FROM BUGS TO BOMBS!

X-Ray Standards for Homeland Security

Larry Hudson

April 27, 2015

NIST involvement began with the anthrax bioterror attack via the US mail: 22 infected, 5 lethal

tasked by OSTP to develop and optimize standard sanitization process & protocols

“suspect” mail from Trenton and Brentwood

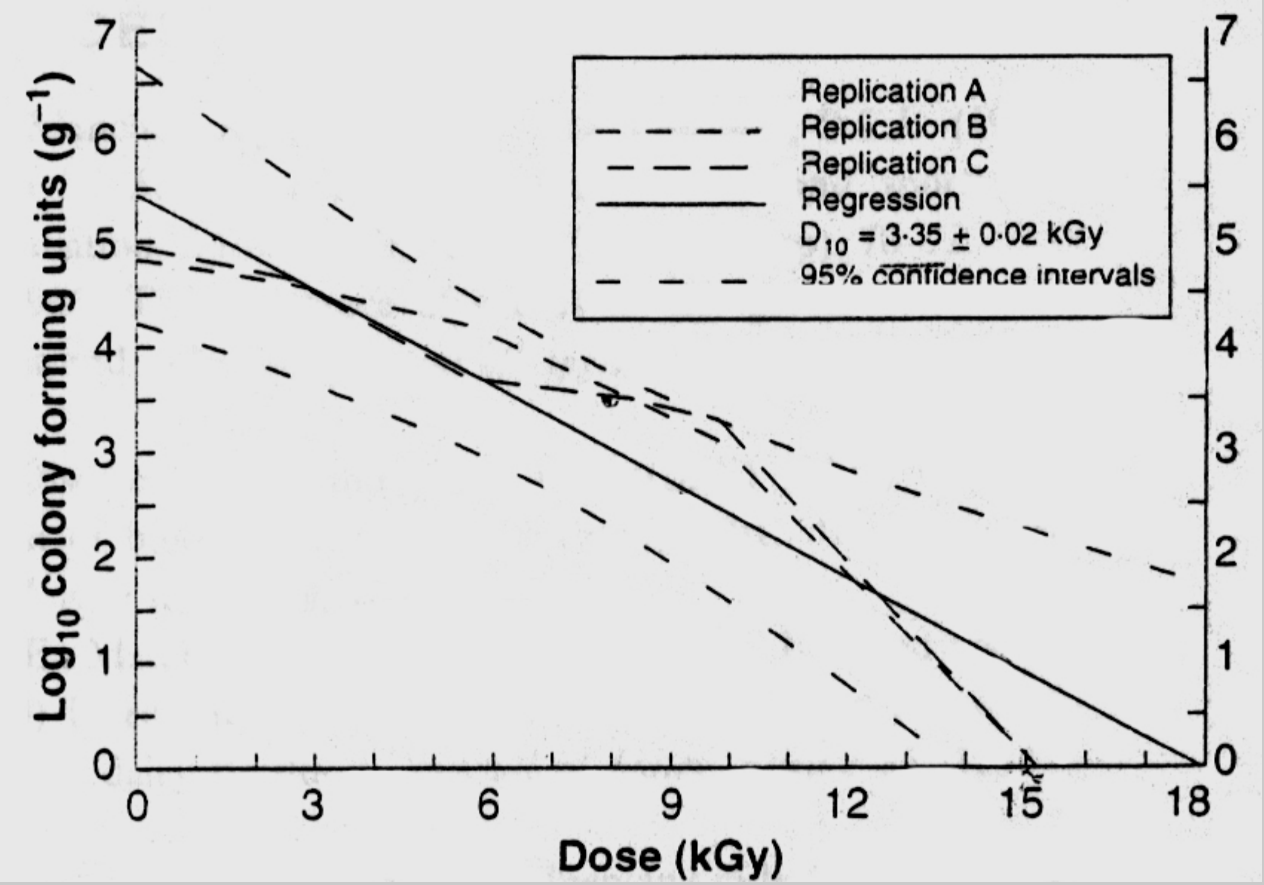
new “Govt” mail

[redacted]

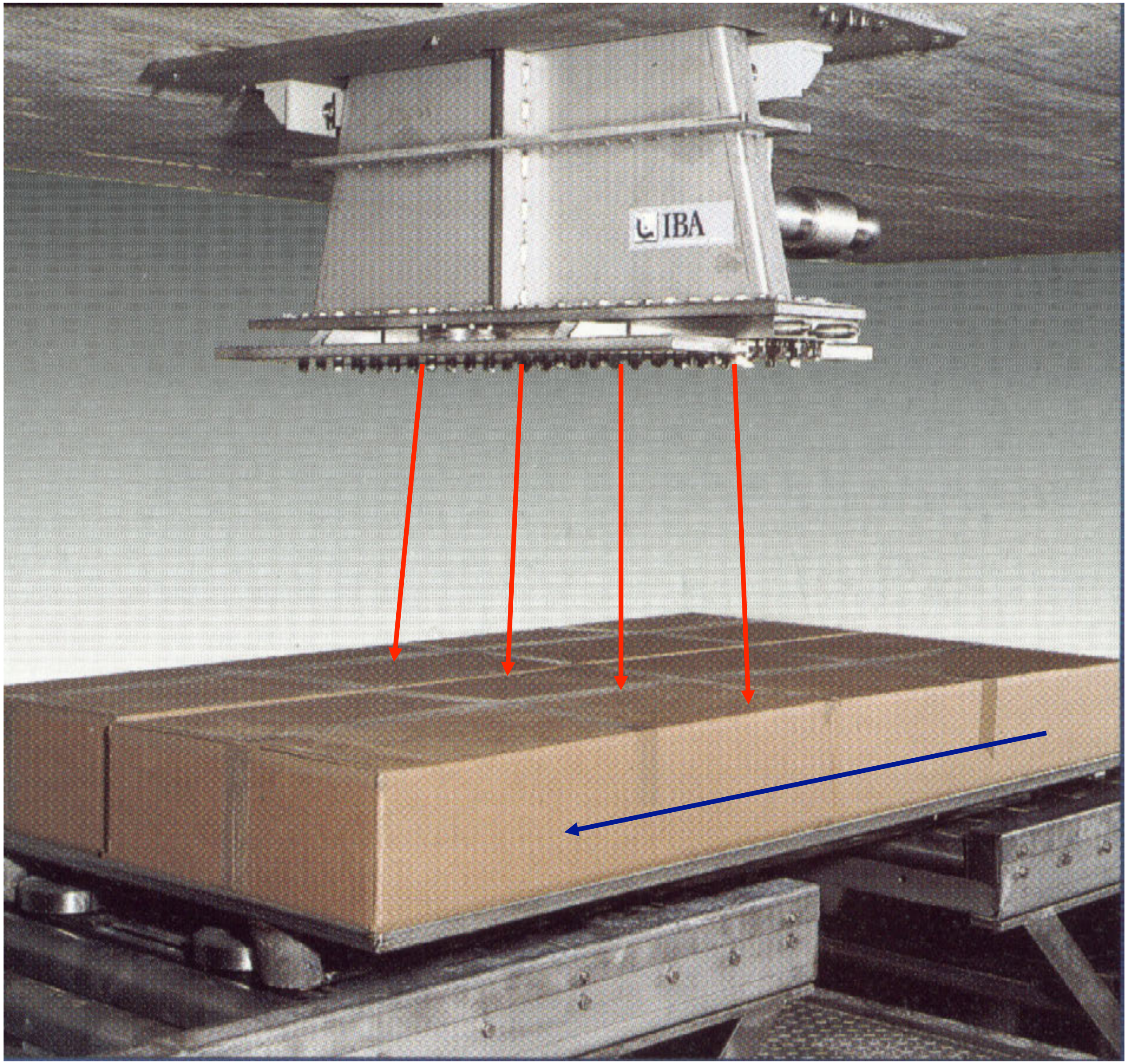
The level of absorbed dose required for sanitization depends upon many factors, many ill defined:

bioburden, kill curve, other pathogens, def. of sanitized (LD50?), immune suppressed, bricks & feathers, dispersal & intake, particle size, time, money, secondary rad effects…

KILL CURVE
Bacillus anthracis strain Sterne,
Iowa State University study, 2003 --->



physicists assume a spherical cow…



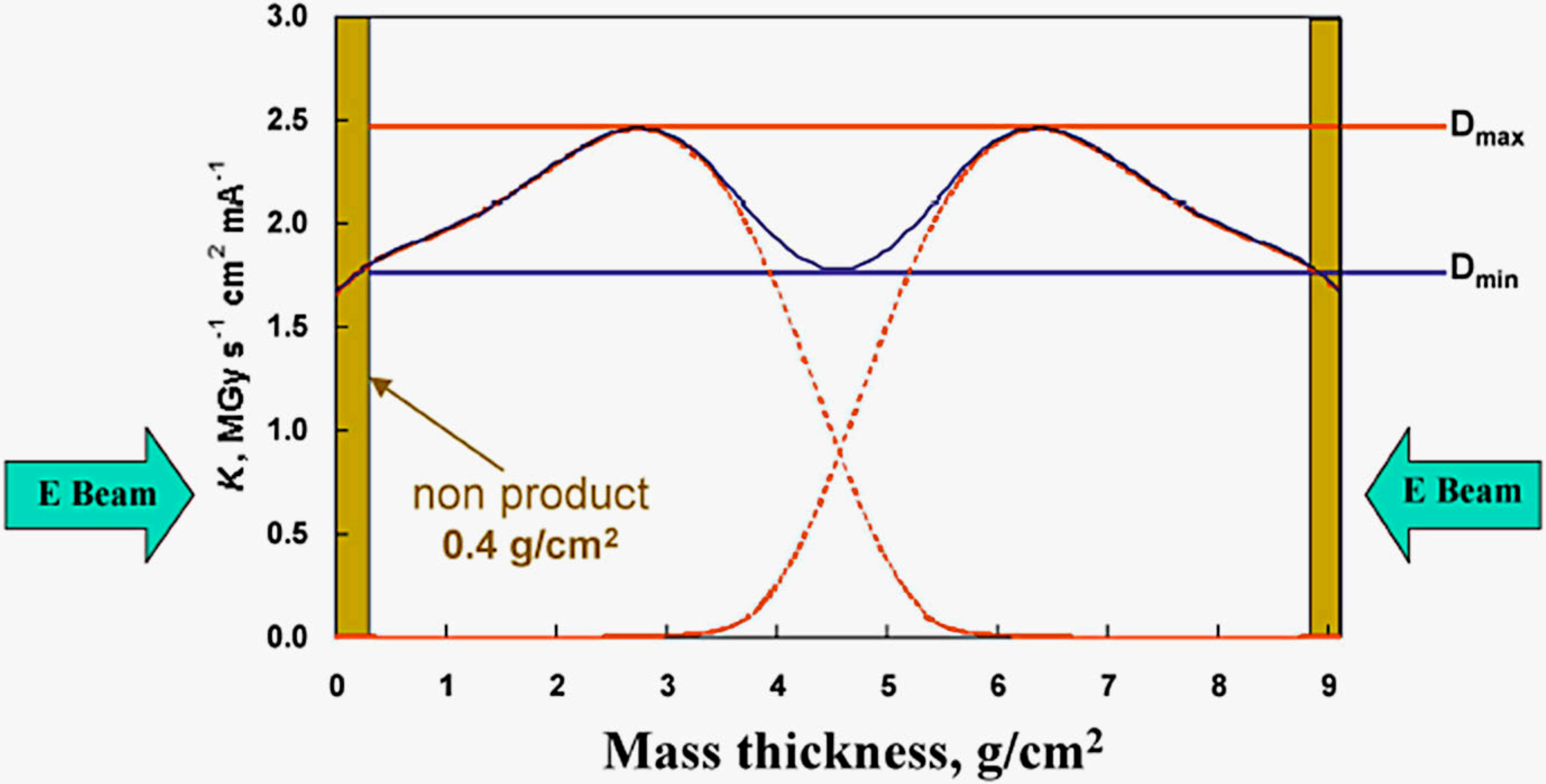
Sterigenics

vertical electron beam for letter mail

in this case, a homogenous medium…

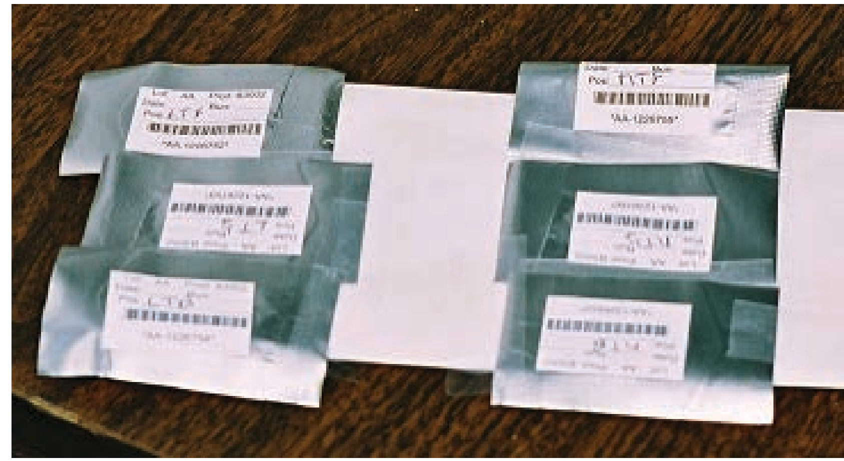
Bridgeport, NJ 10 MV rhodotron accelerator

Two-sided 10 MeV electron irradiation for letter mail

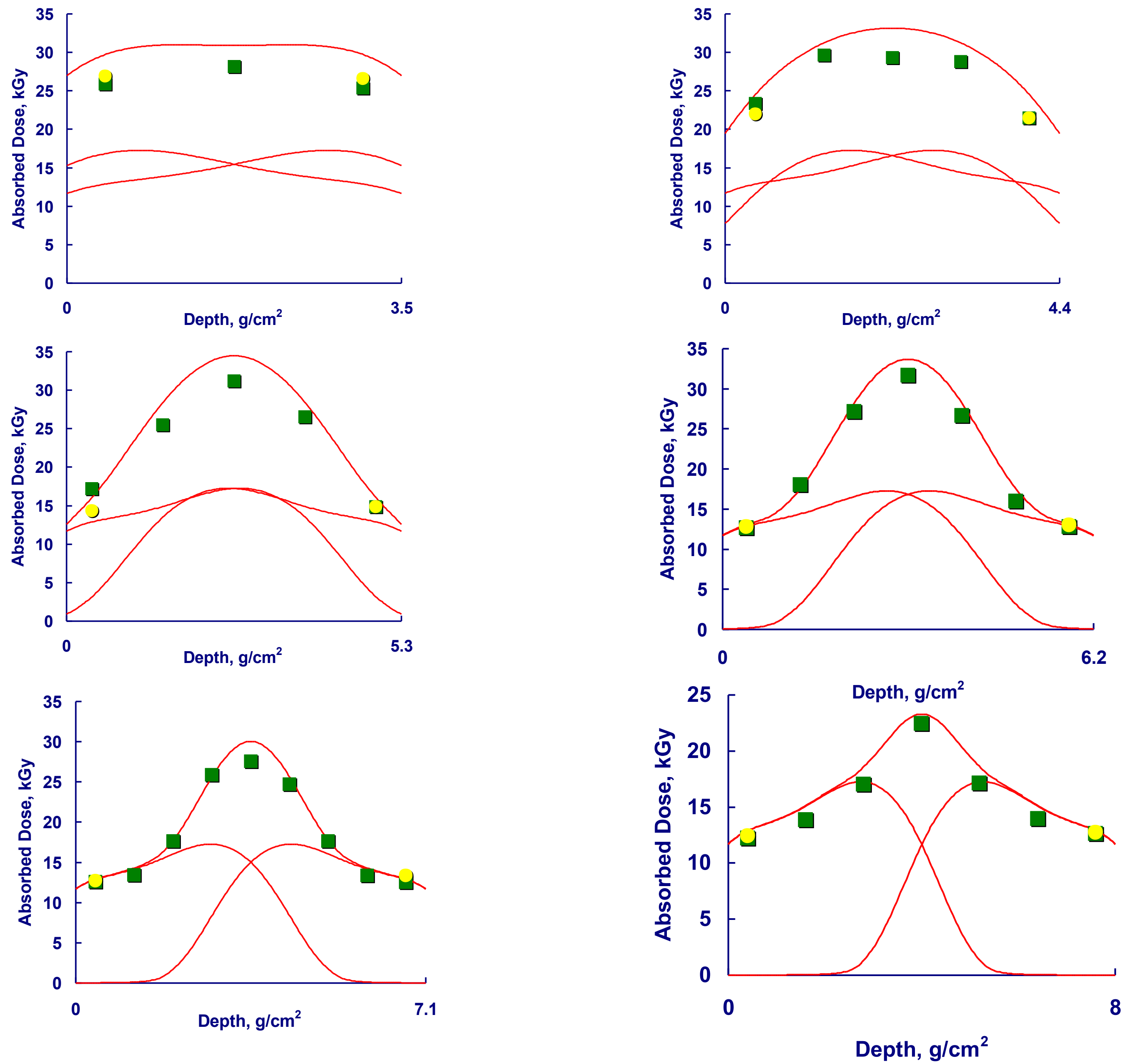


Task: tune product depth and irradiation parameters to achieve the most efficient & uniform dose distribution

Validation Strategy: design and irradiate test mail instrumented with dosimeters and biological indicators, guided by computational dosimetry



calculations verified by measurements



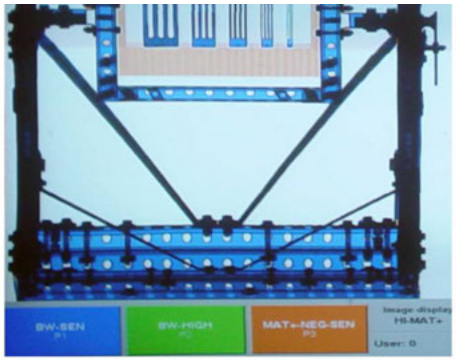
X-RAY

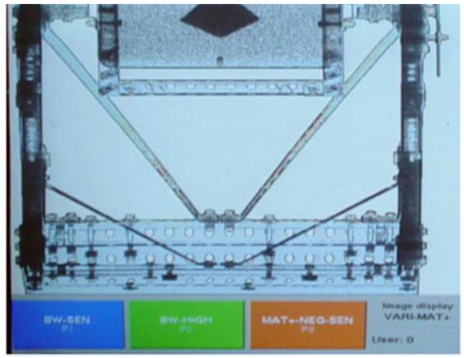
Screening!

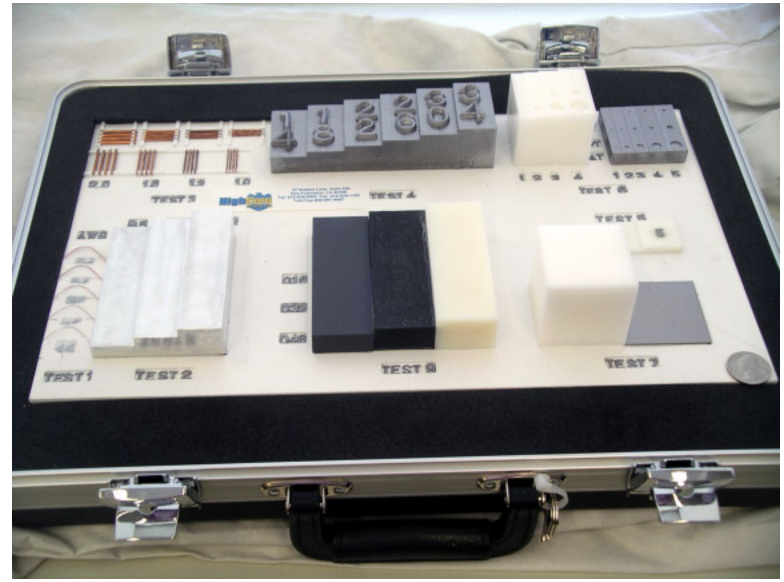
With >10000 IED incidents annually, and global expenditures for aviation and commercial security in the hundreds of billions of dollars, there is a pressing need to develop, apply, and harmonize standards for x-ray and gamma-ray screening systems used to detect explosives and other contraband.

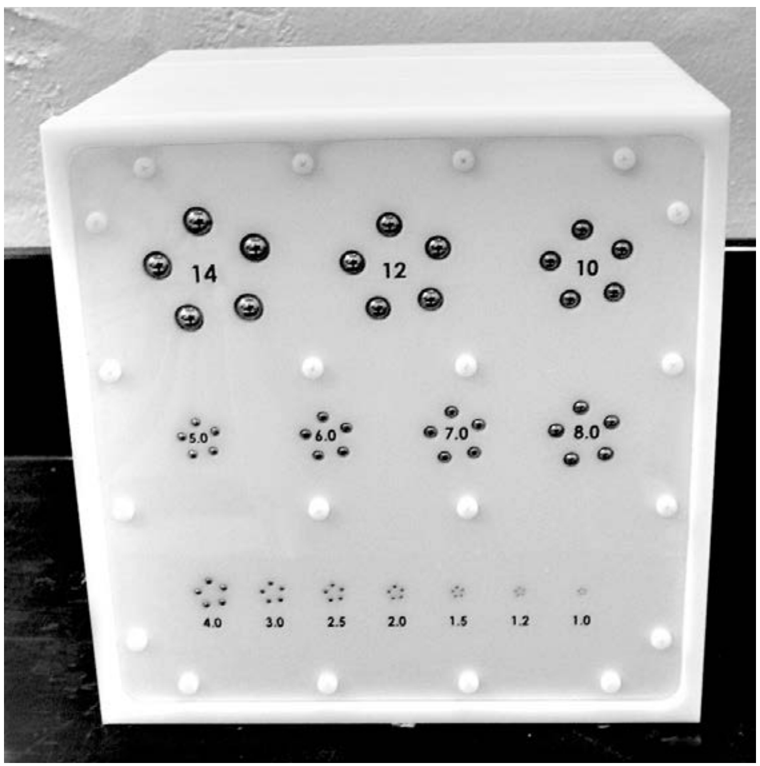
This project morphed into responsibility for national and international *measurement* standards for bulk explosives detection.

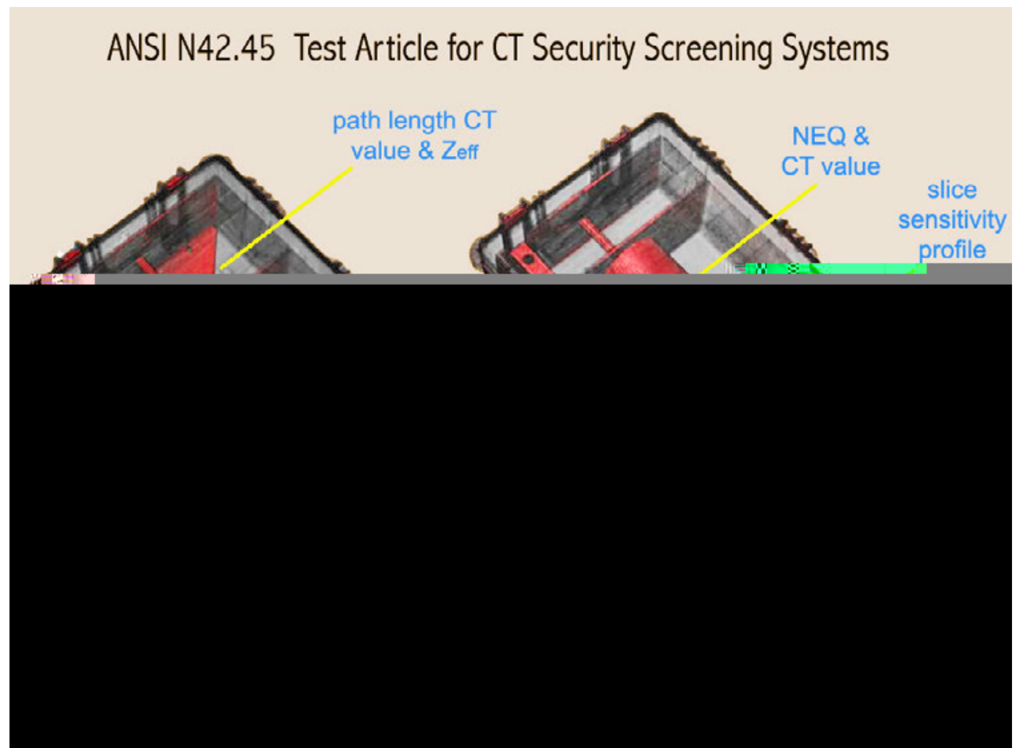
IMAGE QUALITY



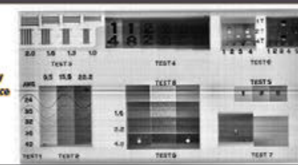
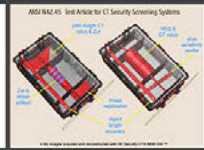
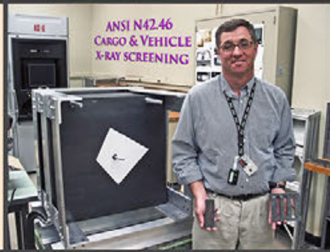
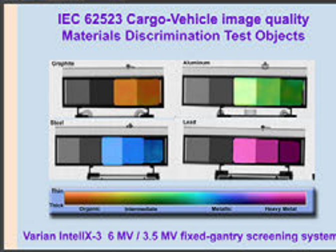
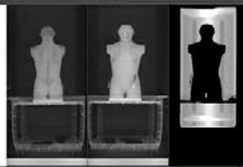
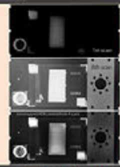
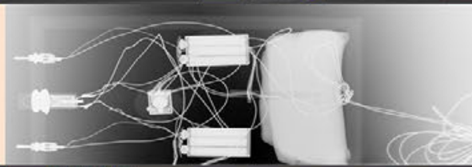








National and International Standards for X-Ray Inspection Systems

Venue	Technical Performance	Radiation Safety
Checkpoint (cabinet x-ray systems)	**IEC 62963** ANSI N42.44 **ASTM F792**   	**ASTM F1039** (21 CFR 1020.40)
CT / EDS (checked luggage)	 **IEC 62945** ANSI N42.45 **IEC 62963** 	**ASTM F1039** (21 CFR 1020.40) 
Cargo / Vehicle (radiographic imaging & active interrogation systems)	 ANSI N42.46 **IEC 62523** ANSI N42.41	  ANSI N43.16 **IEC 62523** ANSI N43.14 (10 CFR 20)
Whole Body Imaging (AIT)	ANSI N42.47 **IEC 62709**  	ANSI/HPS N43.17 **IEC 62463** 
Bomb Squads (portable x-ray sources)	 ANSI N42.55 NIJ 0603.01 	[see list below] 
All Venues	[NEMA DICOS IIC 1 v02] 	 ANSI/HPS N43.3 ANSI/ANS 6.1.1 (29 CFR 1910)

A TRIFURCATION...

Standards for Checkpoint Screening

Human Perception

Quality Assurance

Objective Evaluation

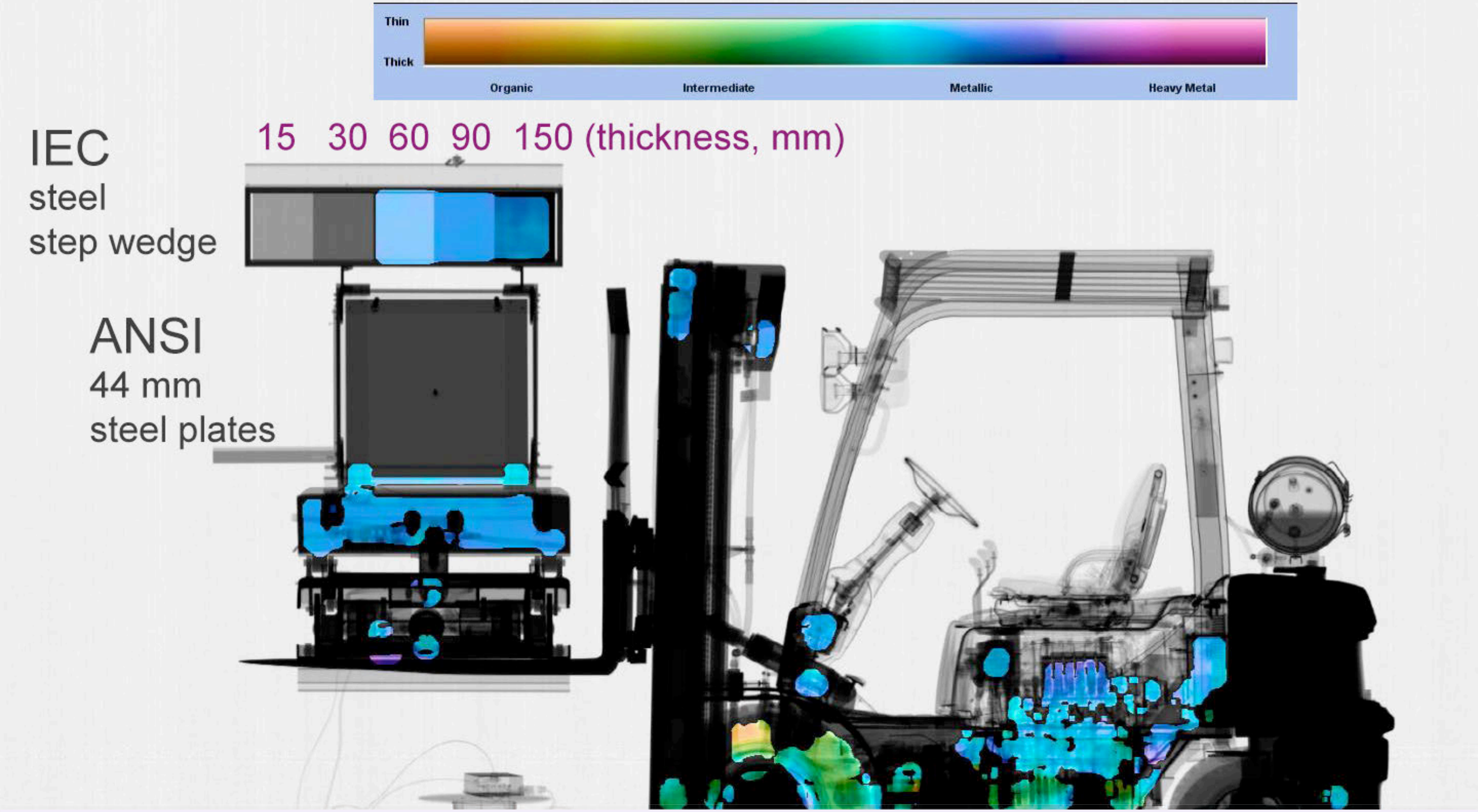
ASTM INTERNATIONAL

Designation: F 792 – 08

Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems

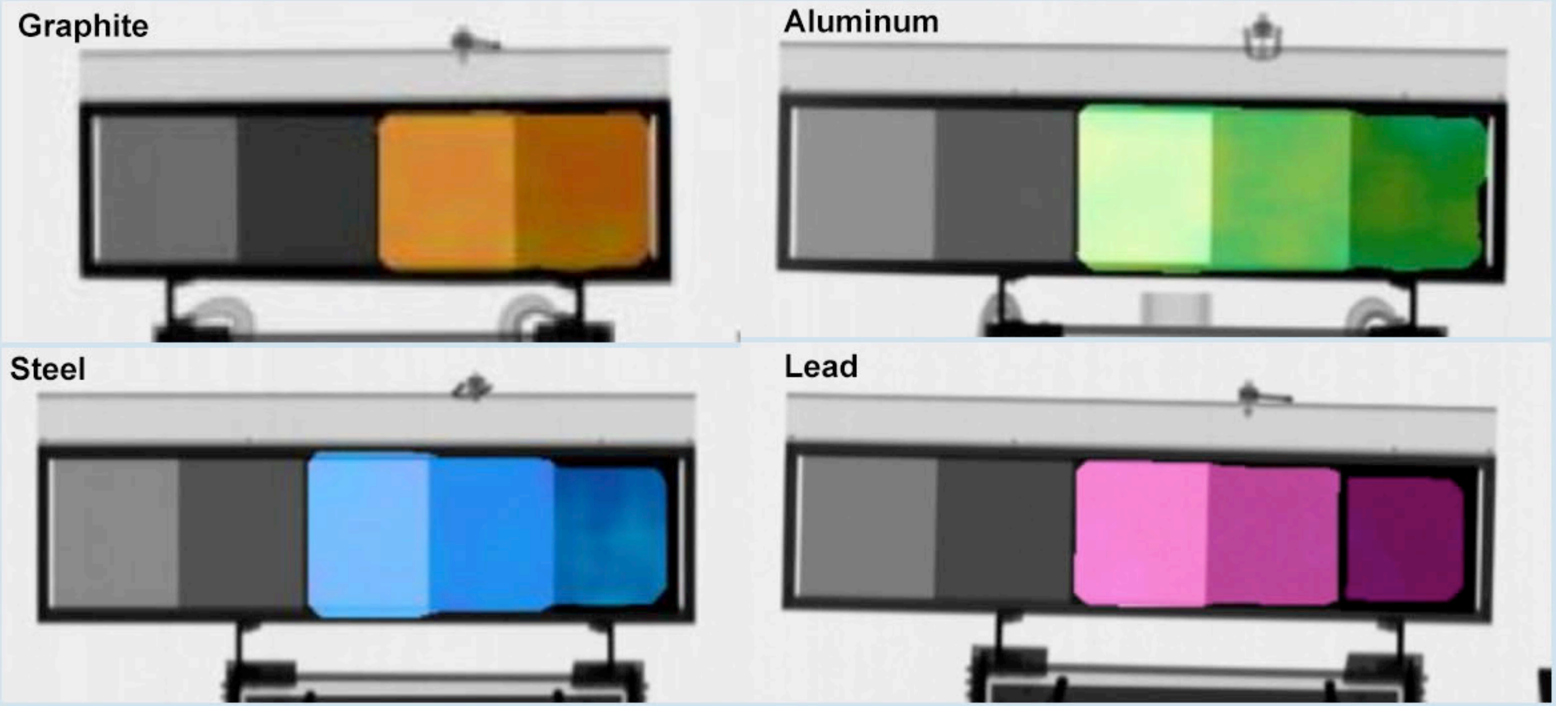
Testing at the new CBP port-of-entry in Tornillo, TX

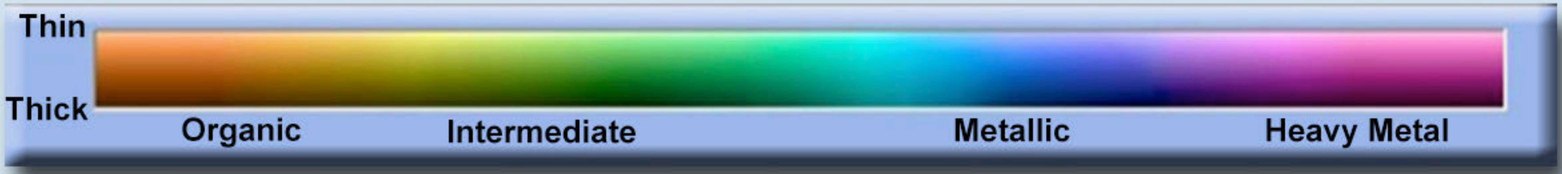
half empty…



…or half full?

IEC 62523-2010 Cargo-Vehicle image quality Materials Discrimination Test Objects





Varian IntellX-3 6 MV / 3.5 MV fixed-gantry screening system

Development of a national protocol for high-E cargo-inspection beams

- Ionization chamber to measure *AIR KERMA* from systems with peak voltages between 6 MV and 10 MeV
- Leakage currents stable < 5 x 10^{-15} A
- Operating voltage is optimized at 300 V
- Chamber response is linear with increasing x-ray fluence
- Charge-collection efficiencies are of the order of 99 %
- Monte Carlo calculations for estimating wall correction (about 8 %); *etc*.
- Testing at both NIST Clinac megavoltage x-ray source and ^{60}Co beams

prototype brass-wall ion chamber to measure high-E beams (cargo)

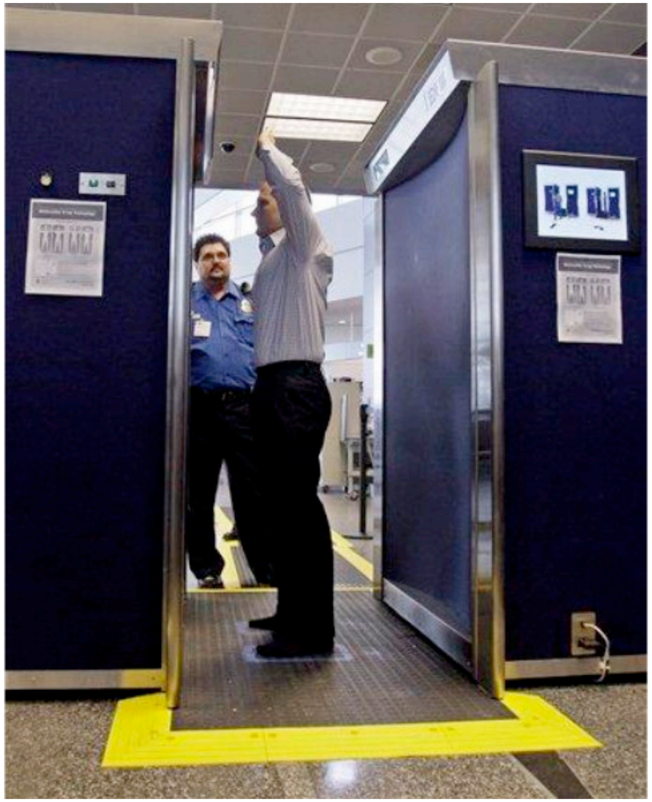
…then, on 12/25/09, someone did what?!

The bomber's syringe detonator was destroyed in the fire

His singed underwear with packet of explosives sewn into it

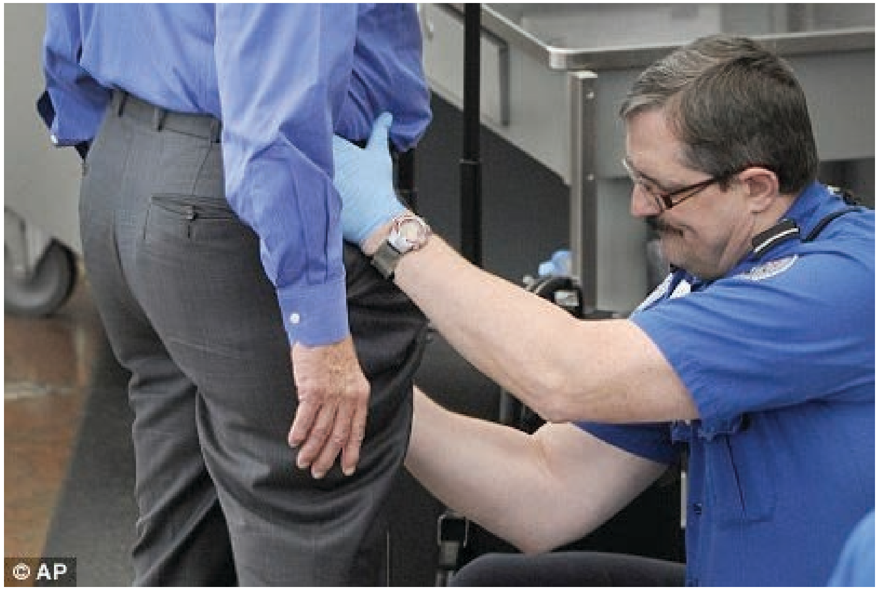
The package of explosive powder that was hidden in his clothes

NIST



what does one do?

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



X-RAY BACKSCATTER NOT TO BE CONFUSED WITH MM-WAVE BODYSCANNING

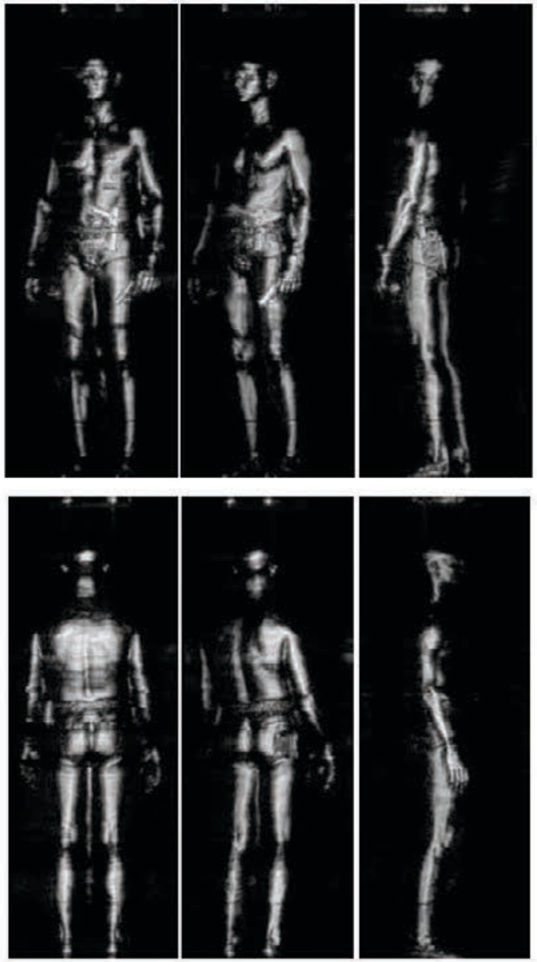
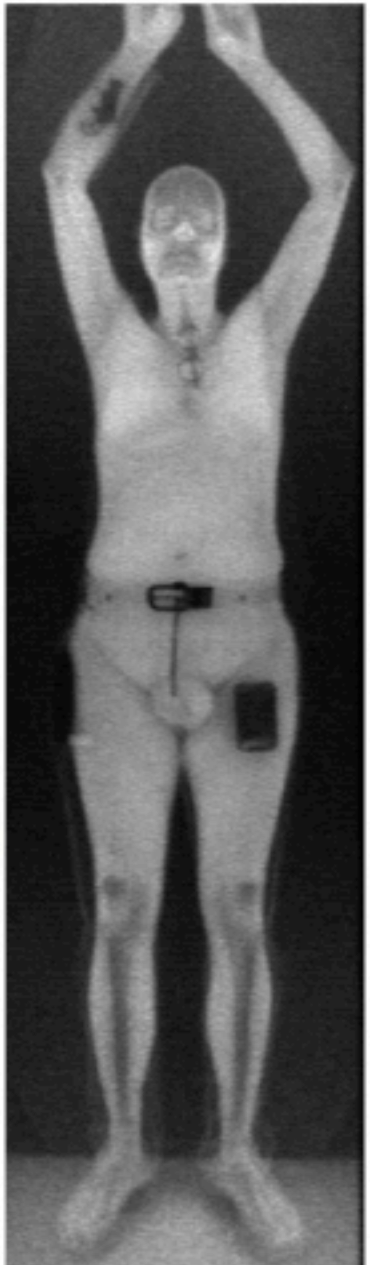


Figure 4 Wideband (27 - 33 GHz) images of a man carrying two concealed handguns along with several innocuous items.

x-ray backscatter is used to screen



Tek84

Engineering Group

Rapiscan

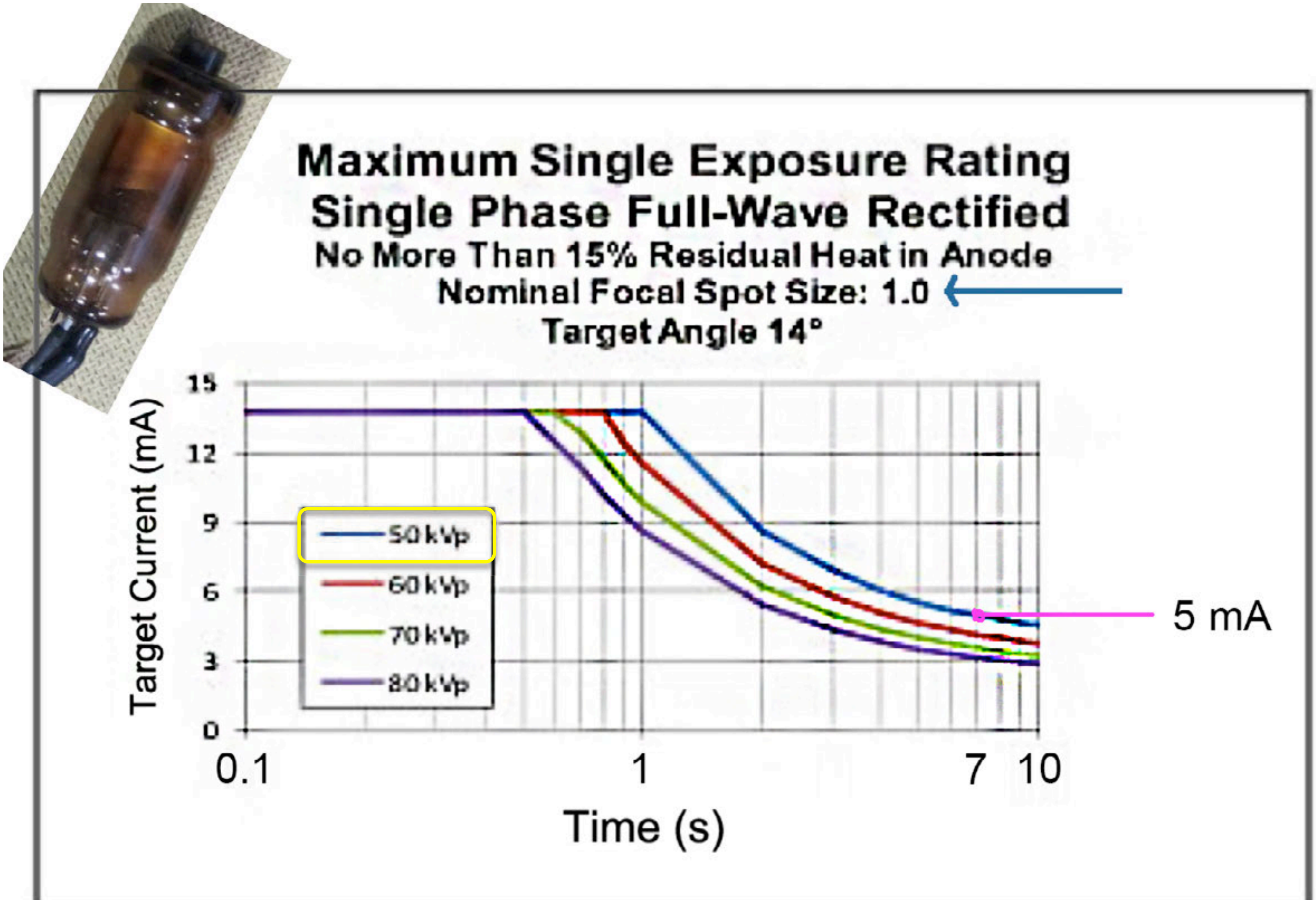
systems

ANSI N42.47

IEC 62709

image quality test objects

HOW DOES XRB WORK?
start with a conventional x-ray tube



pencil beam
(apertured,
not focused)

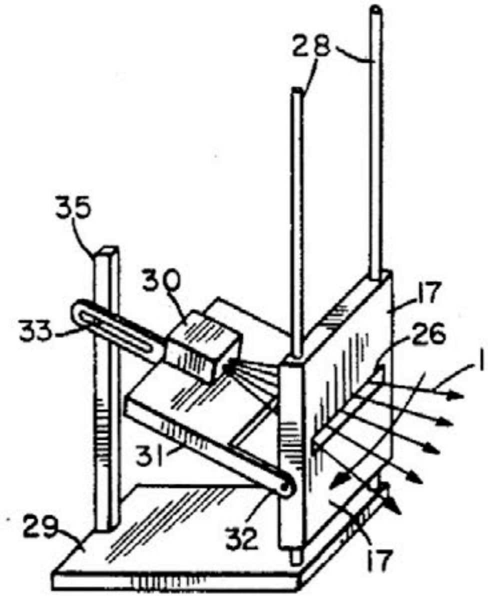


FIG. 5a

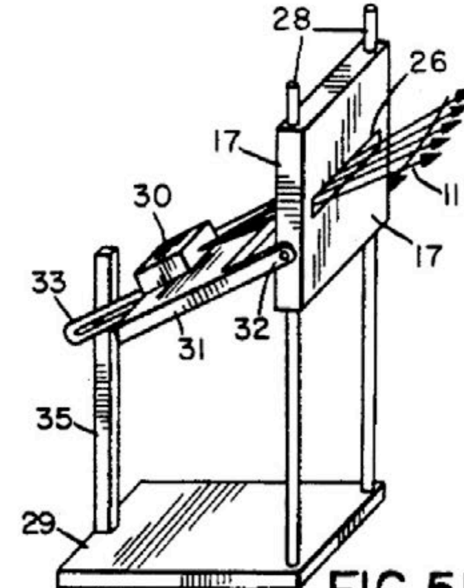


FIG. 5b

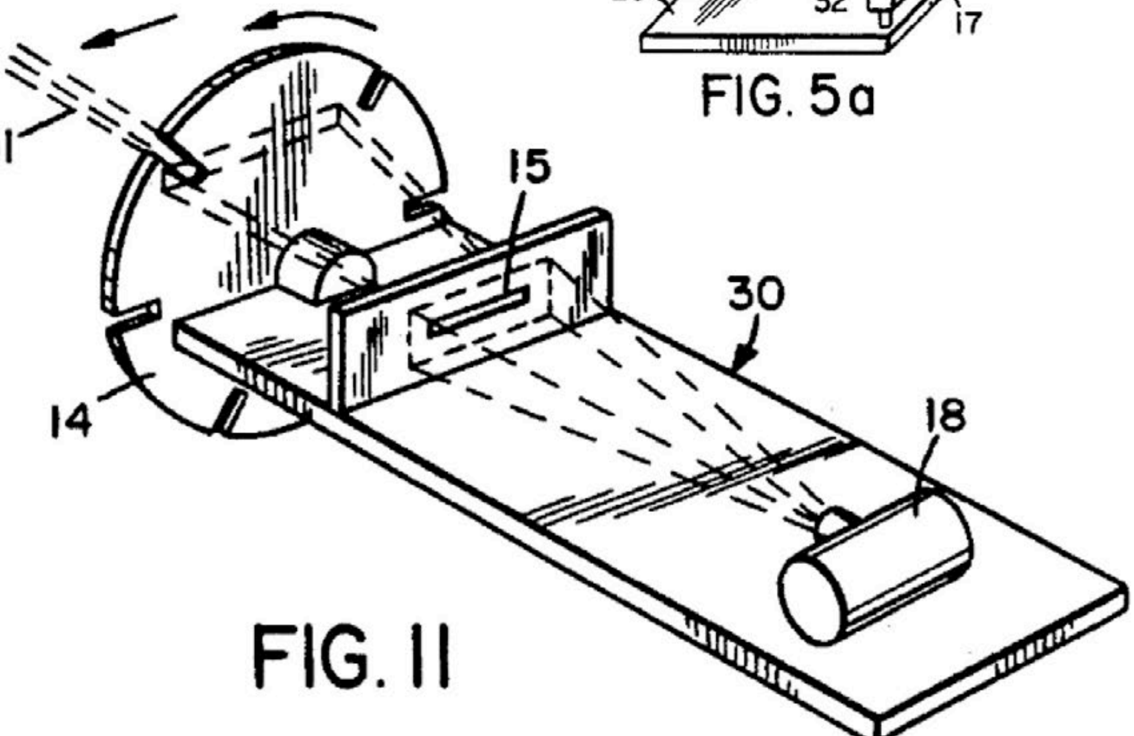


FIG. 11

+ wide-
angle
detectors

p.42, Annex 1
(typical operating parameters)

European Commission

Scientific Committee on Emerging and Newly Identified Health Risks

SCENIHR

Health effects of security scanners for passenger screening (based on X-ray technology)

SCENIHR approved this opinion by written procedure on 26 April 2012

X-ray spectrum:	Tungsten target, 20° anode angle, filtration 1 mm Al equivalent, 50 kV potential
Focal spot size:	1 mm
Tube current:	5 mA
Geometry:	- Centre of inspection area 877 mm from focal spot - beam size at 877 mm: 5.5 mm x 5.5 mm - width of horizontal sweep: 1000 mm - X-ray beam horizontal sweep: 5.45 ms - field moving up 4.82 mm during each horizontal sweep - each location (at one sweep) exposed approximately 35 μs - total scan height: 2.3 m

Front scan followed by back scan at same conditions

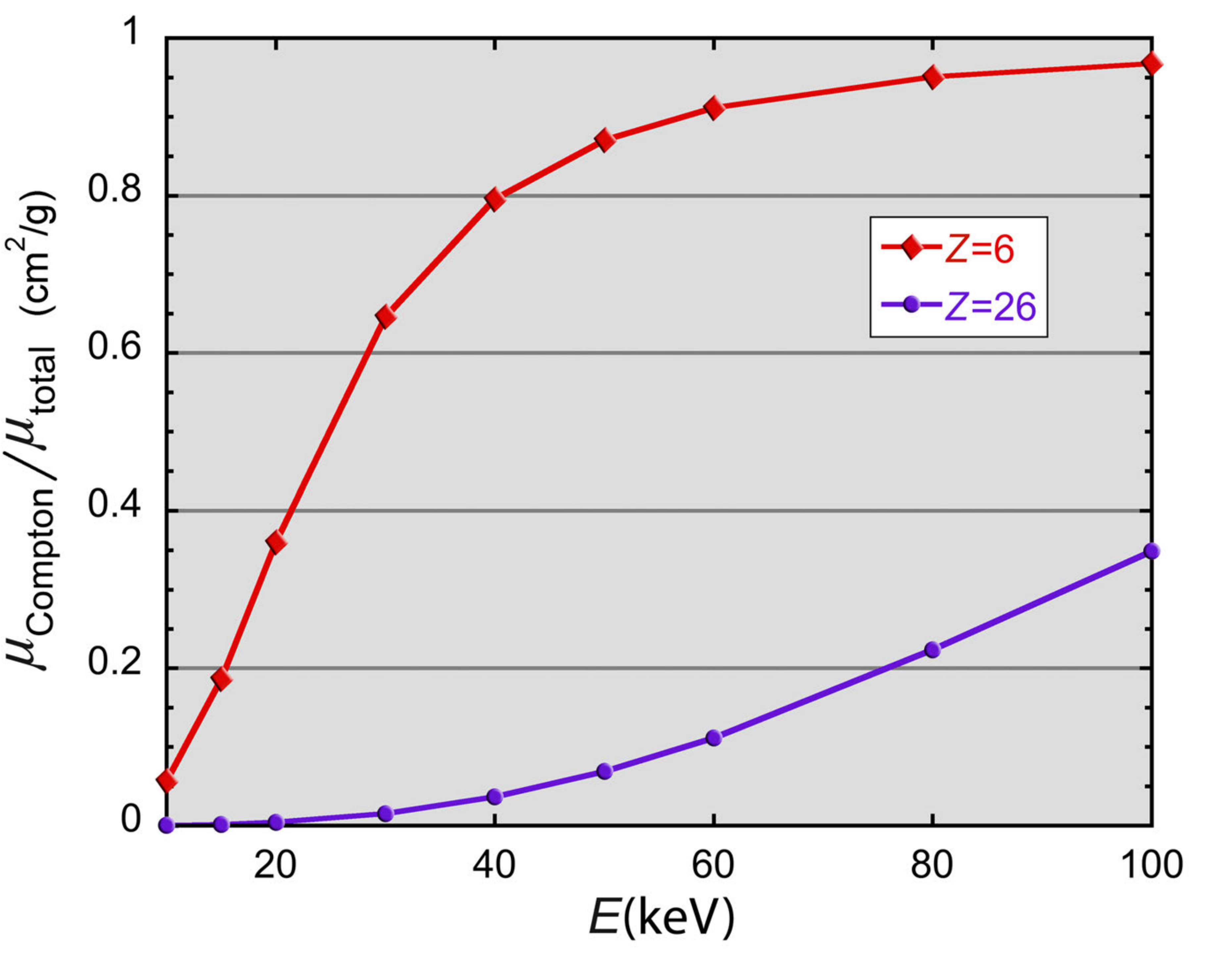
Duration of each scan: 2.6 s

[radiographic exposure = 175 nA·s]

Components of a single-pose system

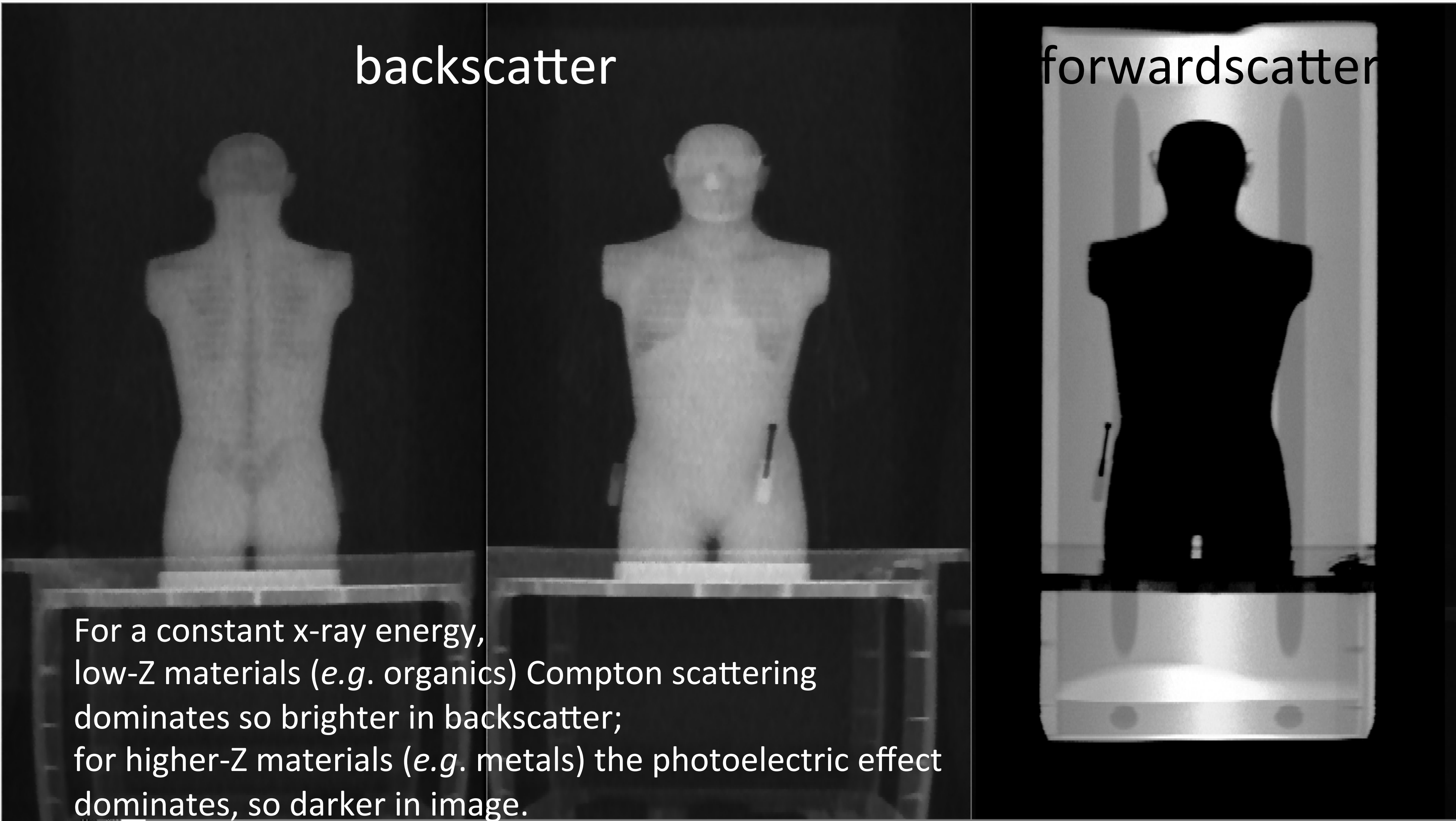
(vendor B)

(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.



1
0.8
0.6
0.4
0.2
0
20
40
60
80
100
$\mu_{Compton}/\mu_{total}$ (cm^2/g)
E(keV)
Z=6
Z=26

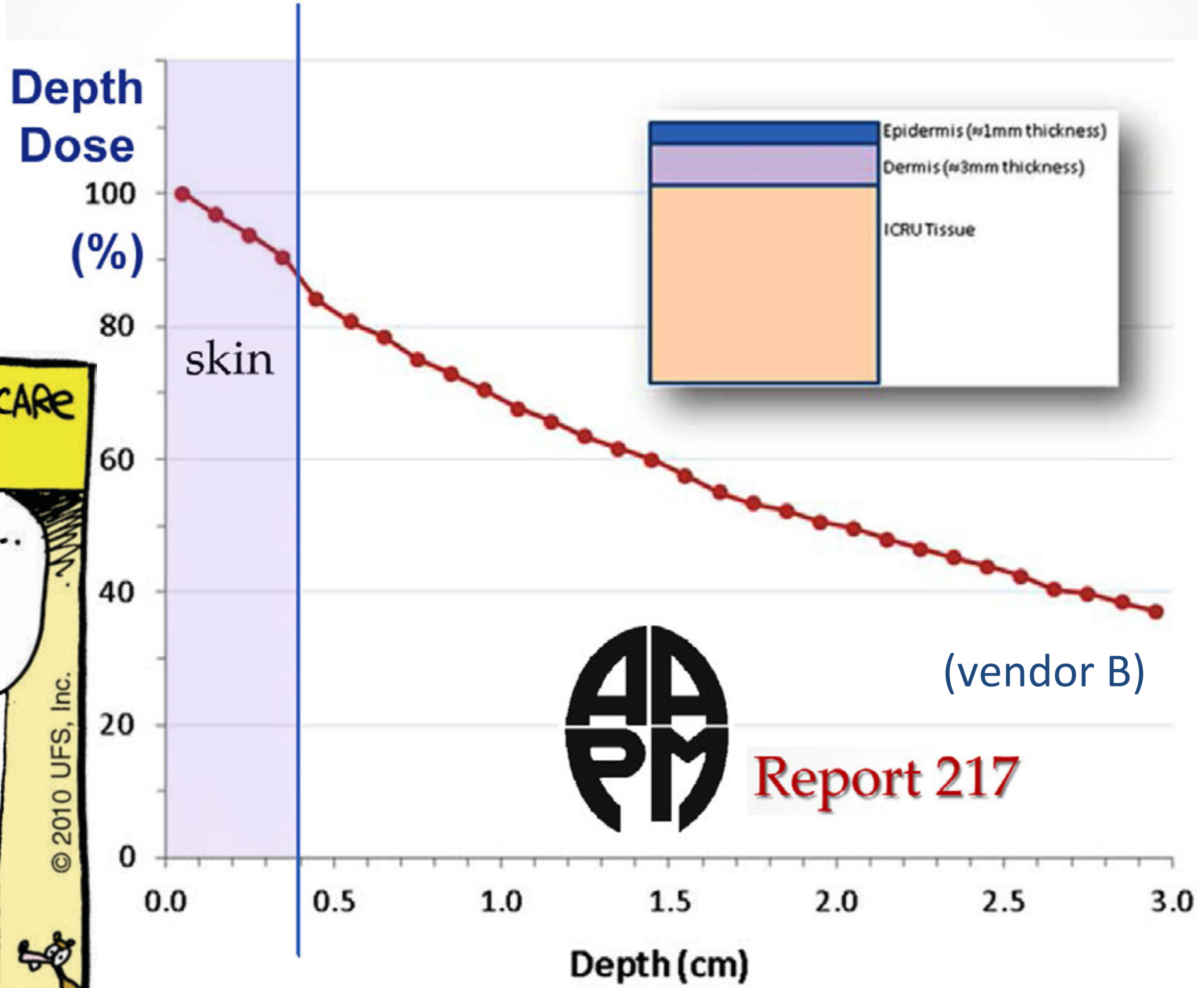
the basic physics & imaging modalities



For a constant x-ray energy,
low-Z materials (*e.g*. organics) Compton scattering dominates so brighter in backscatter;
for higher-Z materials (*e.g*. metals) the photoelectric effect dominates, so darker in image.
[Edge effects also aid in threat detection.]

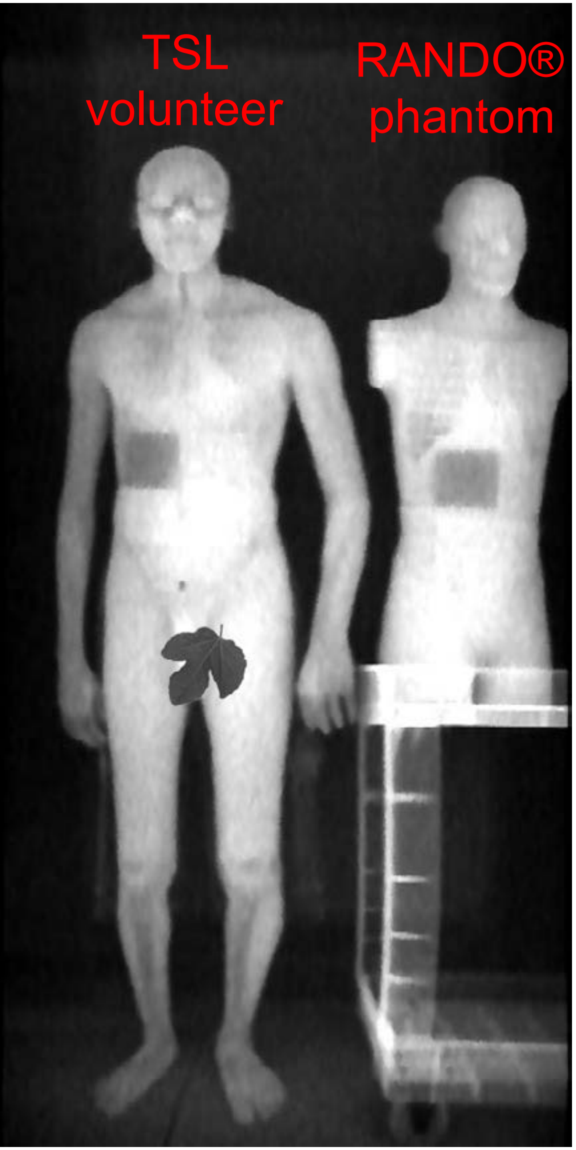
x-ray whole-body imaging...

Monte Carlo Depth Dose data



... is whole-body irradiation

How does one measure a flying spot of x rays?



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Journal of Research of the National Institute of Standards and Technology

The Metrology of a Rastered Spot of X Rays used in Security Screening

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Gaithersburg, MD 20899

In recent times, ionizing radiation has been used around the world to screen persons for non-medical purposes, namely to detect bulk explosives or other contraband hidden on the body including materials not registered by metal detectors. In contrast to conventional transmission or projection imaging, backscatter and forward-scatter systems employ a "flying spot" of x rays and large-area detectors. A small spot is rastered across an individual and the Compton scatter signal collected by these detectors is quickly integrated and assigned to a pixel value in an image corresponding to the transient location of the small flying spot. These systems have been controversial due in part to possible radiation health risks, and lack of independent and accurate measurements of radiation exposures to the subjects, bystanders, and operators of such systems. In this paper we will outline the techniques and instrumentation used at the National Institute of Standards and Technology (NIST) to accurately determine the incident air kerma from a swept beam of x rays. We discuss in detail the response of a large-area free-air ionization chamber under the unusual temporal and spatial radiation fields delivered by commercial scanning systems and report typical values for air kerma levels as well as estimates of air kerma rates.

Key words: advanced imaging technology; air kerma; air kerma rate; backscatter; dosimetry; ionization chamber; rastered beam; security screening; swept beam; x rays.

Guidance for security screening of persons

Guidance	Standards	Reports
Radiation Safety for Personnel Security Screening Systems	ANSI/HPS N43.17 – 2009 **IEC 62463 – 2010**	NCRP Commentary 16

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

- defines 'reference effective dose' E_{ref} (air kerma, HVL)
- requires E_{ref} < 250 nSv/screening, and recommends:
- large-volume (sensitivity) air-filled ionization chamber (IC)
- low-E spectra → thin walls → not pressurized → T&P correction
- absolutely calibrated, fully illuminated, & traceable to national standard beam qualities (Z, kVp, filtration)
- when used with flying spot, IC operated in integrating (not rate) mode, painting entire volume

Calibration / Traceability

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

(a) Radcal 10X5-1800, cylindrical IC

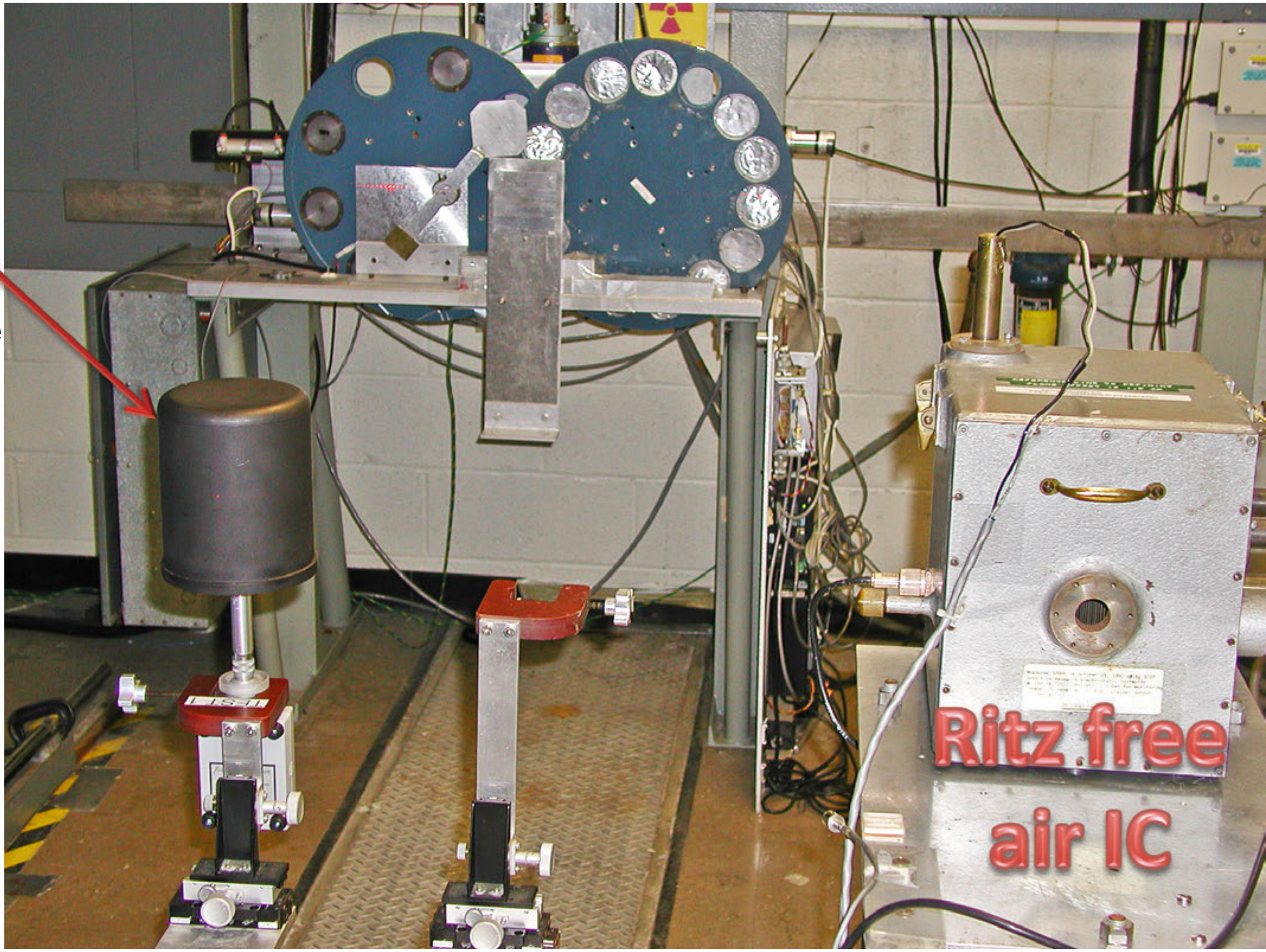
&

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

Also used:

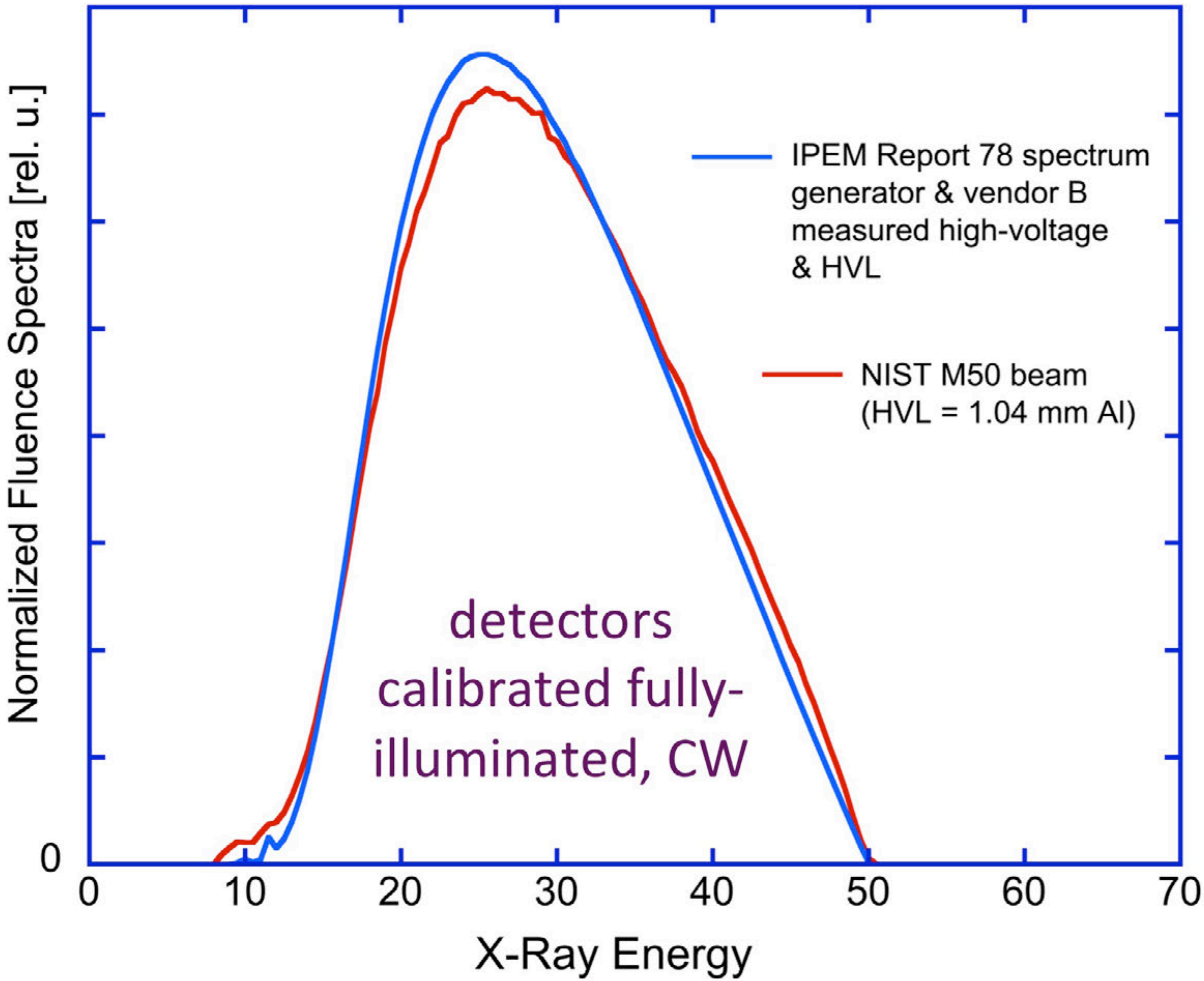
- RTI CTDI100 CT Dose Profiler used for time structure investigation

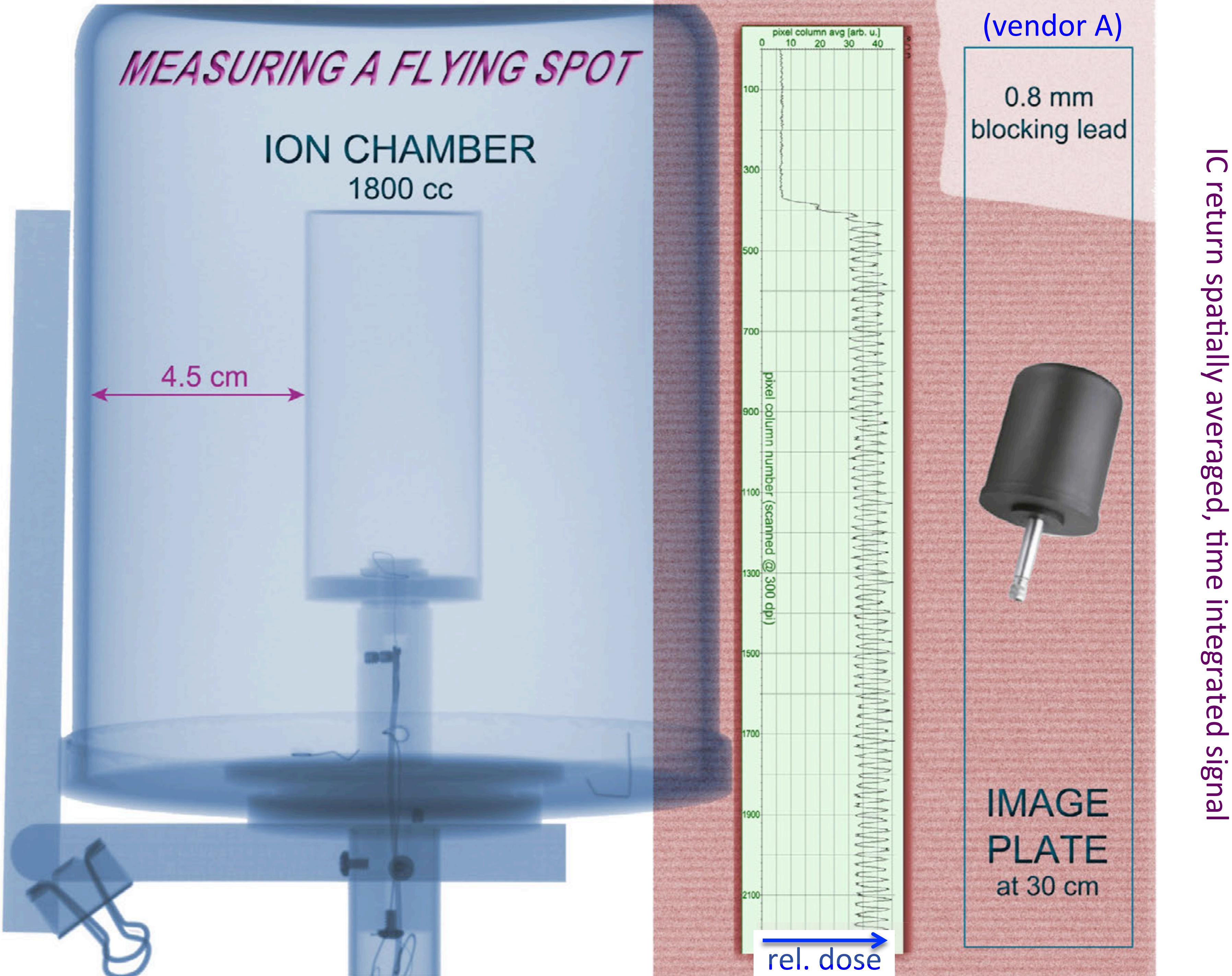
- Imaging plates for high-resolution spatial mapping



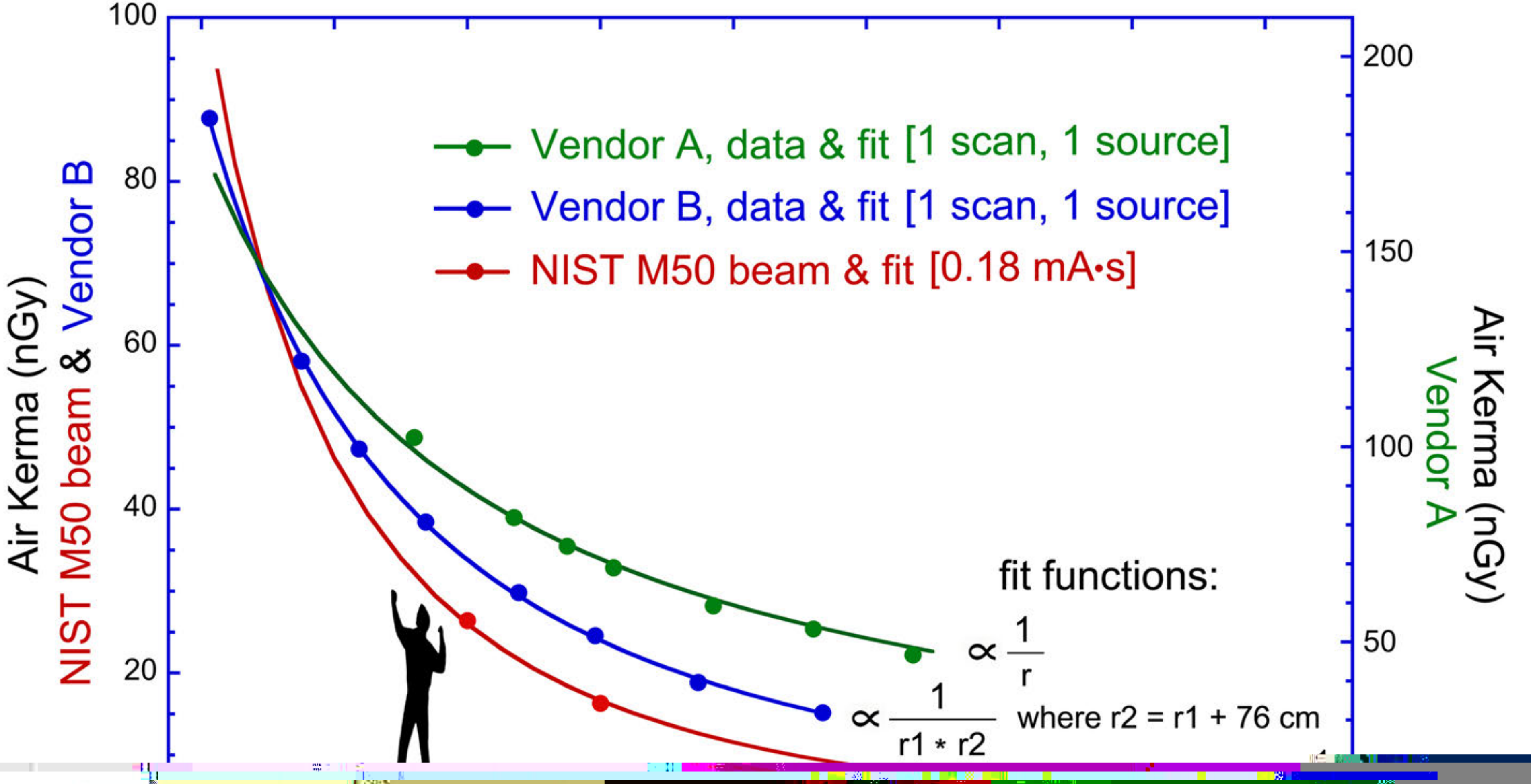
…performed by chamber substitution, with standard beam qualities
Ritz: tube potentials 20 keV to 100 keV

NIST M50: absolute air kerma rate



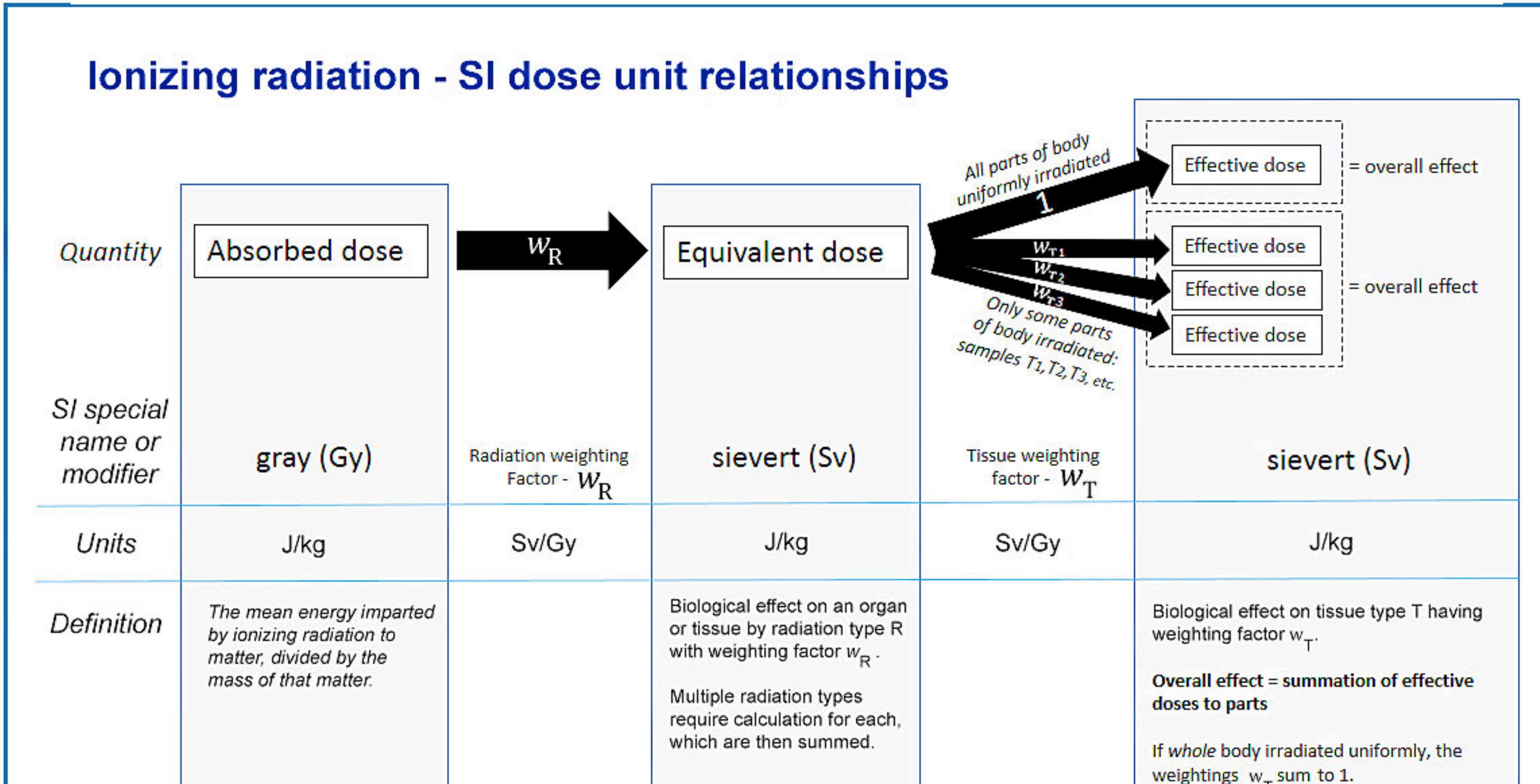

MEASURING A FLYING SPOT
ION CHAMBER
1800 cc
4.5 cm
pixel column avg [arb. u.]
pixel column number (scanned @ 300 dpi)
rel. dose
(vendor A)
0.8 mm
blocking lead
IMAGE
PLATE
at 30 cm
IC return spatially averaged, time integrated signal

location, location, location…



Dose rate determined to be about 1.1 mGy/s…CT dose rate about 50 mGy/s

FROM GRAY TO SIEVERT

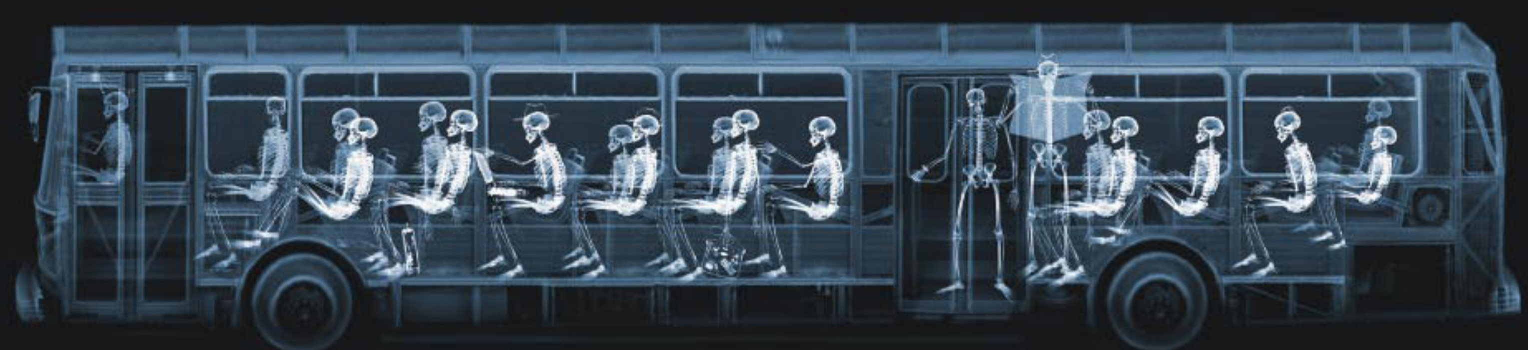


Detector	Average air kerma[1] (front + back scans)[2]
Ionization Chamber	64.2 nGy ± 2 nGy
Solid State Detector	65.6 nGy ± 2 nGy

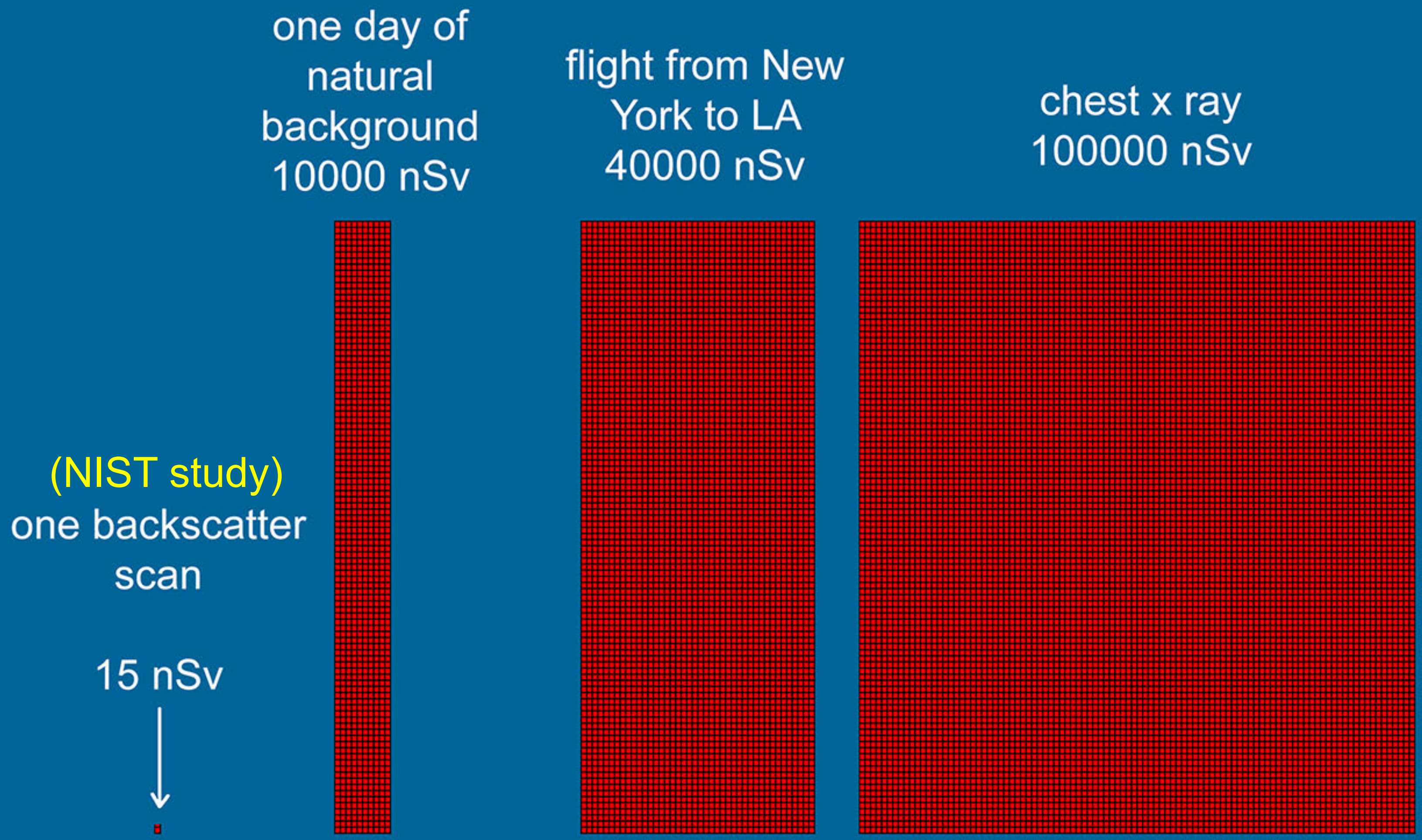
1) After two calibrations, separated by four months
2) At 1 m height, 30 cm from master source beam-emitting surface

Summary of effective (whole-body) dose estimates for "vendor B", adult 30 cm from master unit, two-sided exposure

- 12.6 nSv — ANSI/HSP N43.17-2009 (reference effective dose)
- 14.2 nSv — PCXMC 2.0
- 15.5 nSv — ICRP voxel phantom & conversion coeffs & SRS-78 spectrum generator



Radiation Effective Dose Comparisons



each box represents 10 nSv

ANSI N43.17 Reference Effective Dose limit per scan = 250 nSv

This material is based upon work supported by the Science and Technology Directorate of the U.S. Department of Homeland Security under Awards # HSHQPM-14-X-00023.