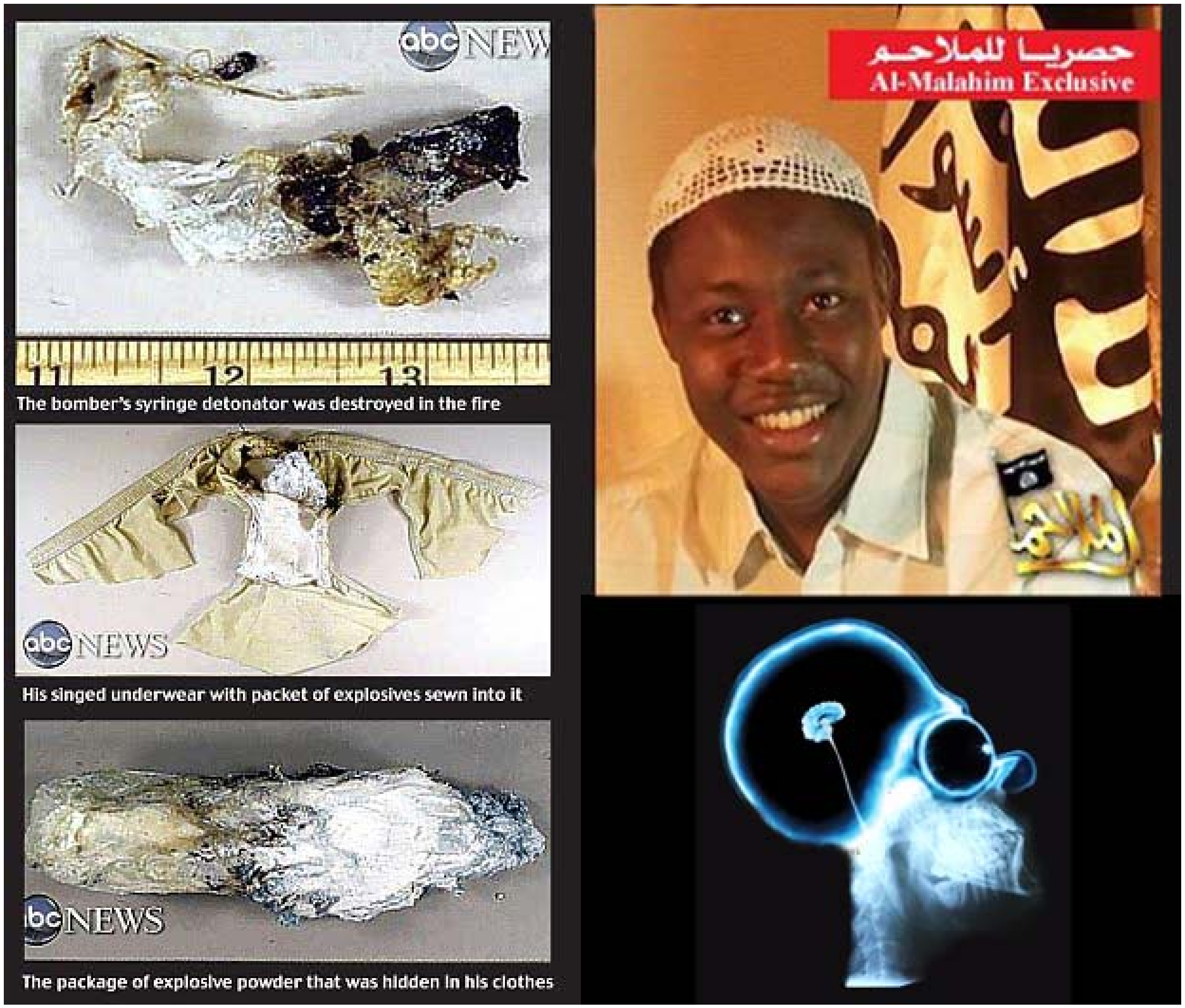
7/7/06
(PINS) Work Item

7/26/10
Published



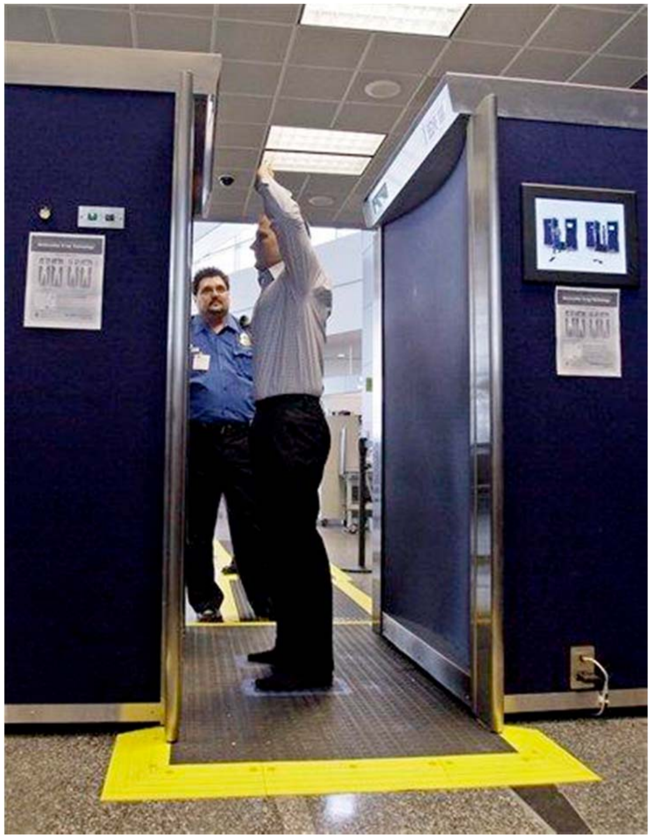
ANSI-IEEE N42.47 test article

Then, on 12/25/09, someone did what?!

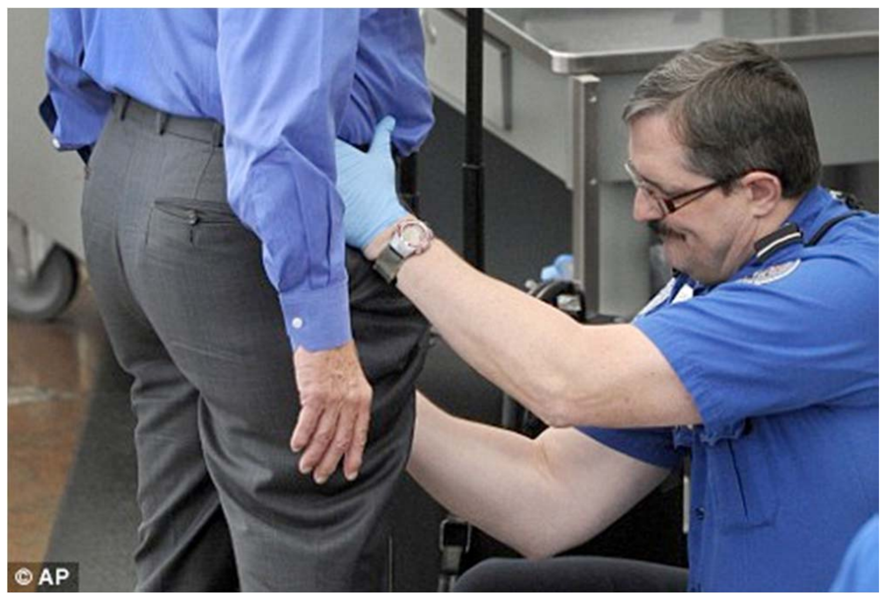


RANDO™ phantom

NIST



Present TSA CONOP



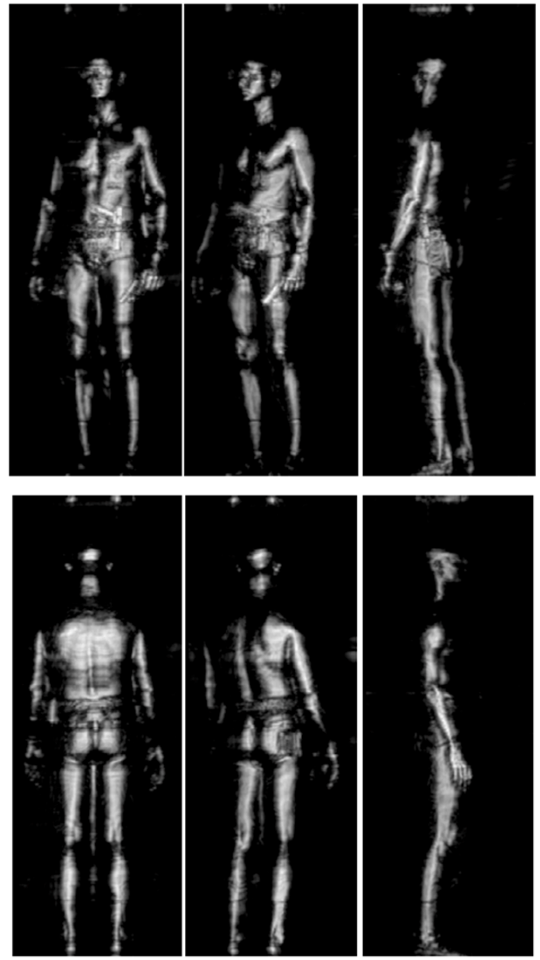
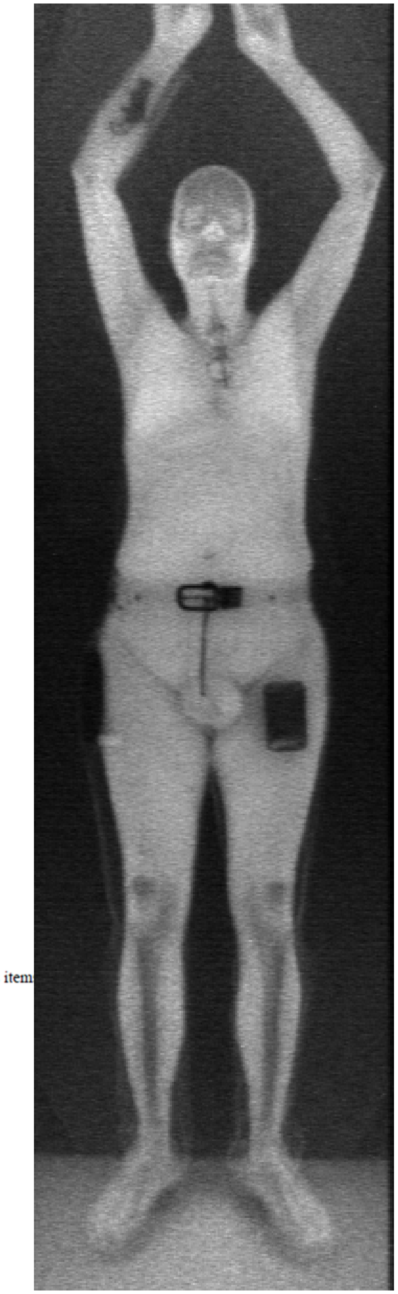


Figure 4 Wideband (27 - 33 GHz) images of a man carrying two concealed handguns along with several innocuous item



TSA investment has been half & half to date: mm-wave vs x-ray backscatter

Bodyscreening in Aviation Security

- privacy
- effectiveness
- cost-benefit
- metrology
- dose & rates

pencil beam

(apertured, not focused)

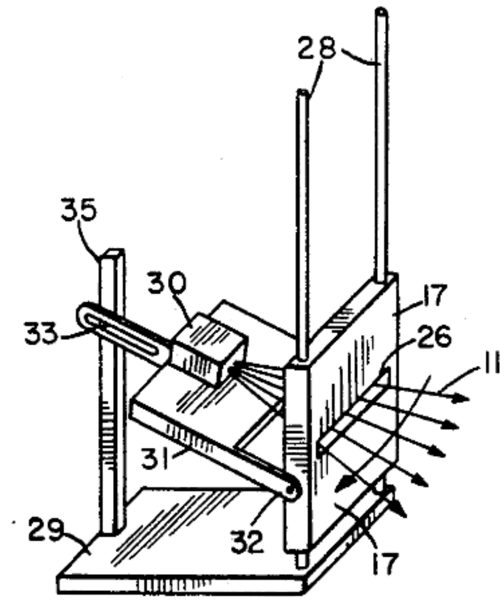


FIG. 5a

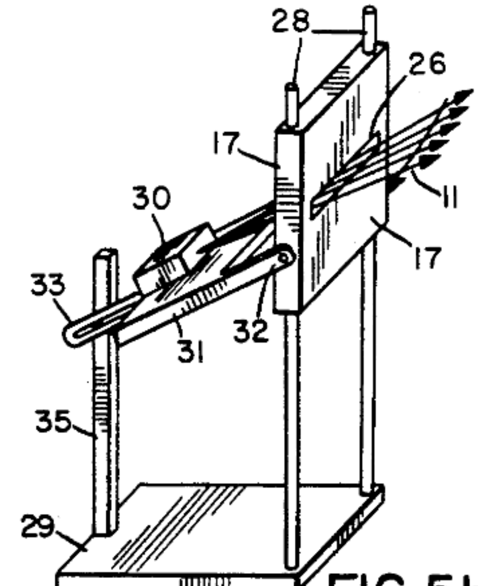


FIG. 5b

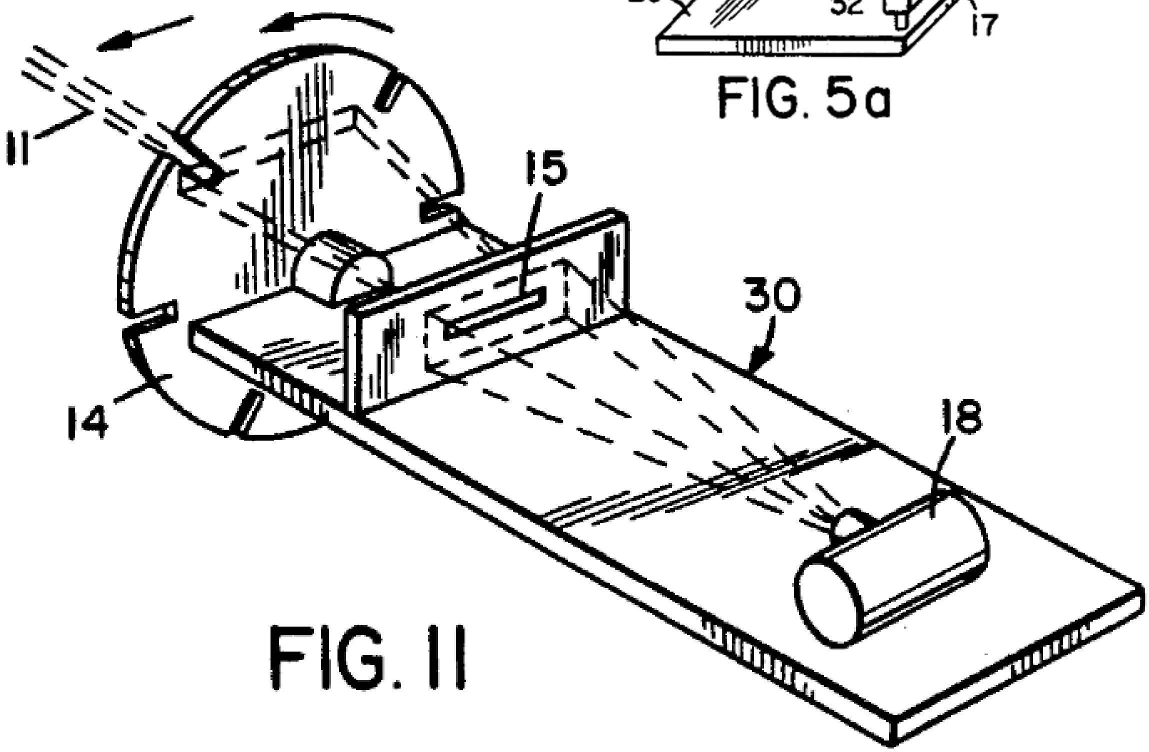
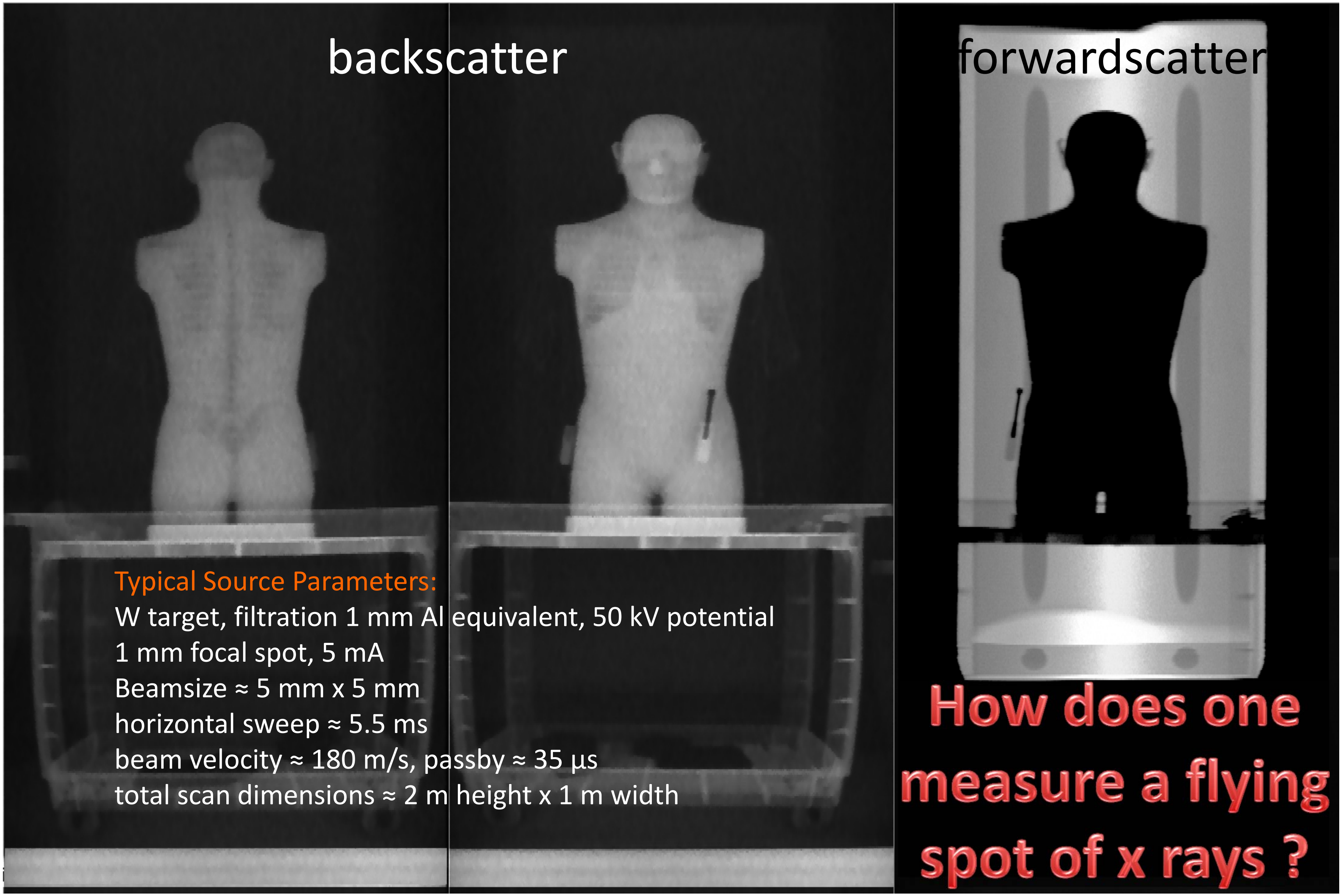


FIG. 11

+ wide-angle detectors

Whole-body imaging modalities



National and International X-Ray Standards for Security Screening of Persons

Venue	Technical Performance	Radiation Safety
Whole Body Imaging for aviation security	ANSI N42.47 – 2010 **IEC 62709 – CDV**	ANSI/HPS N43.17 – 2009 **IEC 62463 – 2010**

IEEE STANDARDS ASSOCIATION **ANSI N43.17** IEEE

guidance:

- air filled Ionization Chamber (IC)
- integrating mode
- entire volume “painted”
- large volume (sensitivity)
- low-E spectra → thin walls → not pressurized → T&P corrections
- absolutely calibrated & traceable

Calibration / Traceability

In this work, the following detectors were calibrated at NIST to air kerma:

(a) Radcal 10X5-1800, cylindrical IC

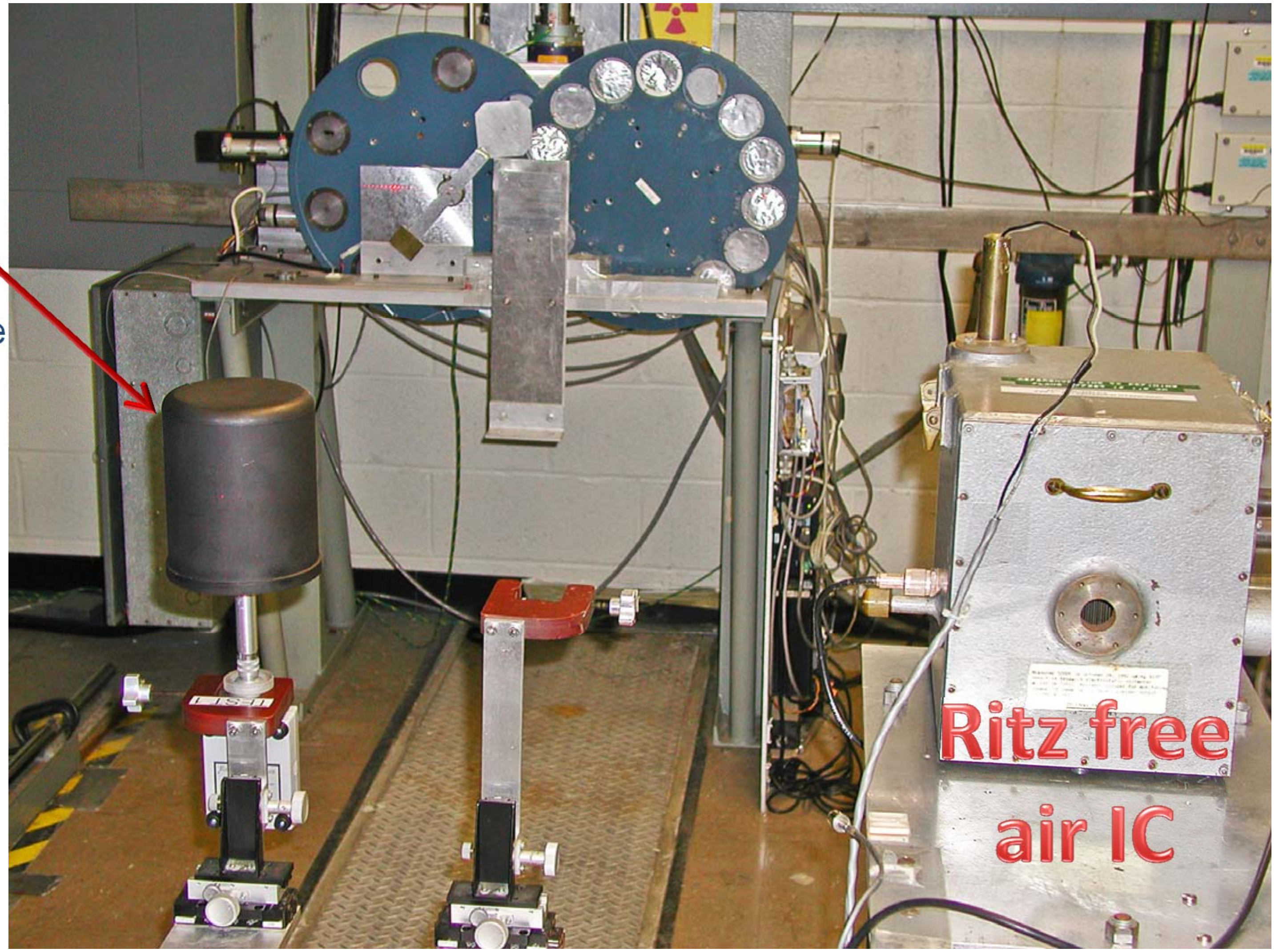
&

(b) RTI R100B solid-state detector,
sensitive area 1 cm^2

Also used:

- RTI CTDI100 CT Dose Profiler used for time structure investigation]

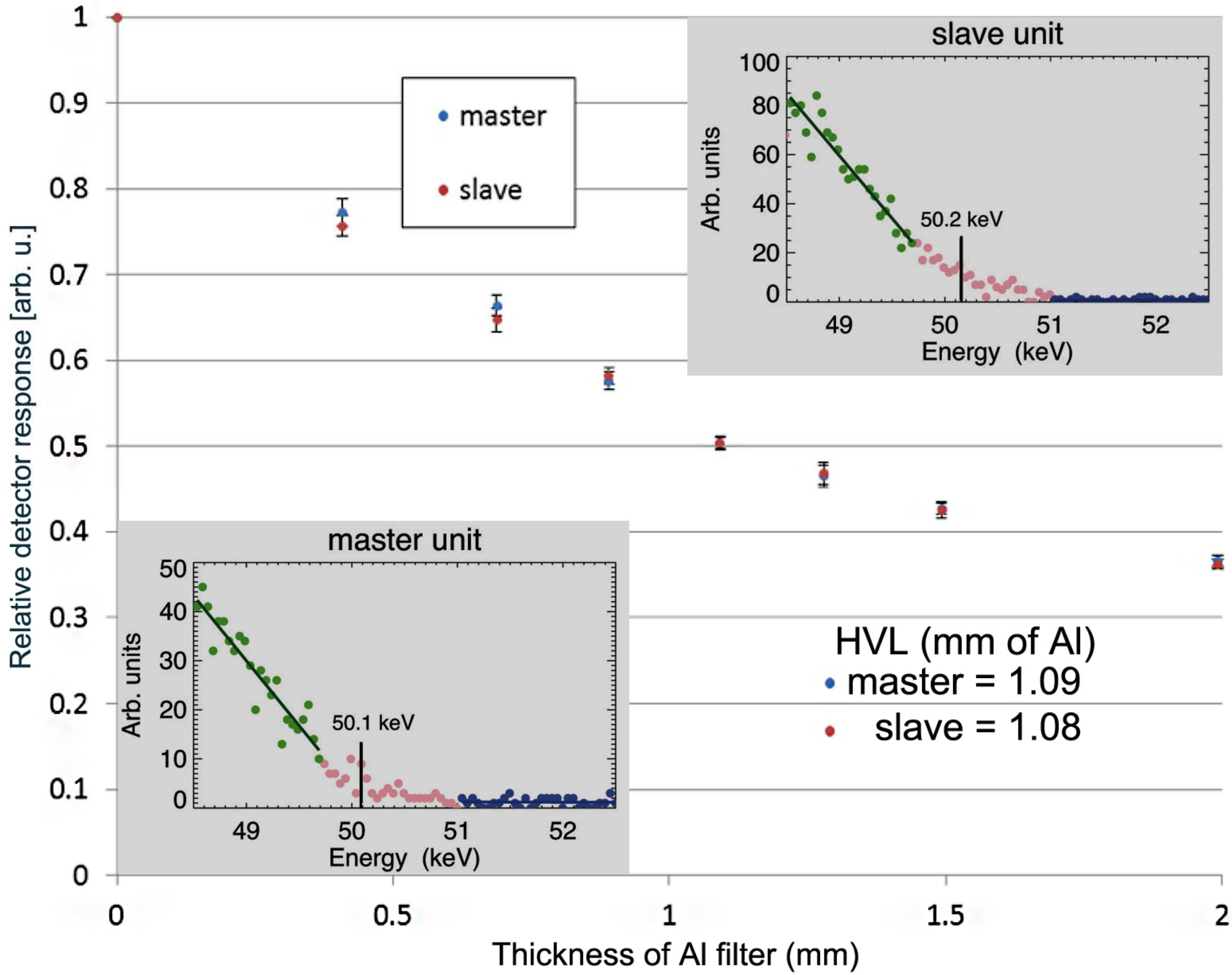
- Imaging plates for high-resolution spatial mapping



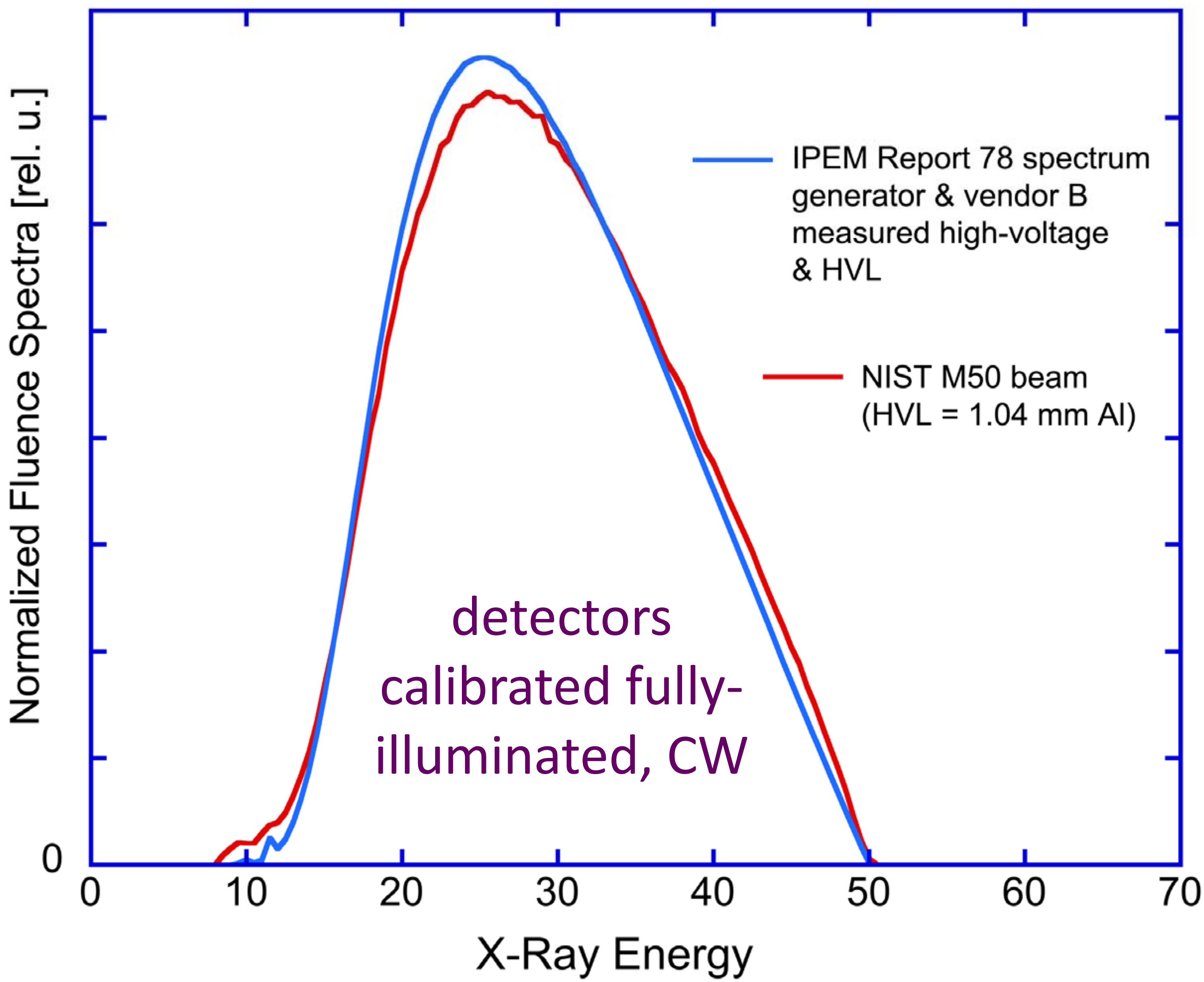
Components of a single-pose system

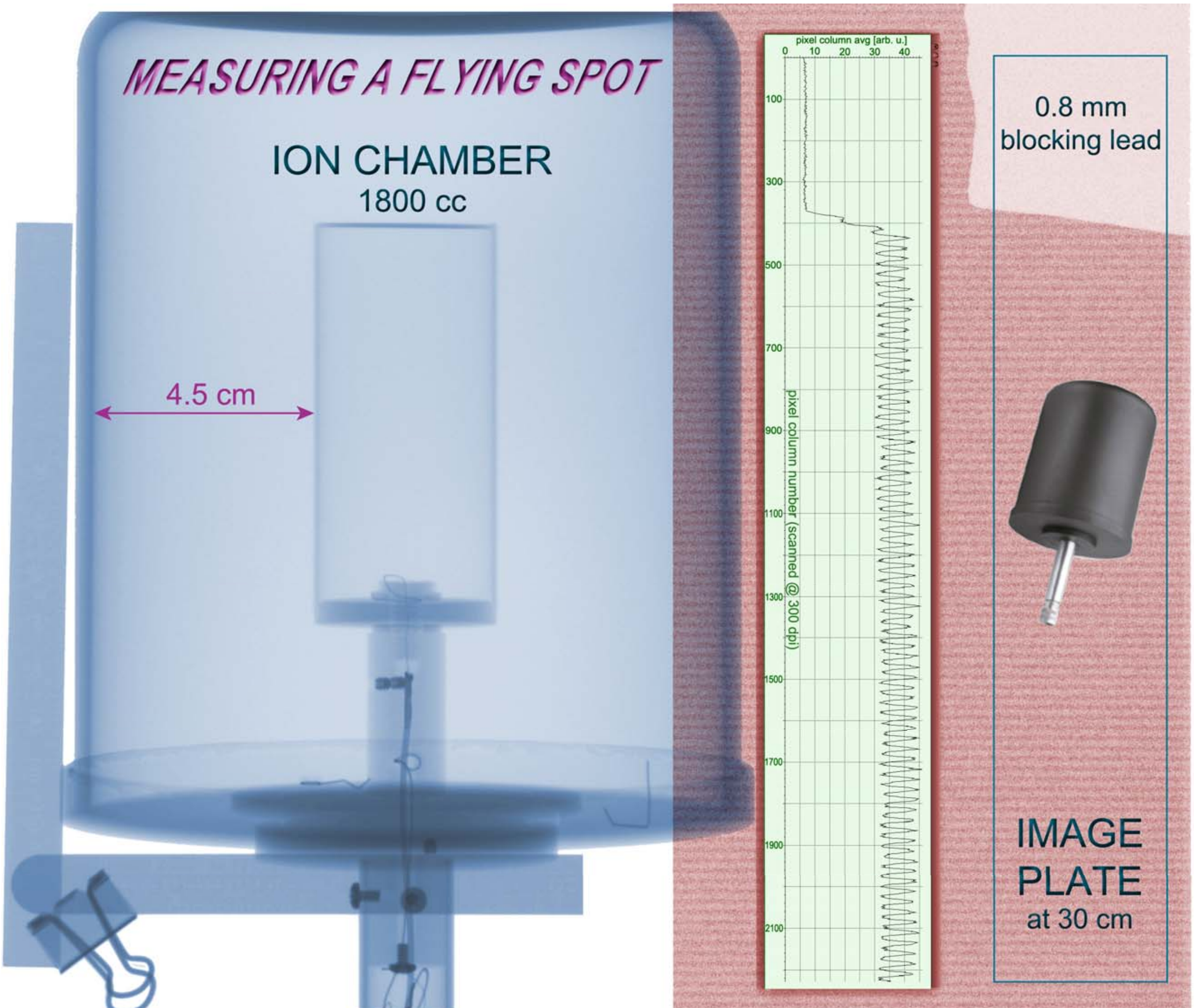
(1) master scanner; (2) slave scanner; (3) operator console; (4) front panel of the slave scanner; (5) floor mat; (6) wings of the slave scanner.

Characterizing the spectrum

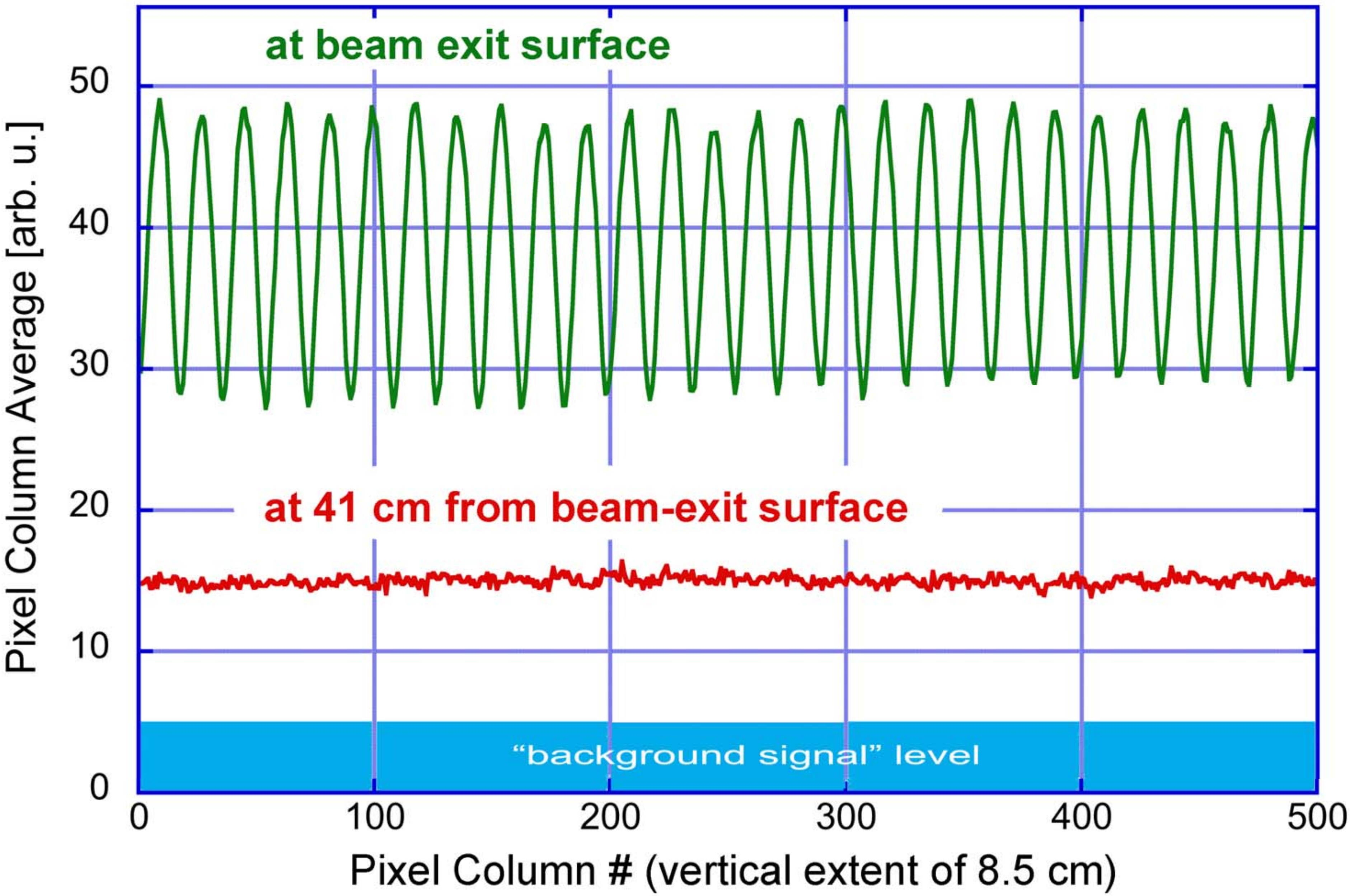


NIST M50: absolute air kerma rate

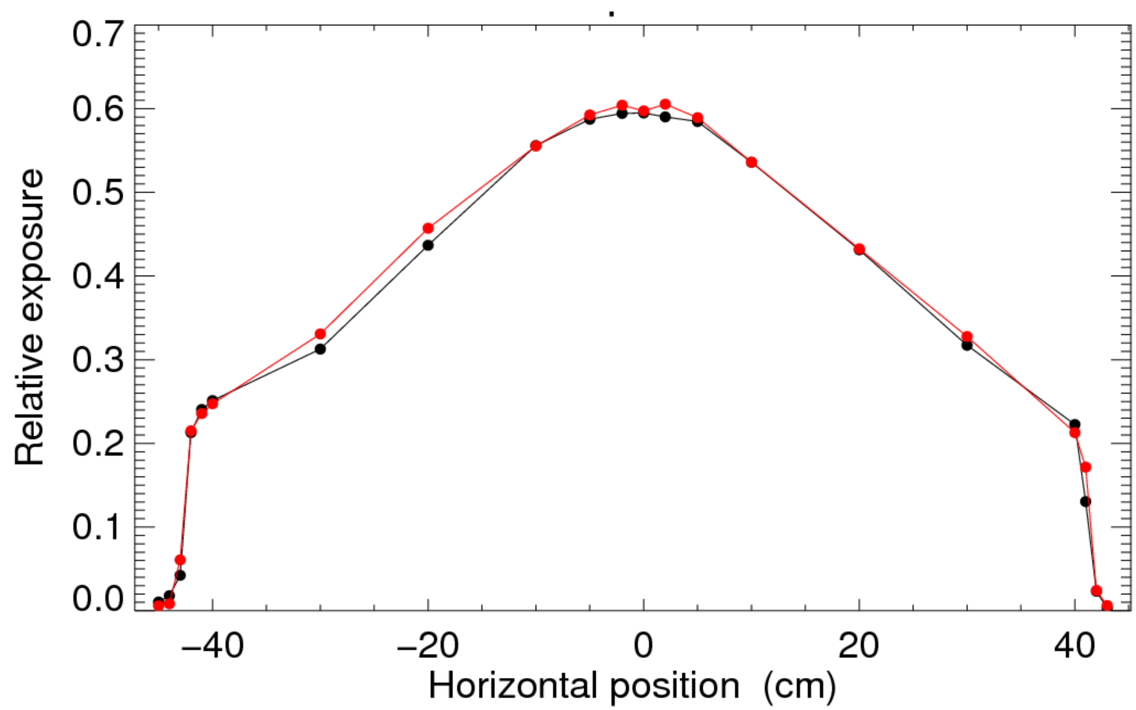



MEASURING A FLYING SPOT
ION CHAMBER
1800 cc
4.5 cm
pixel column avg [arb. u.]
0 10 20 30 40
100
300
500
700
900
1100
1300
1500
1700
1900
2100
pixel column number (scanned @ 300 dpi)
0.8 mm
blocking lead
IMAGE
PLATE
at 30 cm

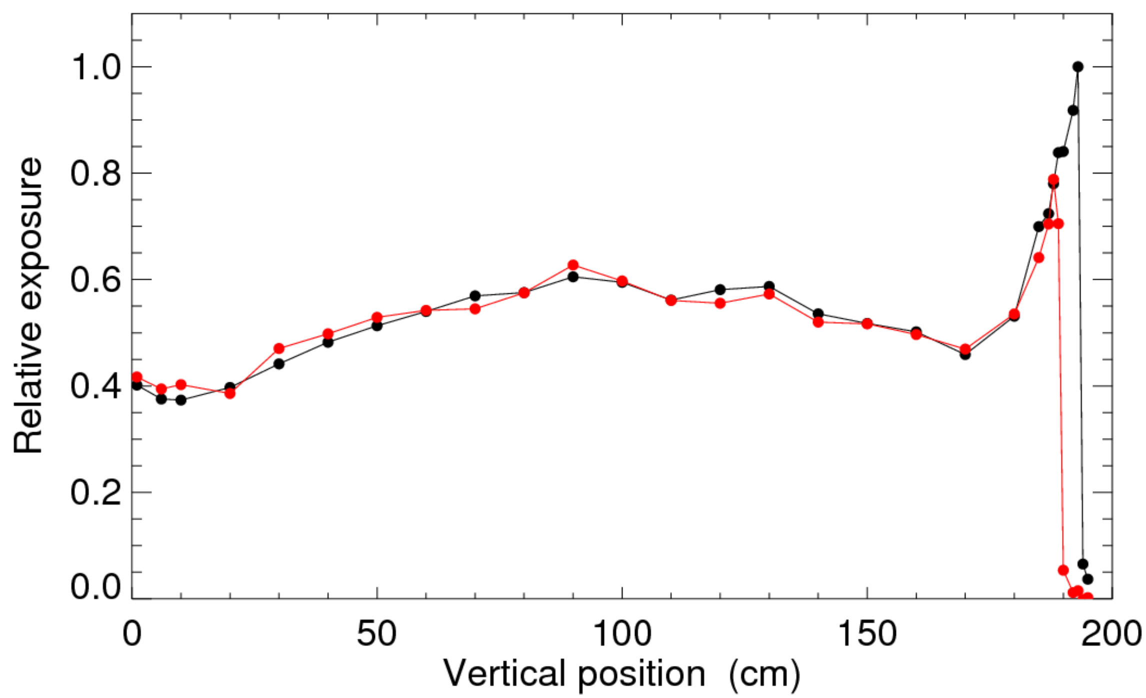
Exposure uniformity as function of distance



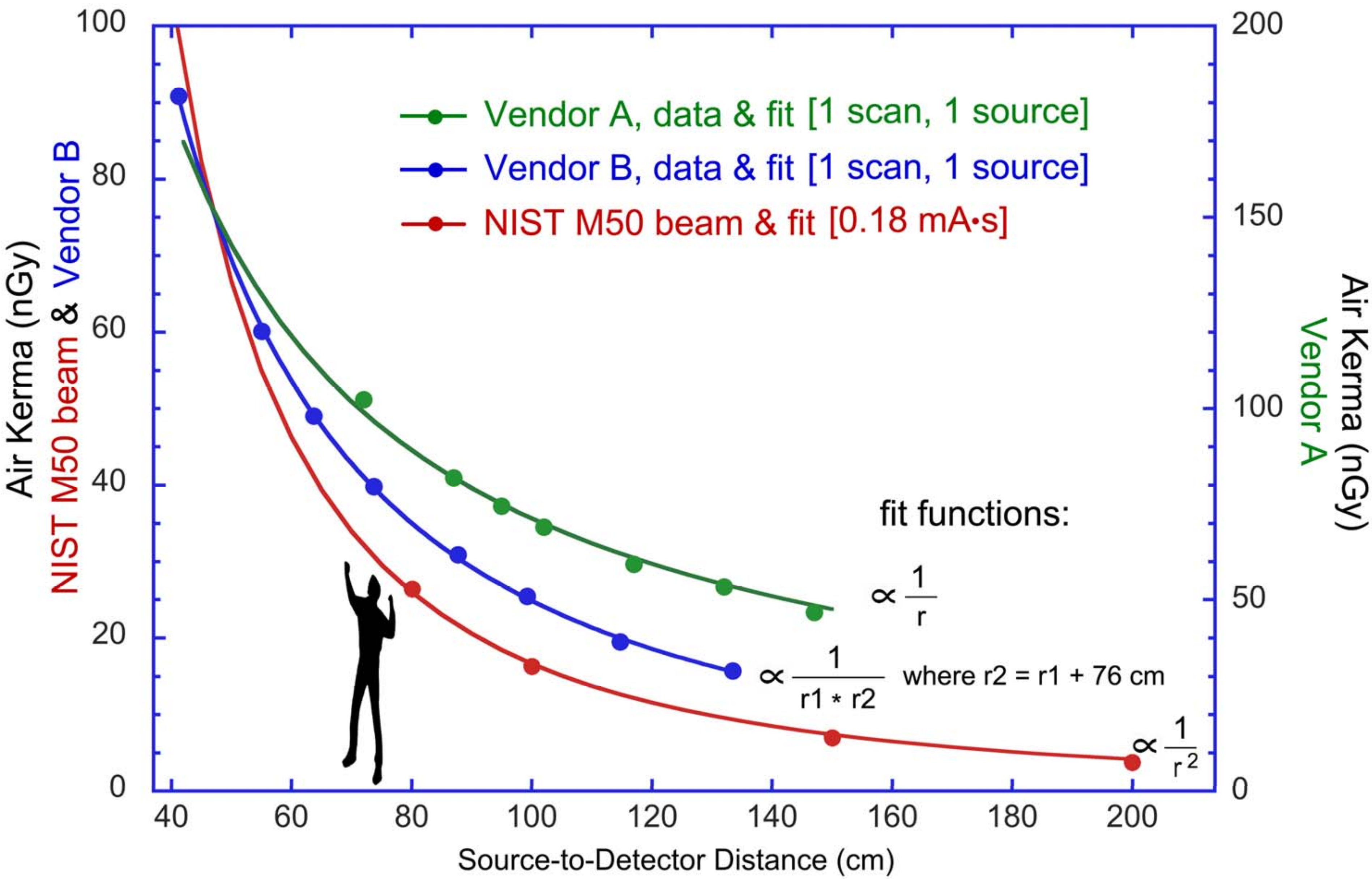
Lateral and vertical field mapping with solid-state detector



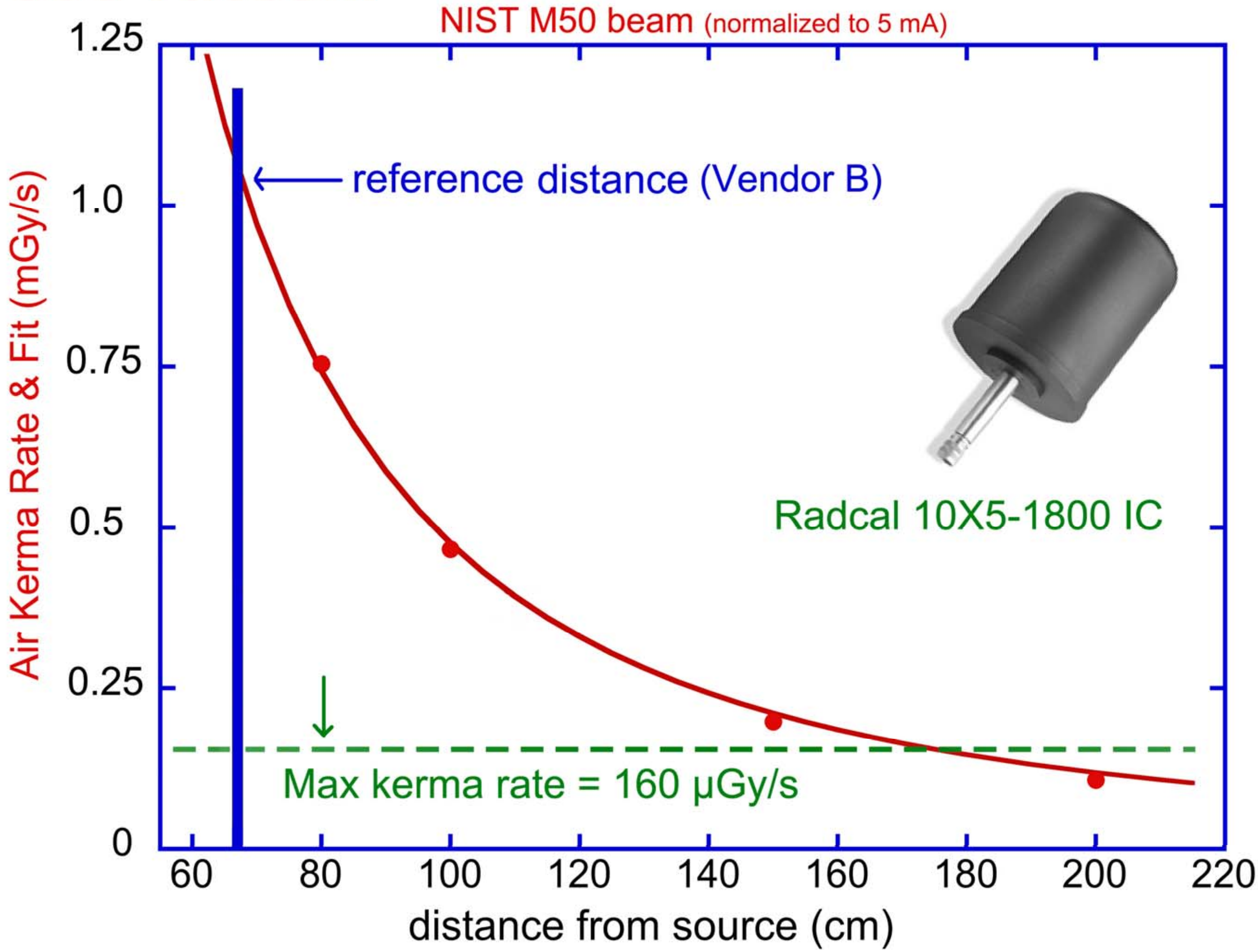
upscan = red
downscan = black



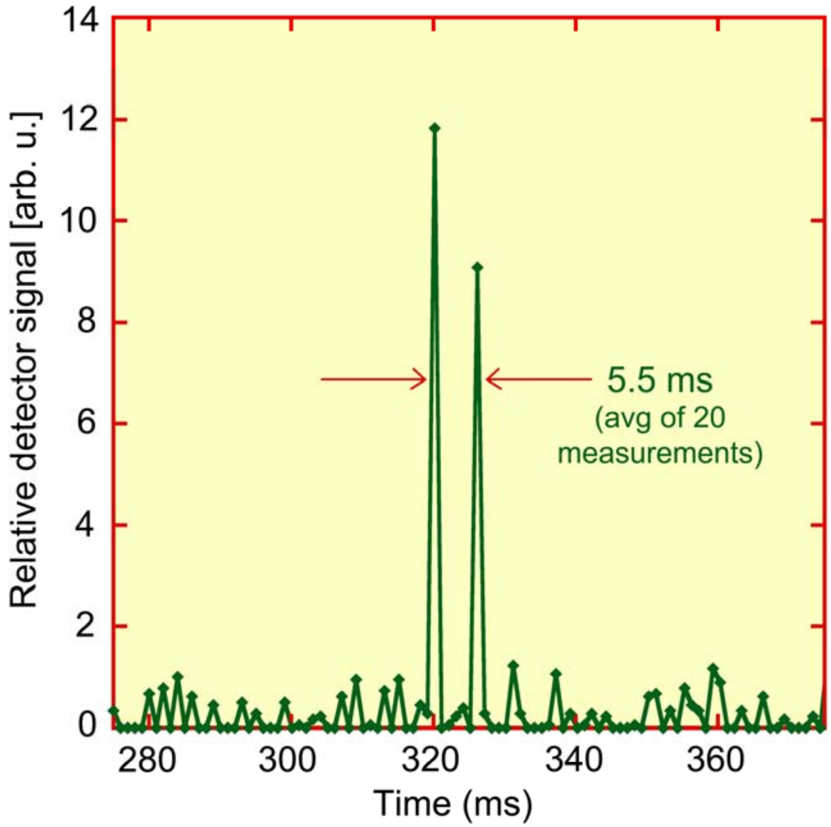
Location, location, location (IC)



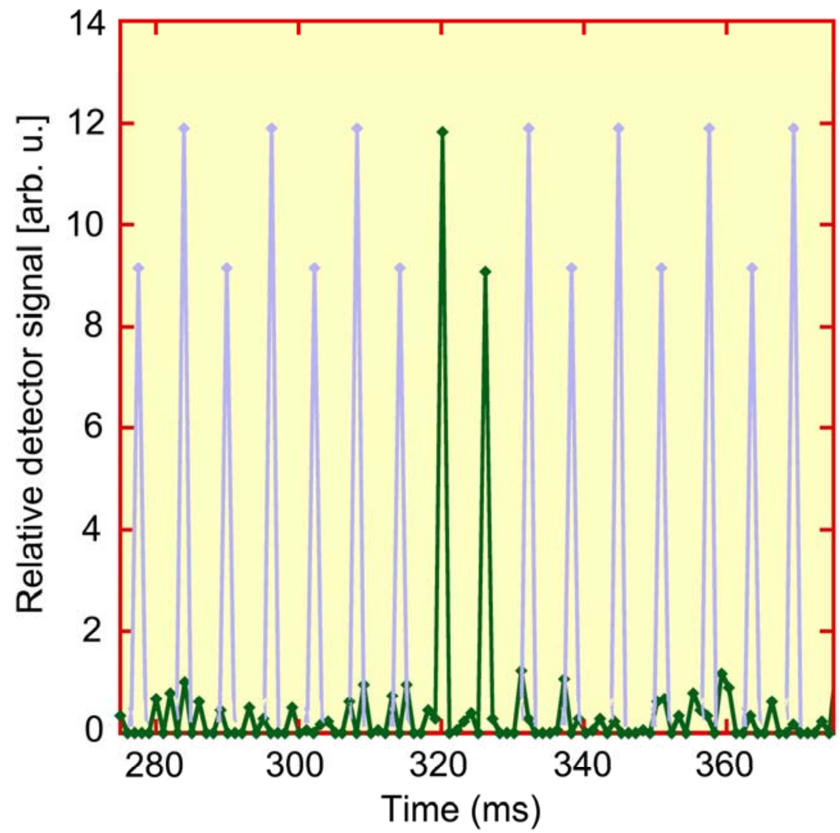
Dose rates…


NIST M50 beam (normalized to 5 mA)
Air Kerma Rate & Fit (mGy/s)
1.25
1.0
0.75
0.5
0.25
0
60
80
100
120
140
160
180
200
220
distance from source (cm)
reference distance (Vendor B)
Radcal 10X5-1800 IC
Max kerma rate = 160 μGy/s

Source time structure:

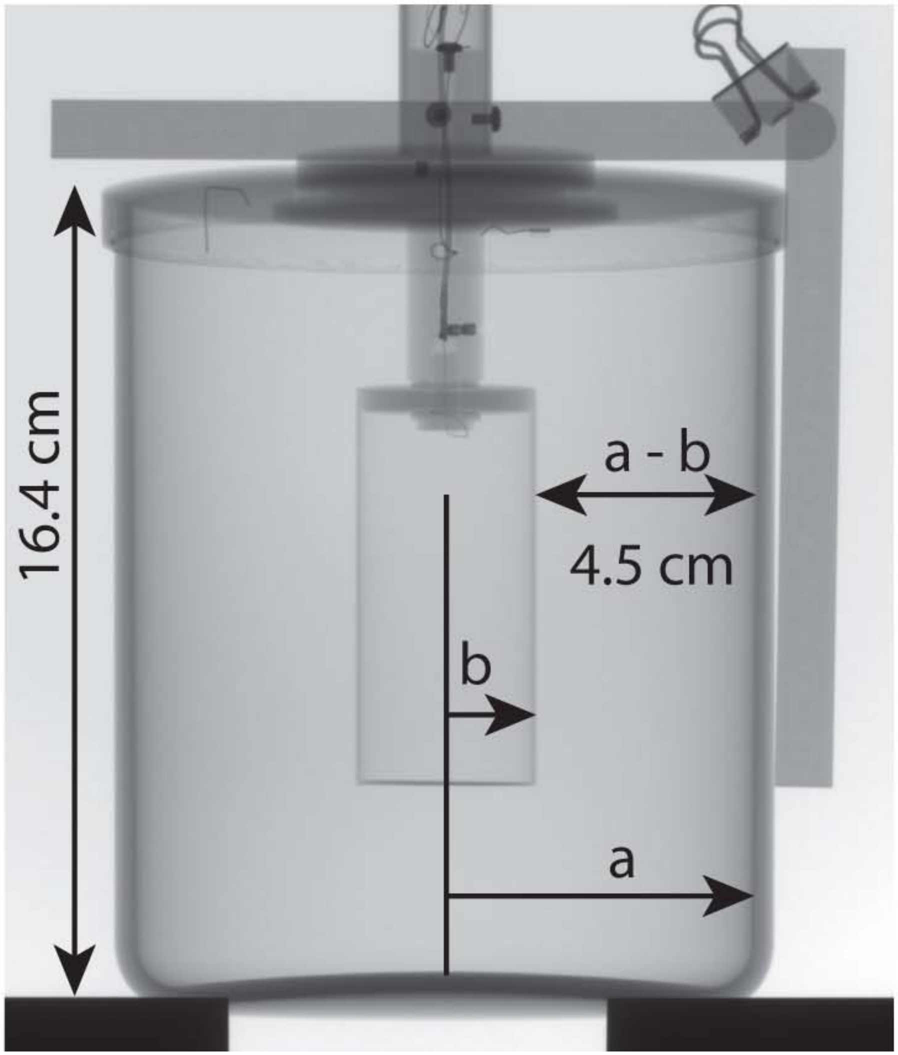


RTI CTDI100 CT Dose Profiler



Recombination: time

X-RAY OF CYLINDRICAL IONIZATION CHAMBER (IC)



The IC sees a pulsed x-ray source with Interpulse Interval ≈ 5.5 ms

T = transit time for positive ions
$= \{(a - b)\ Kcyl\}^2 / V \cdot k$
$= \{(4.5\ \text{cm})(1.05)\}^2 / (300\ \text{V})(1.36\ \text{cm}^2 \text{s}^{-1} \text{V}^{-1})$
≈ 55 ms

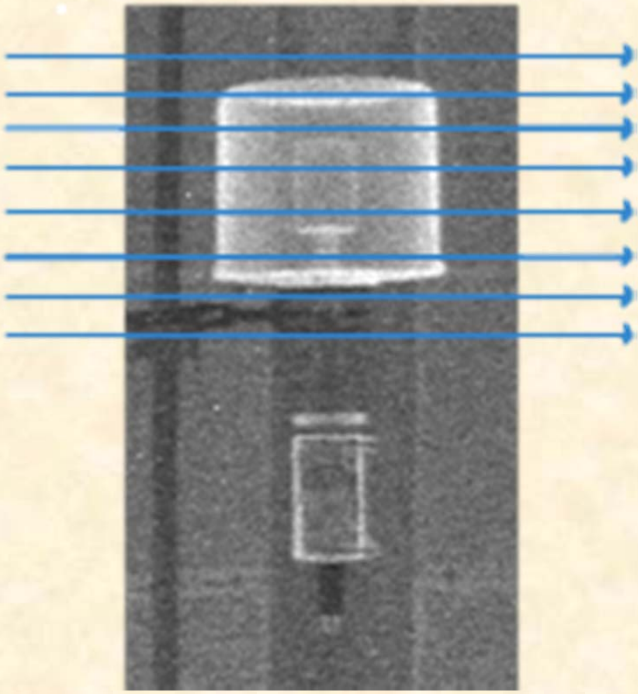
Interpulse interval * T ≈ 10 overlapping ion pulses during most of the scan

In this regime, the electronic recombination is effectively what would be observed with a continous beam with the same mean dose rate

Recombination: spatial

(1) Vendor dose limit is for a fully-illuminated IC

(2) flying spot illuminates < 1% of IC



Finally, *in situ* measurements showed recombination to be immeasurable

Comparison of air kerma measurements from air-filled IC and solid-state detectors

Detector	Average air kerma[1] (front + back scans)[2]
Ionization Chamber	64.2 nGy ± 1 nGy
Solid State Detector	65.6 nGy ± 2 nGy

1) After two calibrations, separated by four months
2) At 1 m height, 30 cm from master source beam-emitting surface

Now, to estimation of doses to persons…

Organ and effective dose estimates

- Spectrum + Air kerma → Dose
- Three methods were used
  - Reference effective dose (ANSI N43.17-2009)
  - PCXMC 2.0 Monte Carlo package
  - ICRP116 tables based on voxel phantom results

ANSI N43.17 ref. eff. dose

- Simple formula (no modelling)
- Based on air kerma at hottest spot
- Some problems
- 13.0 nSv (1.3 µrem)

6.1.3 Determination of the Reference Effective Dose The reference effective dose for Class A full-body scanners shall be determined from measurements of the half-value layer (HVL) and air kerma (or exposure) according to Sections 6.1.3.1 and 6.1.3.2, respectively. One of the equations (1) or (1a) below shall be used.

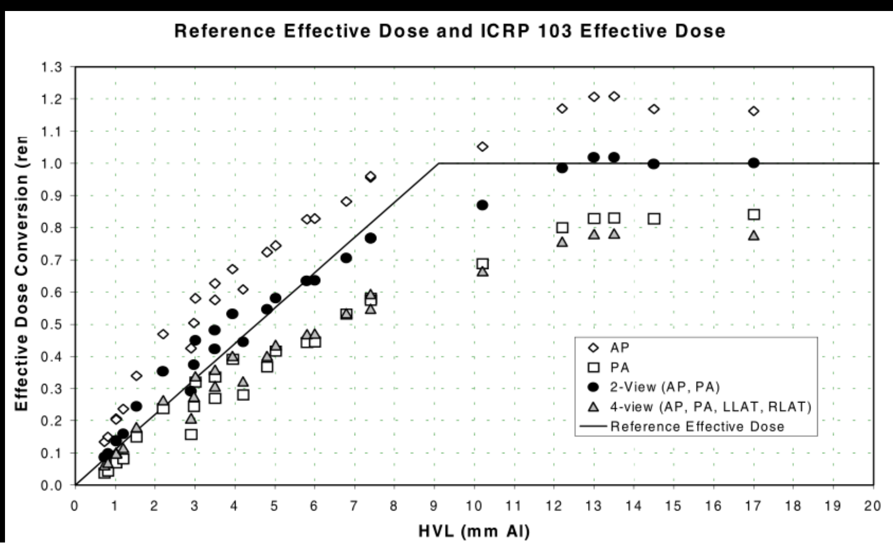
$$E_{REF} = K_a \times C \qquad \text{(eq.1)}$$

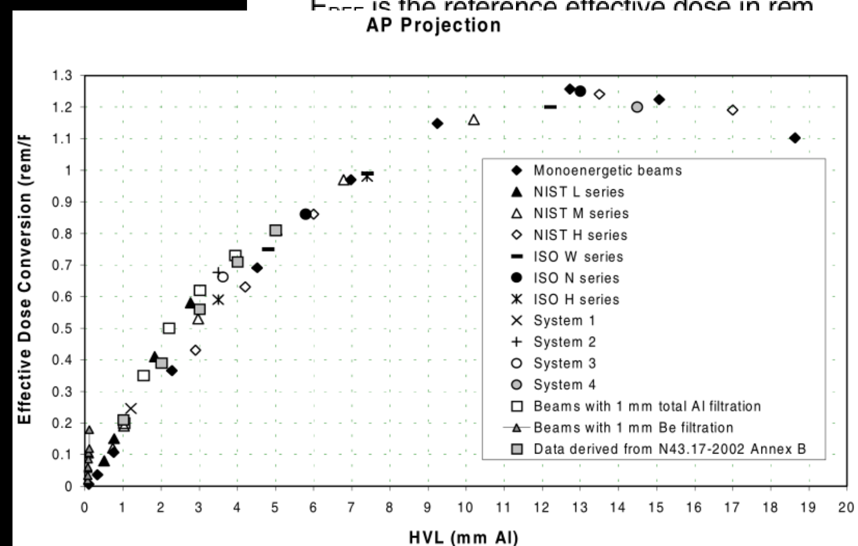
where
E_{REF} is the reference effective dose in Sv,
K_a is the measured air kerma in Gy, and
C in Sv/Gy is given by
$C = 0.125 \times$ HVL in mm of Al or
$C = 1.14$, whichever is smaller.

Or, when using traditional units the equivalent equation is

$$E_{REF} = X \times C_R \qquad \text{(eq. 1a)}$$

where
E_{REF} is the reference effective dose in rem





PCXMC

- Monte Carlo
- Gives organ and effective doses
- age-specific hermaphrodite phantoms of Cristy and Eckerman

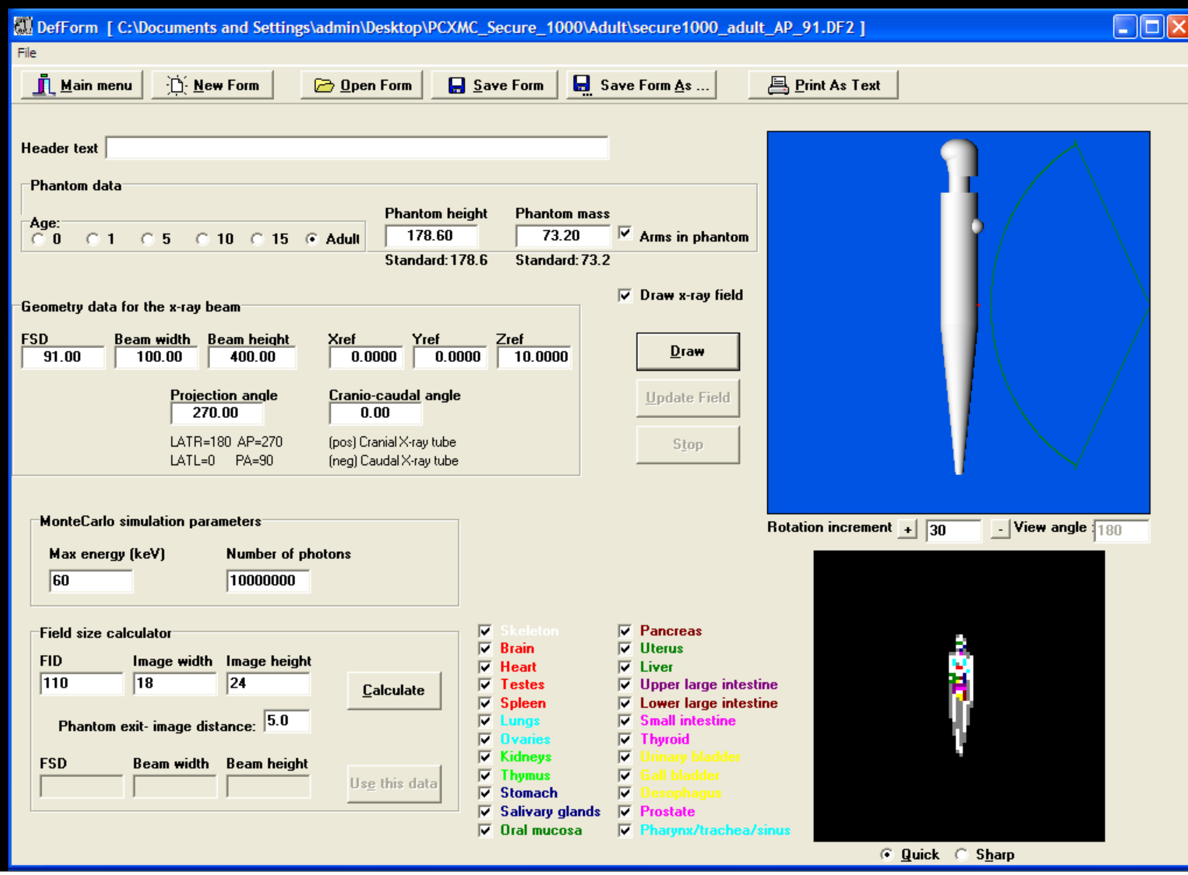


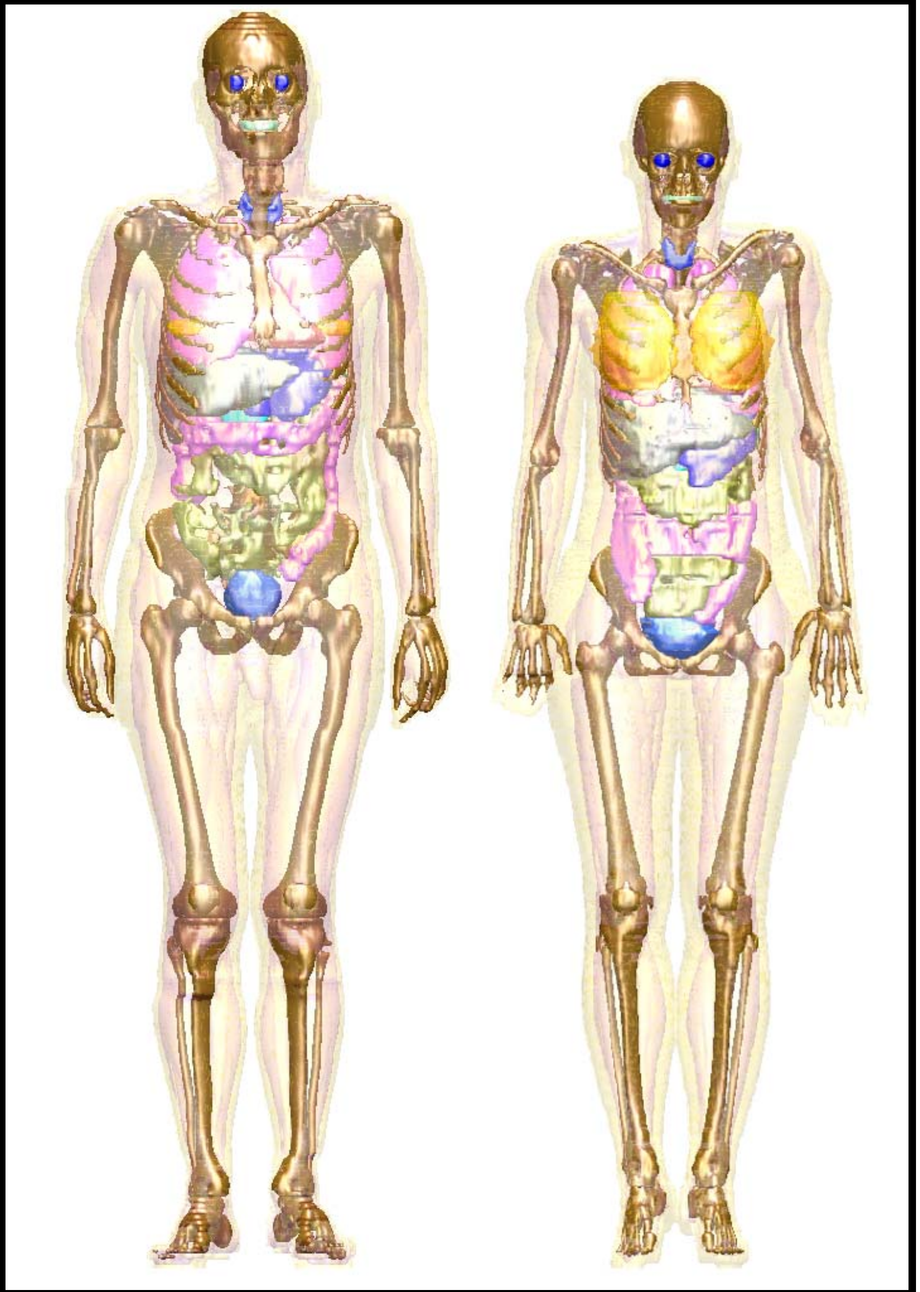
Table 3: Absorbed doses in organs per screening (AP + PA) calculated using PCXMC 2.0 Monte Carlo software

Organ	Adult, 30 cm from front panel of master unit (nGy)	Adult, 10 cm from front panel of master unit (nGy)	Adult, 10 cm from front panel of slave unit (nGy)	Child, age 5, 30 cm from front panel of master unit (nGy)	Infant, 30 cm from front panel of master unit (nGy)
Active bone marrow	8.4	10.4	14.1	12.4	25.6
Adrenals	6.7	6.1	16.2	8.8	15.4
Brain	3.5	4.6	5.3	6.2	16.5
Breasts	31.2	53.4	15.5	49.4	46.3
Colon (Large intestine)	8.2	13.1	6.5	12.3	20.6
(Upper large intestine)	9.2	15.1	6.4	13.4	21.9
(Lower large intestine)	6.9	10.4	6.7	10.8	18.9
Extrathoracic airways	10.5	17.6	6.2	13.3	26.8
Gall bladder	8.9	14.5	6.2	12.9	19.6
Heart	11.3	18.7	7.2	17.1	26.4
Kidneys	10.8	9.0	28.7	14.3	21.1
Liver	11.3	17.2	10.6	16.8	26.3
Lungs	12.5	16.7	17.6	19.6	29.0
Lymph nodes	10.4	16.0	9.5	15.2	24.3
Muscle	17.3	24.2	21.6	22.5	29.8
Oesophagus	3.2	4.4	4.1	6.5	12.8
Oral mucosa	11.5	18.4	8.7	17.1	30.3
Ovaries	5.6	8.5	5.3	9.7	19.0
Pancreas	5.2	7.5	6.0	9.1	16.7
Prostate	9.0	14.5	6.5	12.9	21.2
Salivary glands	16.4	22.2	22.3	21.1	34.2
Skeleton	28.9	38.3	41.5	48.8	76.2
(Skull)	27.5	39.3	32.6	46.7	76.0
(Upper Spine)	16.8	19.7	30.4	27.4	44.7
(Middle Spine)	11.5	10.2	28.8	20.1	36.4
(Lower Spine)	13.7	11.9	34.7	22.0	38.7
(Scapulae)	44.5	35.7	120.5	58.2	74.7
(Clavicles)	47.0	80.2	23.6	71.0	94.6
(Ribs)	71.0	99.2	89.8	87.1	99.2
(Upper arm bones)	28.5	39.9	35.9	43.5	69.6
(Middle arm bones)	33.3	46.5	42.3	48.2	75.3
(Lower arm bones)	40.3	56.2	51.4	56.3	83.0
(Pelvis)	21.1	21.9	45.2	32.1	50.0
(Upper leg bones)	9.8	13.5	12.5	26.6	56.2
(Middle leg bones)	13.6	19.0	17.3	33.6	67.3
(Lower leg bones)	28.1	39.1	35.7	53.8	95.2
Skin	43.7	61.1	54.9	46.6	52.5
Small intestine	7.4	11.6	6.3	11.4	19.2
Spleen	7.5	7.8	16.1	11.4	19.0
Stomach	13.6	22.7	8.1	19.5	26.8
Testicles	34.8	59.6	17.0	47.2	55.4
Thymus	20.2	34.7	9.6	25.9	35.3
Thyroid	21.2	36.3	10.6	32.8	43.8
Urinary bladder	14.5	24.4	8.1	19.3	27.2
Uterus	7.0	11.0	6.0	10.6	18.7
Effective dose ICRP103 (nSv)	14.7 nSv	23.1 nSv	12.3 nSv	21.9 nSv	29.8 nSv

Effective dose
14.7 nSv
(1.5 µrem)

ICRP116

- Voxel phantom based on real CT data (ICRP110)
- Kerma to dose tables
- Calculated using EGSnrc, MCNPX, PHITS, FLUKA and GEANT4
- Irradiation geometry
- 16.0 nSv (1.6 μrem)



Hoppe and Schmidt

- Estimated organ and effective dose from a body scan
- June 2012
- Used measurements made by Johns Hopkins
- MC simulation


CNN Travel

SEARCH

POWERED BY Google

tics Justice Entertainment Tech Health Living Travel Opinion iReport Money Sports

BACKSCATTER

Airport body scanners: Are they safe?

June 11, 2012 | By Mike Ahlers, CNN

Share Twitter Email

Recommend 398 people recommend this. Be the first of your friends.

Radiation from airport body scanners penetrates organs beneath the skin but at low doses that meet national standards, according to a study by Marquette University's Department of Biomedical Engineering.

But the study's author, professor Taly Gilat-Schmidt, said the research does not answer the biggest question on travelers' minds: Are scanners safe? She said more independent research is needed.

A new study of backscatter machines finds they meet national standards for radiation exposure.

The Marquette study subjected government and vendor data to sophisticated computer modeling to estimate the radiation doses travelers receive when they are scanned by backscatter machines, one of two types of imagers used to detect weapons at security checkpoints.

Hoppe and Schmidt, Med. Phys. **39**, 3396 (2012)
Glover and Hudson, Med. Phys. **39**, 5782 (2012)
Hoppe and Schmidt, Med. Phys. **39**, 5785 (2012)

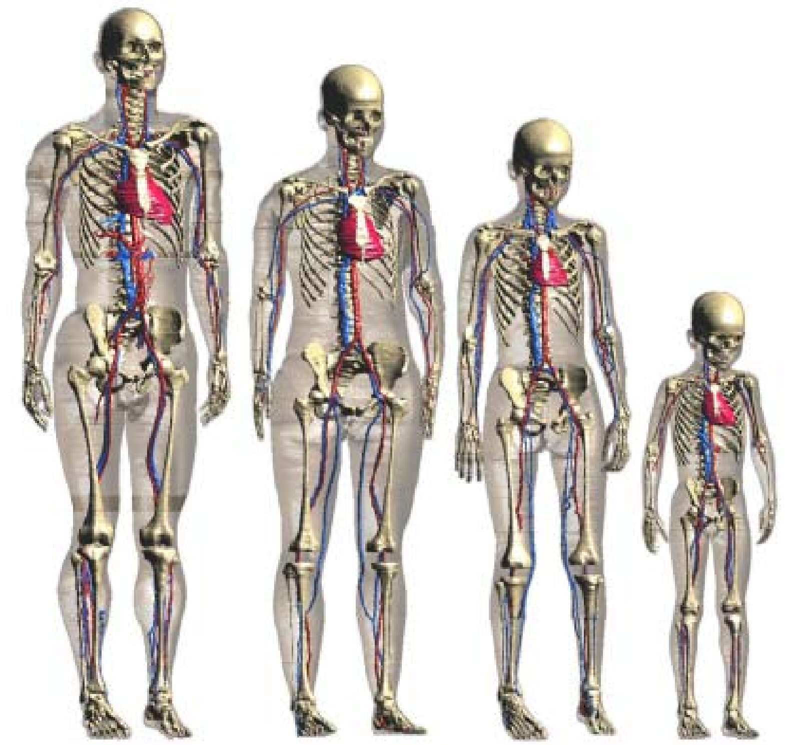


Figure 3. The Virtual Family: Duke, Ella, Billie, Thelonious (from left to right).

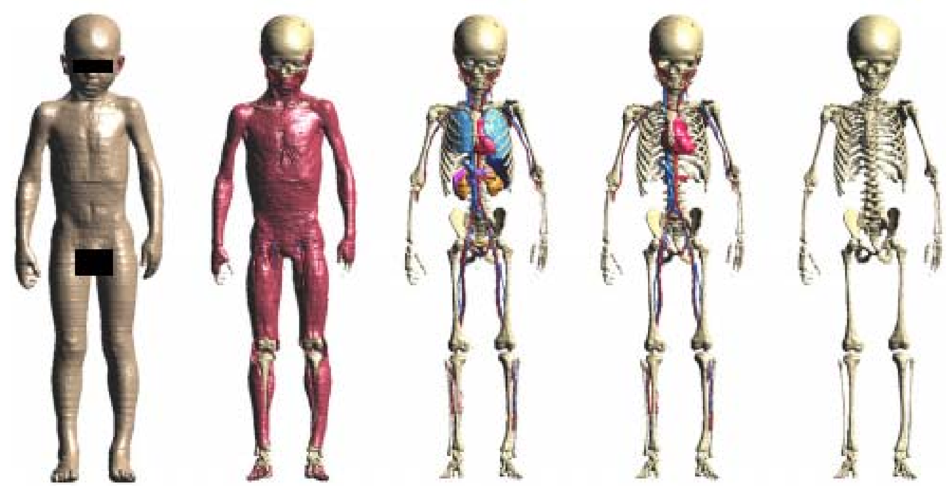


Figure 4. Thelonious: skin, muscle, inner organs, blood vessels, skeleton.

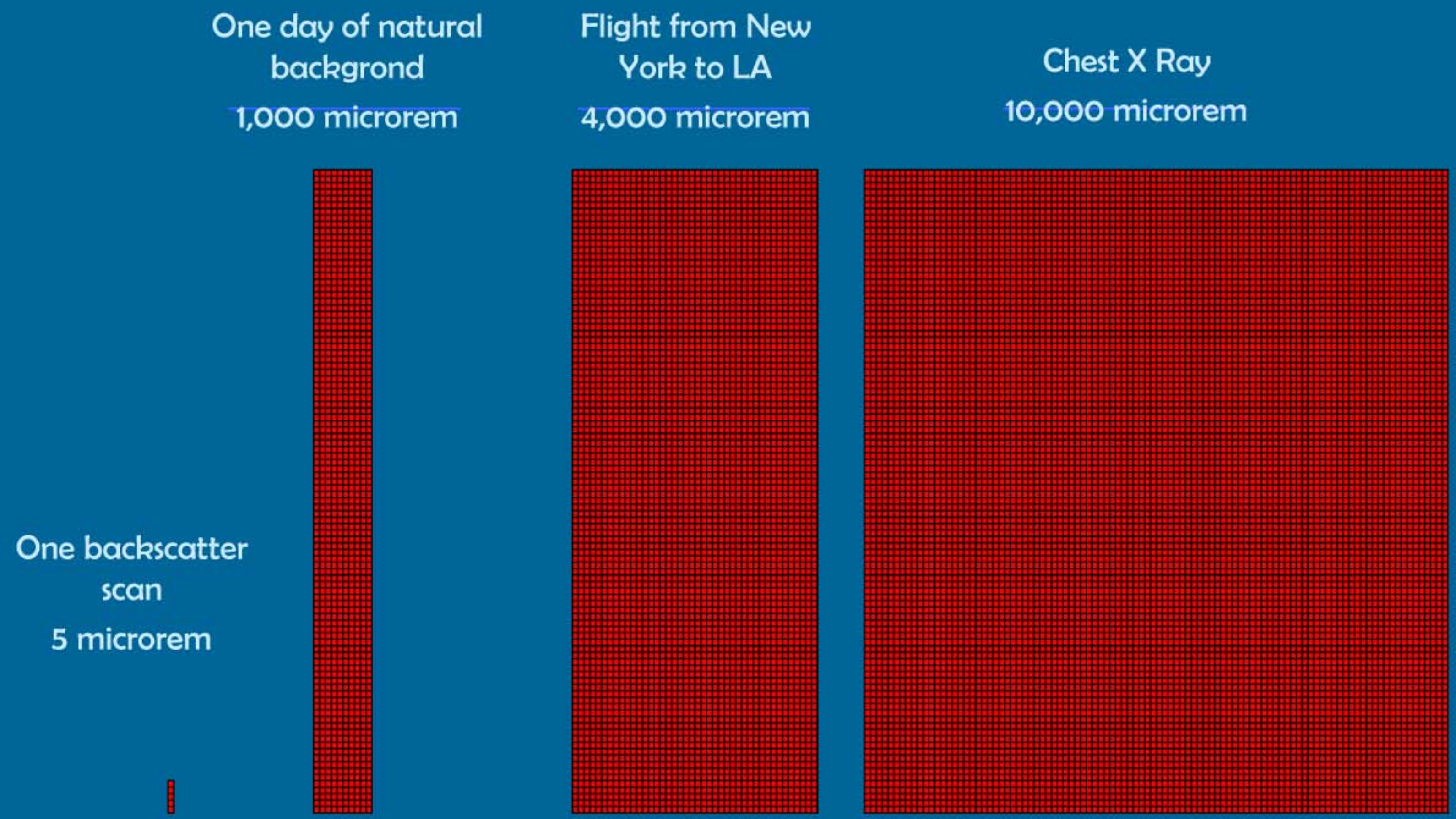
Hoppe and Schmidt

- Used an excellent model of the beam geometry
- After correcting problems with air kerma normalisation and phantom position
- Estimated effective dose
  - Adult male: 14.4 nSv
  - Adult female: 15.9 nSv

Effective dose from Rapiscan Secure 1000 SP ATR

- 13.0 nSv ANSI/HSP N43.17-2009 reference effective dose
- 14.7 nSv PCXMC 2.0
- 16.0 nSv ICRP voxel phantom, ICRP116 conversion coefficients and SRS-78 spectrum generator
- 15.2 nSv Hoppe and Schmidt

Radiation Dose Comparisons (effective dose)



Each tiny box represents 1 microrem

(ANSI N43.17 requires < 25 µrem / scan)


QUESTIONS