Airport Passenger Screening Using Backscatter X-Ray Machines:

Will they be redeployed

Presented by

Harry E. Martz, Jr.

at

ADSA 13

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

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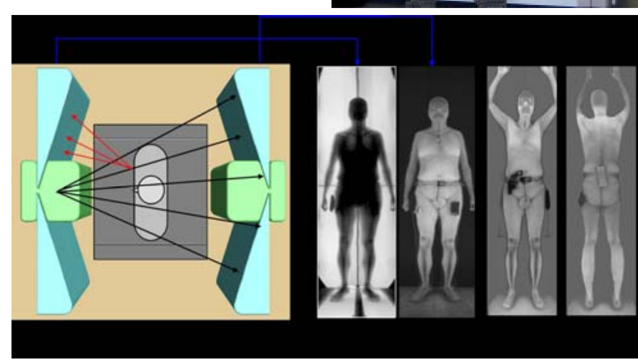
Will X-ray Backscatter Systems be redeployed

- XBS AIT pulled from field with multiple issues (some also for MMW)
  - Lack of ATR, privacy
  - X-ray exposure (stop at skin, QA deficient)
  - Negative press and public perceptions
  - Negative scientific articles (reverse-engineering)
- XBS AIT may be complementary (fuse-able) to or better than MMW AIT
- XBS used at prisons and military choke points, and by US customs
- Could it be redeployed for aviation security?
  - Manufacturers and scientists: can ATR be developed?
  - Can effects of ionizing radiation be accepted?
  - Can better QA be performed?
- Will the EU non-deployment effect TSA's decisions?
- Is it possible with external oversight from AAPM, FDA, NAS, other independent party?



BACKUP SLIDES

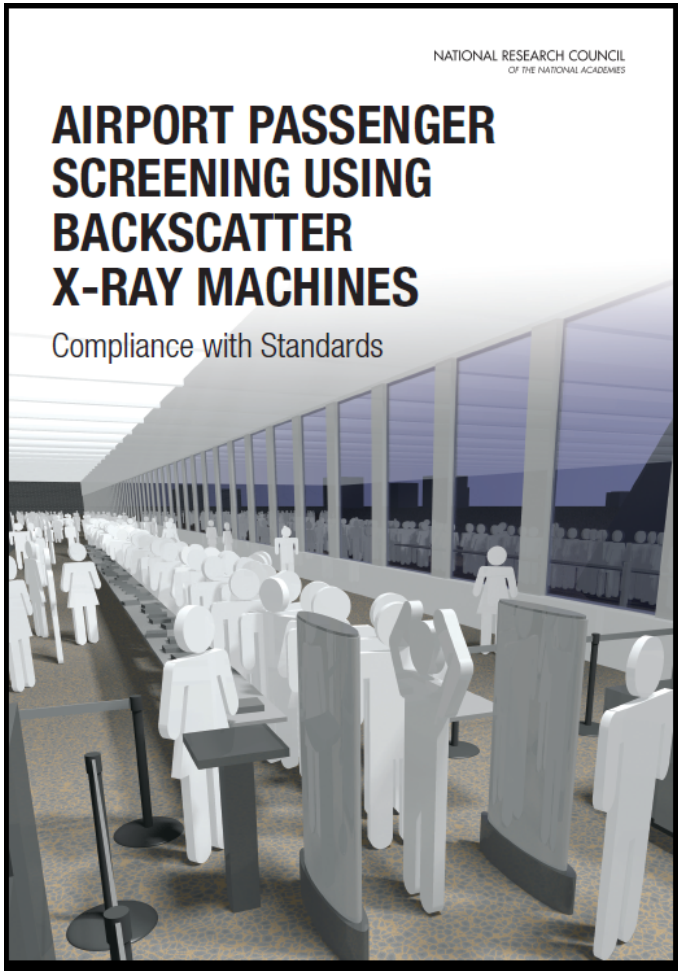
Will X-ray Backscatter Systems be redeployed (cont'd)

- If ATR developed for XBS AITs, will they be redeployed even though there are MMW AITs?
- XBS used at prisons and military choke points, and by US customs, so why not airports?
- Will the EU non-deployment effect TSA's decisions?

- Why do you think they will
  - Be redeployed?
  - Not be redeployed?
- What is required for them to be redeployed?
- What will keep them from being redeployed?

Transportation Security Administration

NAS Study: Committee, Staff and Subcontractors



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DAVID HINTENLANG, Measurement Team (University of Florida)

Summary of the NAS Study

HEALTH & SAFETY STDS	What are the relevant health and safety standards?	• American National Standards Institute / Health Physics Society (ANSI/HPS N.43.17) specifies limits for equipment for non-medical radiation applications
RADIATION EXPOSURE	Are passengers or bystanders receiving a radiation dose that exceeds relevant safety standards?	• Regardless of measurement technique or modelling approach, all measurements and computations agree dose is at least 5X below the ANSI/HPS limit. • No measurable dose for operators and bystanders.
SYSTEM DESIGN	Are the system design and operating procedures sufficient to prevent overexposure to passengers and bystanders?	• The system design and safety interlocks appear to be sufficient to prevent increase in radiation exposure. • Over-exposure would occur after 16 hours at full x-ray dose in case of machine malfunction.

NAS Study: A study supported by new NAS information

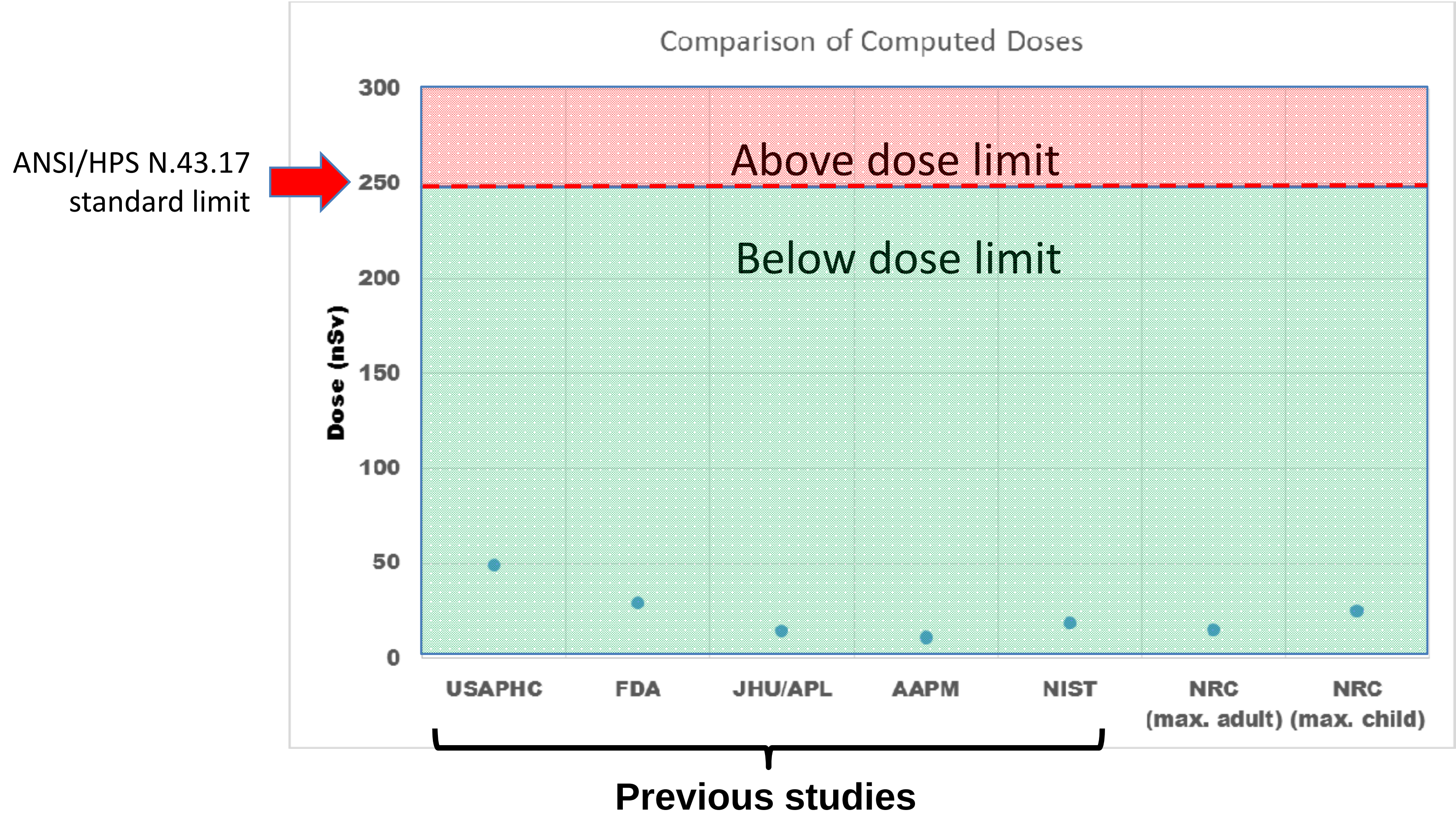
This study goes beyond the traditional Academy report that by tradition mainly relies on committee member expertise and deliberation on preexisting information.

In this study the committee subcontracted with experts to make new independent , and in some cases novel

- Measurements – including x-ray radiation measurements on both historical (Rapiscan Secure 1000) as well as potential future x-ray backscatter machines (AS&E SmartCheck)
- Computations – using the most recent modeling approaches and the measurements, determined typical radiation exposures as well as exposure to a variety of body sizes and in worst-case AIT malfunction scenarios.

Even though the x-ray radiation doses were measured and some safety interlocks were tested it was not possible to investigate all safety interlocks that protect a person being screened, operators, and bystanders from radiation overexposure.

Measurements and computations results



* ANSI/HPS N.43.17 limits radiation dose exposure per screening to less than 250 nSv for up to 1000 screenings per year

Evaluation of System Design and Procedures

Limitations of Evaluation:

- The X-ray based Advanced Imaging Technologies (AIT) have been removed from airports but the committee was able to inspect the interior of Rapiscan and AS&E X-ray AITs in laboratories.
- Committee was not given
  - The opportunity to independently test how all the interlocks perform in different situations
  - A demonstration of interlock checks at the manufacturer level
  - Detailed electrical and mechanical drawings and computer codes and documents describing internal functions at the most fundamental level of the machine

Key Findings:

- The X-ray backscatter machines appear to adhere to ANSI recommended safety mechanisms.
- Acceptance and inspection tests previously used during deployment appear to be sufficient to ensure the installed machines continue to meet ANSI requirements.
- Based on NAS measurements and computations, a screening must extend over 60 seconds to expose an individual to radiation that exceeds ANSI limit for a standard screening.

Key Recommendations:

- Future testing procedures should at a minimum continue to follow ANSI requirements, and include daily verification of safety parameters by a test piece.
- Future X-ray backscatter AITs should have an independent mechanism to ensure that screening time does not exceed time needed to acquire the necessary images.

Advanced Imaging Technology (AIT) in Airports

2008	TSA introduces X-ray backscatter AIT Rapiscan Secure 1000
2009	Umar Abdulmutallab attempts to detonate plastic explosives inside underwear on Northwest airlines 250 Rapiscan AITs are deployed across US airports
2012	Congress mandates privacy software for AITs
2013	Rapiscan fails to introduce software. All Rapiscan AITs removed from airports.
2015	740 millimeter wave AIT units across US airports Next-generation millimeter wave units being evaluated Next-generation x-ray backscatter units being evaluated

X-ray Backscatter AITs Studied by NAS

RAPISCAN SECURE 1000

- Located at National Institute of Standards and Technology (NIST), Gaithersburg, MD
- Previously deployed at LaGuardia airport

AS&E SmartCheck HT

- Second-generation AS&E SmartCheck undergoing evaluation by TSA
- Located at Transportation Systems Integration Facility (TSIF), VA

Technical Details

Outline

- Advanced Imaging Technology (AIT) used by Transportation Security Administration (DHS/TSA)
- X-ray backscatter technology
- Study request to the National Academy of Sciences (NAS)
- Study scope and methods
- Radiation protection standards
- Review of previous studies
- Measurements and computations
- Findings and recommendations

Transportation Security Administration

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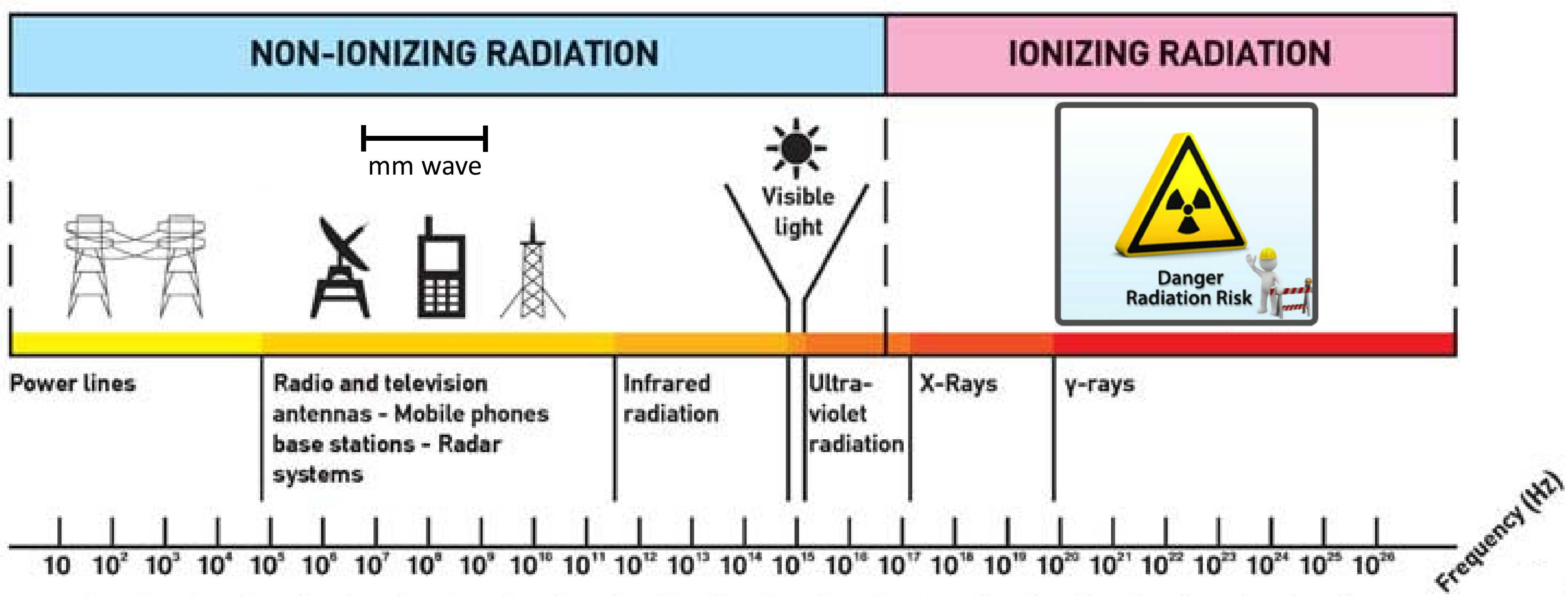
Advanced Imaging Technology (AIT)

Advanced Imaging Technology (AIT) uses one of two types of radiation to penetrate clothing and create a reflected image of the body:

- non-ionizing radiation (millimeter waves)
- ionizing radiation (x-rays)



X-ray Backscattering: Advantages

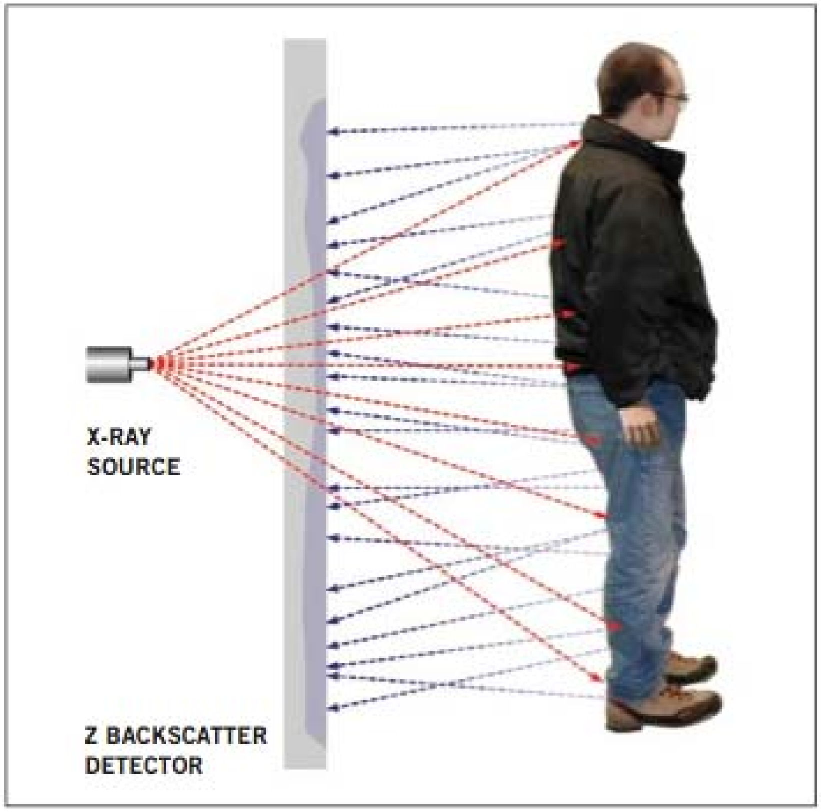
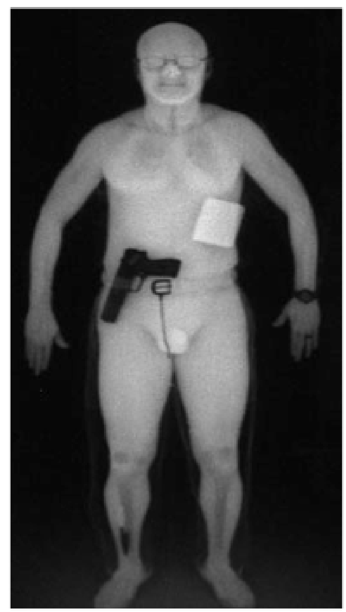


Image formed on detector on the same side as x-ray source:

- Eliminates need to set up detector on opposite side of target

Distinguishes high-Z (metallic) and low-Z (non-metallic) materials:

- Identifies anomalies on people such as metal, plastic, organic threats, e.g., knives, explosives & drugs



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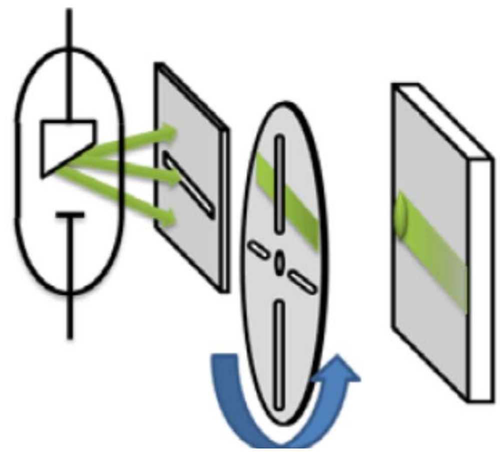
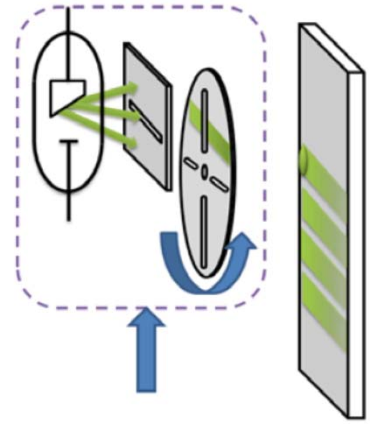
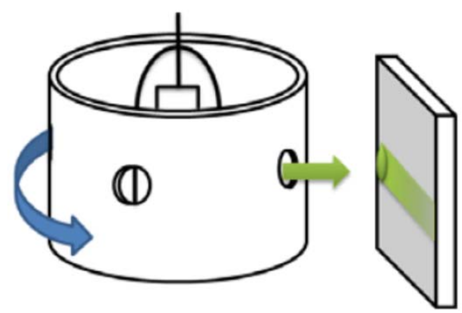
X-ray Backscatter AITs Rastered Pencil Beam

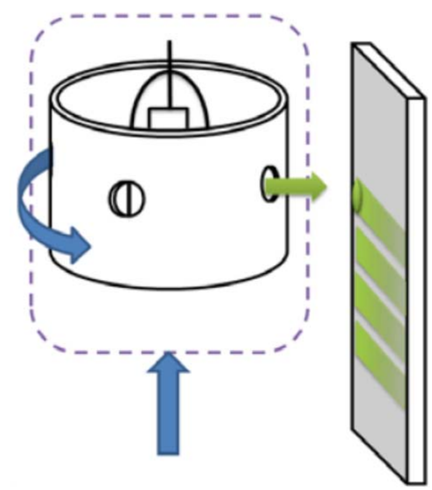
RAPISCAN
Secure 1000





AS&E
SmartCheck HT



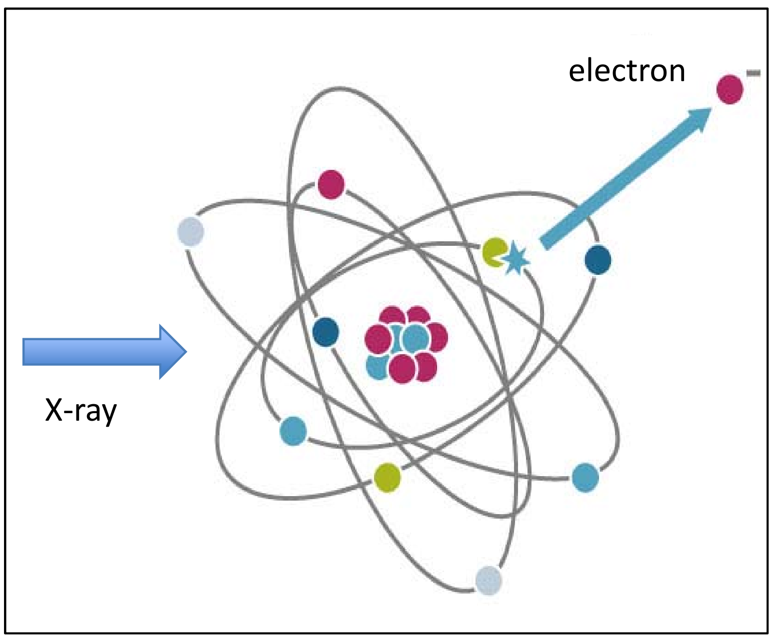


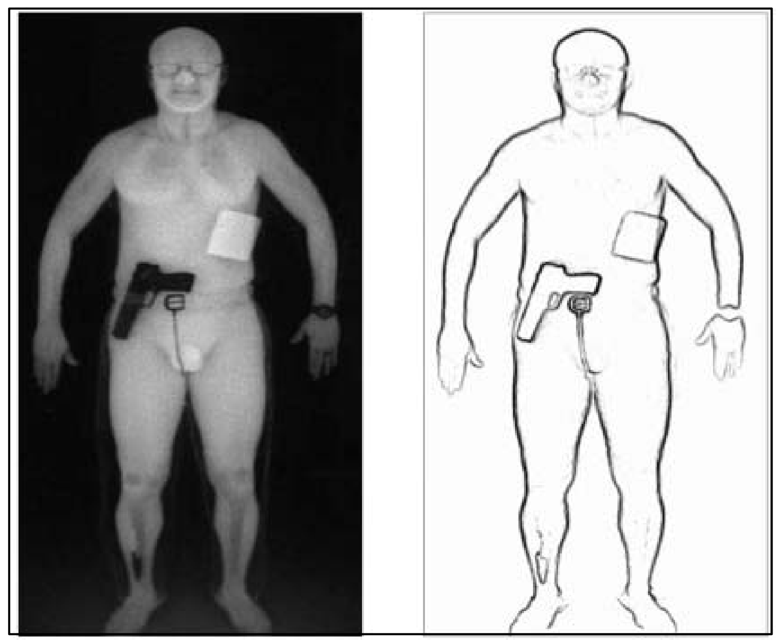
X-ray Backscattering: Concerns

Exposure to Ionizing Radiation	
Person Being Screened	**Bystander**
• Subgroups: children, pregnant women • Cumulative effects on frequent fliers • Potential for overexposure	• Scattered radiation to bystanders • Cumulative effects on operators • Potential for overexposure

Privacy

- Congressional mandate (2012) – Automated Target Recognition (ATR) to display potential threats on generic figure, rather than image of body





Components of the NAS Study

HEALTH & SAFETY STANDARDS	What are the relevant health and safety standards?
RADIATION EXPOSURE	Are passengers or bystanders receiving a radiation dose that exceeds relevant safety standards?
SYSTEM DESIGN	Are the system design and operating procedures sufficient to prevent overexposure to passengers and bystanders?

Relevant Quantities & Standards

X-ray Properties

Kerma (K)	Half Value Layer (HVL)
• Energy transferred from x-rays to a kilogram of matter • Measured in Gray (Gy), where 1 Gy = 1 J/kg • Provides value of X-ray intensity at a given location	• Thickness of aluminum needed to reduce X-ray intensity by half • Measured in millimeter (mm) • Provides understanding of X-ray spectrum

Radiation Exposure

Effective Dose (E)	Reference Effective Dose (E_{ref})
• Sum of doses to specific organs or tissues, multiplied by tissue weighting factor • Measured in Sievert (Sv) • Accounts for sensitivity of different tissues	• Product of air kerma and HVL • Measured in Sievert (Sv) • Provides dose for comparison to standard limits

ANSI/HPS N43.17 (2009)

Upper Limits for Exposure	Guidance for Design & Operation
• E_{ref} per screening: 250 nSv • E_{ref} per 12-month period: 250,000 nSv • E_{ref} in case of machine malfunction: 250,000 nSv	• Fail-safe mechanisms (hardware and software) • Operating procedures • Warning labels, training, and maintenance

Compliance with the ANSI/HPS N43.17 2009 Standard

Backscatter systems must conform to ANSI/HPS N43.17, 2009, a consensus radiation safety standard.

- Provides guidelines for both manufacturers and users of systems and covers dose to subject, interlocks, operational procedures, and information to be provided to the travelers by the operators.

  - ❑ Sets per screening limit of **250 nSv** reference effective dose.
  - ❑ Sets a 12-month period limit of **250,000 nSv** reference effective dose (1,000 screens per year).
  - ❑ Sets a limit of **250,000 nSv** reference effective dose in case of machine malfunction

Compliance with Federal Requirements

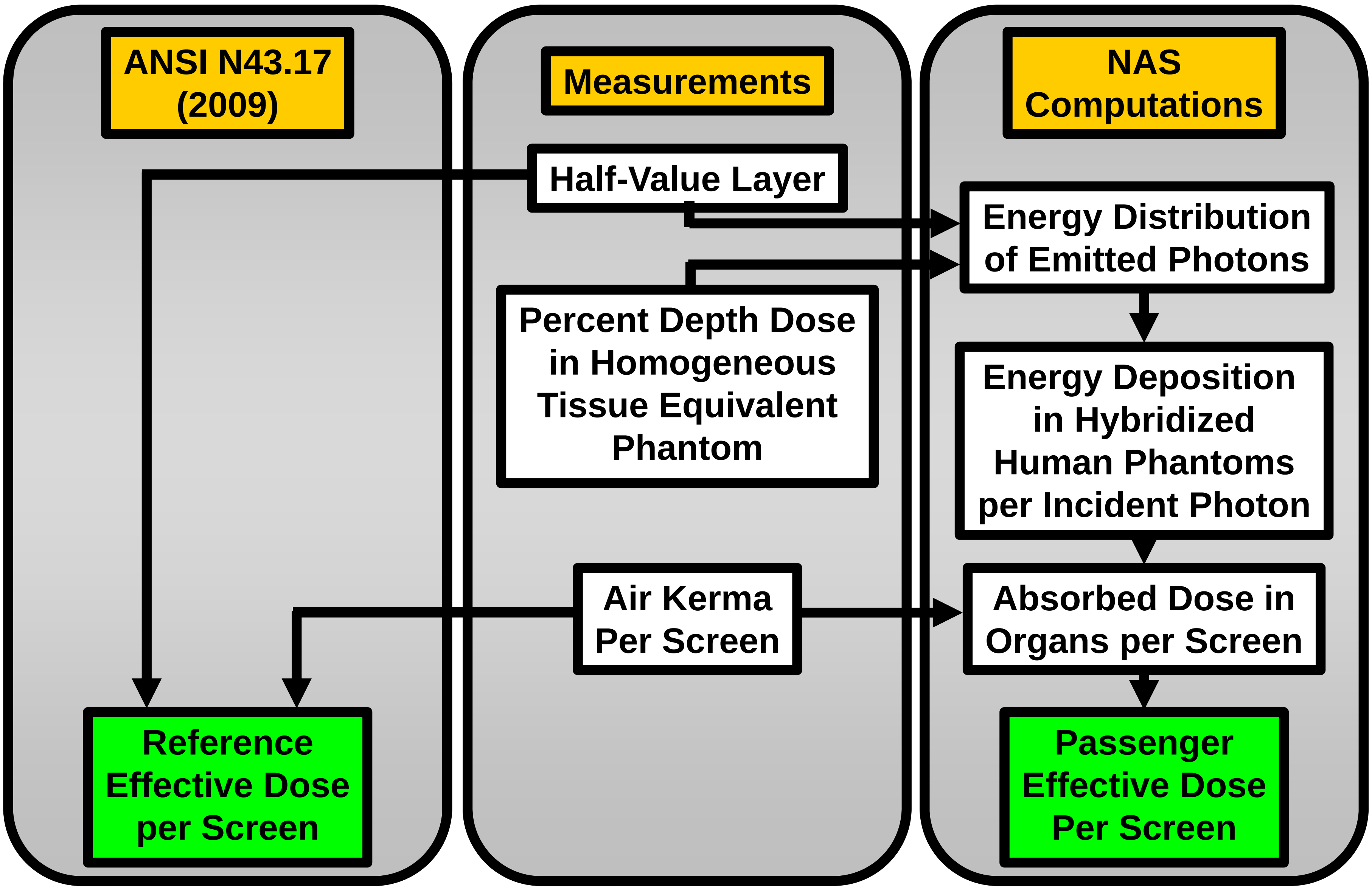
Manufacturers need to comply with:

- Federal Food, Drug and Cosmetic Act, Chapter V, Subchapter C
- Applicable requirements of Title 21 of the Code of Federal Regulations 1000-1005.

System Operators need to comply with:

- Occupational Safety and Health Administration ionizing radiation safety limits as promulgated in Title 29 of the Code of Federal Regulations, Part 1910.1096.

Measurements & computations to determine dose



NAS Review of Previous Studies

Rapiscan 1000 measured by:

- US Food and Drug Administration (FDA)
- Johns Hopkins University Applied Physics Laboratory (APL)
- US Army Public Health Command (USAPHC)
- National Institute of Standards and Technology (NIST)
- American Association of Physicists in Medicine (AAPM)

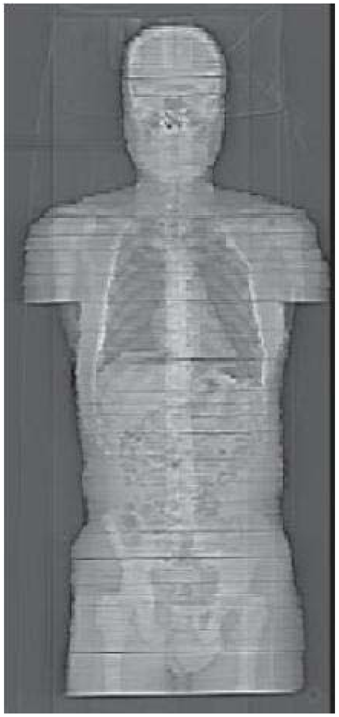
Key Findings:

- Inside screening area: Exposure per screening is about a factor of 10 below ANSI limit of 250 nSv.
- Outside screening area: Detectors failed to distinguish AIT X-ray scatter signal from background, possibly due to use of detectors designed for higher-energy X-rays.

NAS Study: Differences from previous studies

- Detectors calibrated for appropriate energy range
- Fabricated custom-made layers of tissue equivalent materials with realistic internal anatomy (shown below left) to mimic response of tissues in low-energy range
- Computations incorporate irradiation geometry, skin sensitivity, failure mode, and digitized phantoms with realistic morphology

Phantom based on: (a) segmented CT scan data set; (b) computational adult female hybrid data set; (c) computational adult male hybrid data set

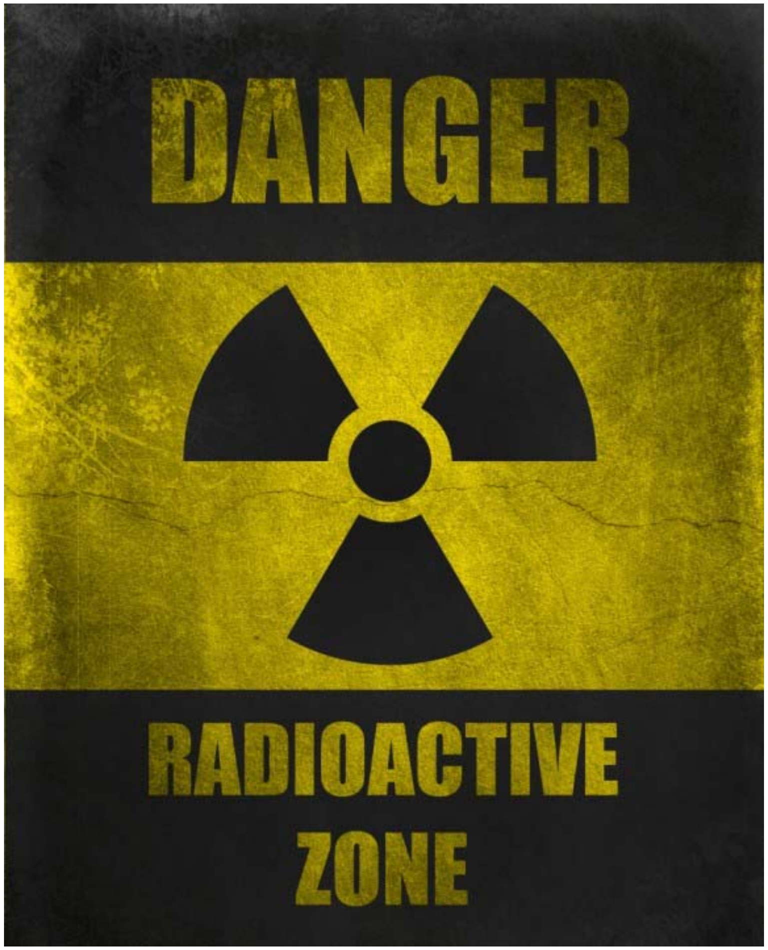


CT topogram of a tomographic physical phantom

NAS Study: Other Considerations

Some concerns addressed:

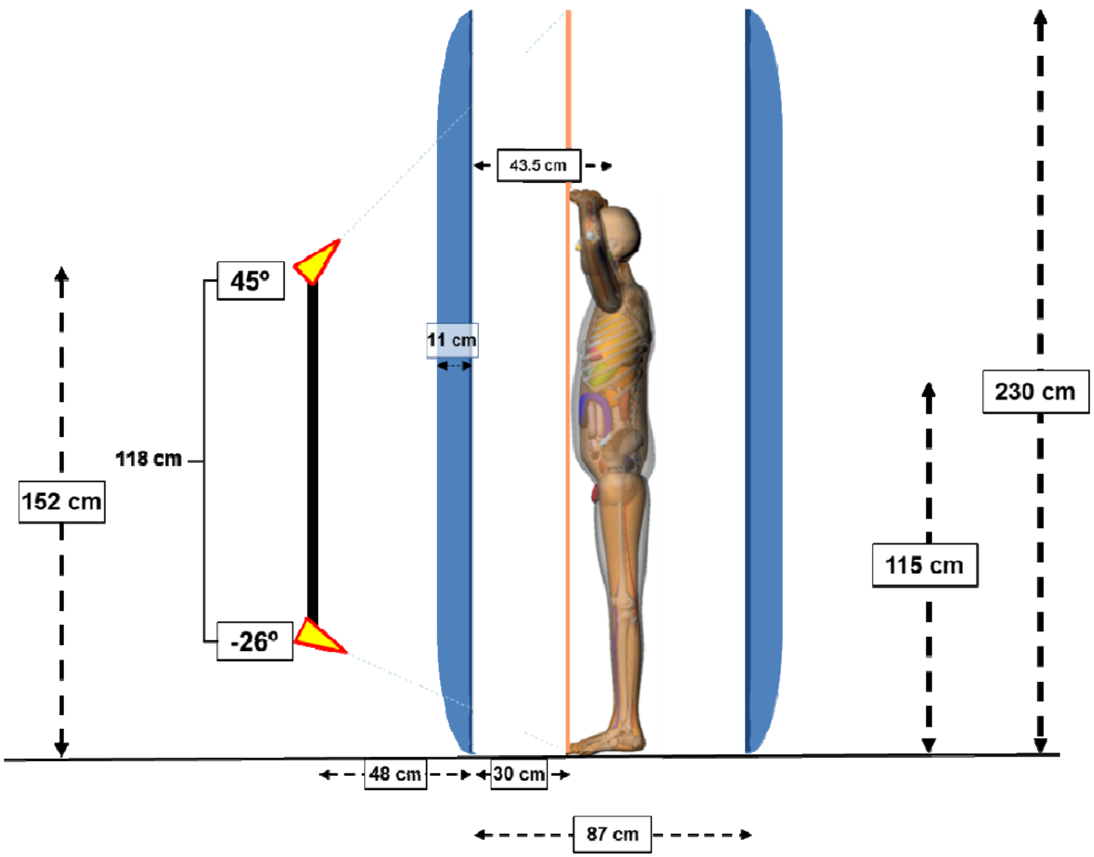
- Can higher-energy X-rays penetrate tissues beyond surface layers?
- Is it possible to have peak X-ray doses delivered to radio-sensitive portions of the skin?
- Are there sufficient safety mechanisms (e.g., interlocks) to prevent overexposure?
- What is exposure to operators outside scanning area from leakage or scattering of X-rays?
- What are exposure levels for pediatric passengers and developing fetuses?



NAS Study: Measurements

Quantities Measured:

- **Half-Value Layer (HVL):** Determine energy distribution of X-rays incident on passengers
- **Percent Depth Dose (PDD):** Measure dose as a function of depth into tissue
- **Air Kerma:** Measure kerma in various locations within screening area
- **Dose outside screening area:** Determine dose per screening at various locations outside scanning area

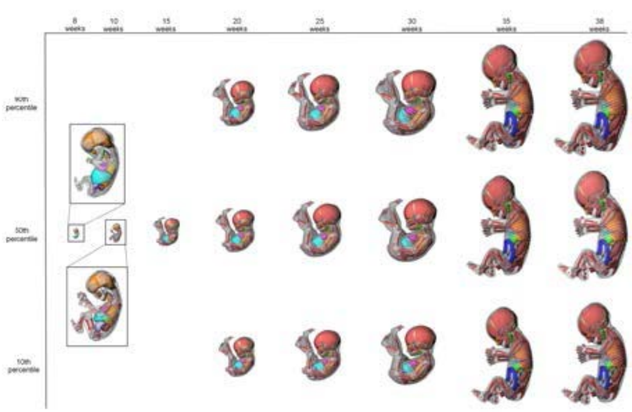


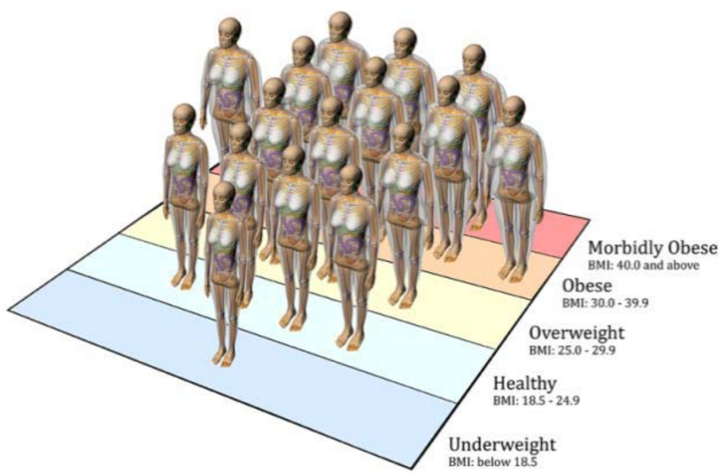
Not to scale

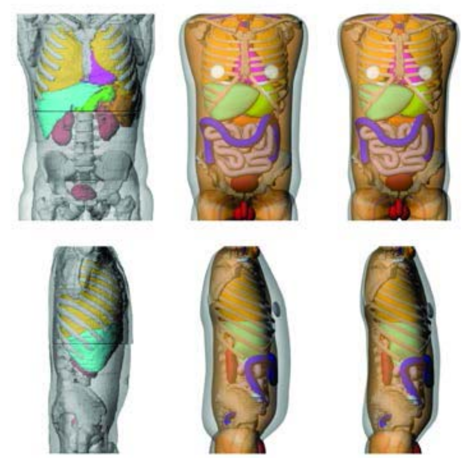
NAS Study: Computations

Effective dose to reference and at-risk populations:

- Combine measurements, radiation-tissue interaction processes, and anatomically realistic phantoms
- Passengers simulated by suite of hybrid digitized phantoms, including male and female adults and children
- Assess dose to developing fetus at selected gestation periods
- Special attention focus on surface and near-surface tissues (e.g., skin and eye)







Key Results of Measurements & Computations

- Reference effective dose is an order of magnitude (10X) less than ANSI limit of 250 nSv

	HVL (mm)	50% DD (mm)	Air Kerma (nGy)	E_{ref} (nSv)
Rapiscan (anterior)	0.92	~11	30.6	3.5
Rapiscan (posterior)	0.85	~11	29.8	3.2
AS&E (per side)	1.1	~12.5	113	15.5

- Radiation measured outside screening area is statistically indistinguishable from zero

	Air Kerma per Scan (nGy)	Standard Deviation (nGy)
Rapiscan leakage (rear exterior)	3.6	6.0
Rapiscan scatter (operator side)	7.3	3.5
AS&E leakage (rear exterior)	0.23	0.83
AS&E scatter (operator side)	2.8	0.25

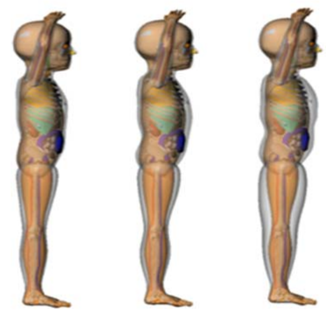
Adult Results of Measurements & Computations

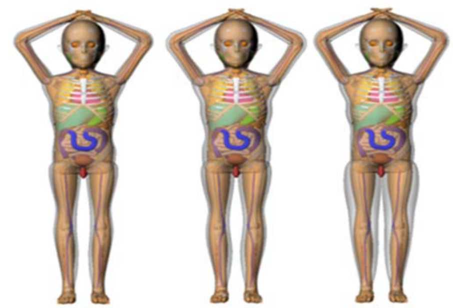
- Absorbed dose to tissues and organs for adult phantoms is less than 50 nGy per screen
- Effective dose to an adult phantoms is ≤15 nSv per screen

	U.S. Adults				
	5th	25th	50th	75th	95th
Male Absorbed Dose					
Thyroid Dose (nGy) per Screen	31	27	24	24	16
Skin Dose (nGy) per Screen	44	43	43	42	42
Eye Lens Dose (nGy) per Screen	44	44	42	42	39
Female Absorbed Dose					
Breast Dose (nGy) per Screen	26	23	23	20	18
Thyroid Dose (nGy) per Screen	22	21	17	11	4
Skin Dose (nGy) per Screen	46	45	44	45	46
Eye Lens Dose (nGy) per Screen	46	44	43	37	32
Adult Effective Dose					
Effective Dose (nSv) per Anterior Scan	12	10	9	7	4
Effective Dose (nSv) per Posterior Scan	3	3	3	2	2
Effective Dose (nSv) per Screen	15	13	12	9	6

Pediatric Results of Measurements & Computations

- Absorbed dose to tissues and organs of pediatric phantoms were all less than 60 nGy per screen
- Effective dose to pediatric phantoms is less than 26 nSv per screen

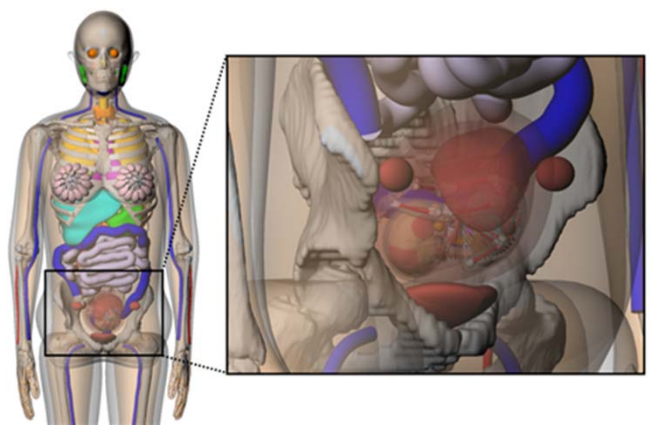


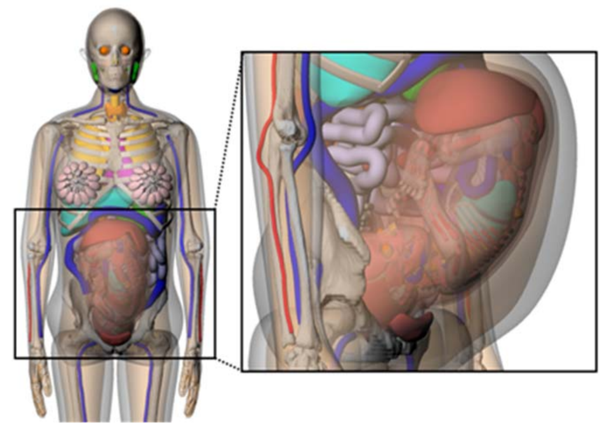


	U.S. Children		
	5th	50th	95th
Male Absorbed Dose			
Thyroid Dose (nGy) per Screen	47	45	47
Skin Dose (nGy) per Screen	49	49	48
Eye Lens Dose (nGy) per Screen	60	60	60
Female Absorbed Dose			
Breast Dose (nGy) per Screen	43	39	32
Thyroid Dose (nGy) per Screen	47	44	48
Skin Dose (nGy) per Screen	49	46	48
Eye Lens Dose (nGy) per Screen	60	54	60
Effective Dose			
Effective Dose (nSv) per Anterior Scan	20	18	16
Effective Dose (nSv) per Posterior Scan	6	5	5
Effective Dose (nSv) per Screen	26	23	21

Developing Fetus Results of Measurements & Computations

- Whole-body absorbed dose to fetus for three stages of fetal development is less than 10 nGy per screen





	Three Stages of Fetal Development								
	15 Weeks PC			25 Weeks PC			38 Weeks PC		
Absorbed Dose (nGy)	Anterior	Posterior	Screen	Anterior	Posterior	Screen	Anterior	Posterior	Screen
Whole Body	7.2	1.3	8.5	3.4	0.6	4.0	3.4	0.9	4.3
Brain	3.7	2.3	6.0	0.8	1.4	2.2	0.5	2.7	3.2
Lungs	8.3	0.9	9.2	5.1	0.2	5.3	2.6	0.2	2.7
Thyroid	5.8	1.4	7.2	2.5	0.4	2.9	1.3	0.3	1.6
Active Bone Marrow	13.9	2.5	16.4	6.4	1.8	8.1	8.4	2.7	11.1

Key Results of Measurements & Computations

- Absorbed dose to locations of radiosensitive skin cells, at depths 50 to 100 um, were not significantly larger than dose averaged over complete layer of skin

	Stylized Phantom	Hybrid Phantom
Absorbed Dose per Screen (nGy)		
Target - Total Skin	37.3	43.5 *
Target - Radiosenstive Layer	37.9	44.2 **
Ratio (Total Skin / Radiosensitive Layer)	1.02	

- Gender-averaged dose with adult hybrid

** Hybrid phantom total skin dose x 1.02

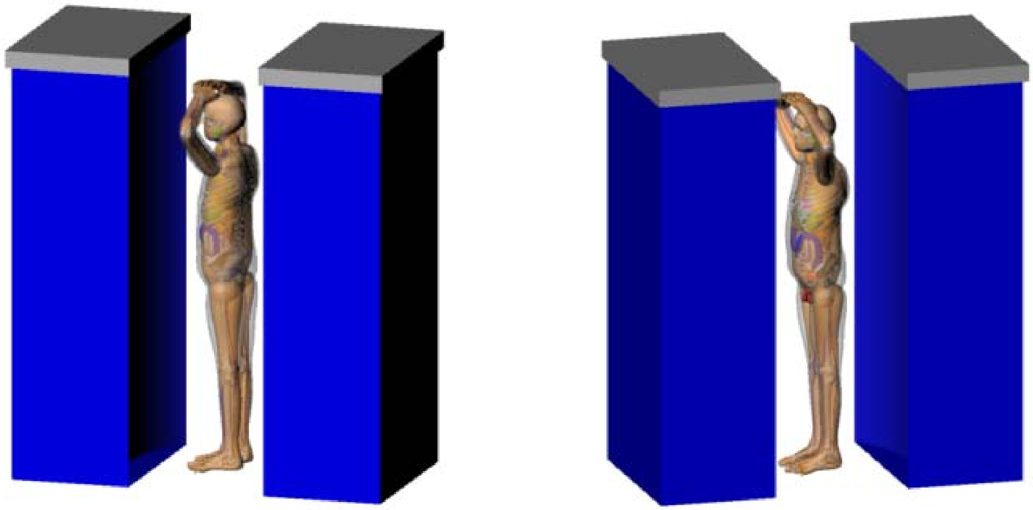
- Localized absorbed doses for stationary beam and normal scan duration were on the order of 1,000,000 nGy for the lens of the eye and skin, and 7,000 nGy for the breast.

Tissue	Normal Screen nGy	Failure Mode 1 nGy	Failure Mode 2 nGy	Tissue Reaction Threshold	
				nGy	Gy
Lens	43	29,000	1,100,000	500,000,000	0.5
Skin	44	26,000	870,000	2,000,000,000	2
Breast	23	310	7,400	--	

Failure Mode 1 - Beam fixed vertically but not horizontally (chopper wheel operational)
Failure Mode 2 - Beam fixed vertically and horizontally (chopper wheel not operational)

Summary of Measurements & Computations

- No individual, without regard to age and weight, would exceed ANSI limit (250 nSv per screen).
- Absorbed dose per screen to the developing fetus at any of three stages of fetal development is less than 0.0002% of the recommended limit for radiation protection of the fetus during the entire gestation period.
- Dose received by lens of the eye, skin, or female breast under worst-case AIT malfunction scenarios for a normal scan duration are at least 2 orders of magnitude below tissue-reaction thresholds where tissue injury might occur.
- Agreement between estimated dose results from the NAS study and previous studies confirms that the computations performed in the previous studies all comply with the ANSI standard



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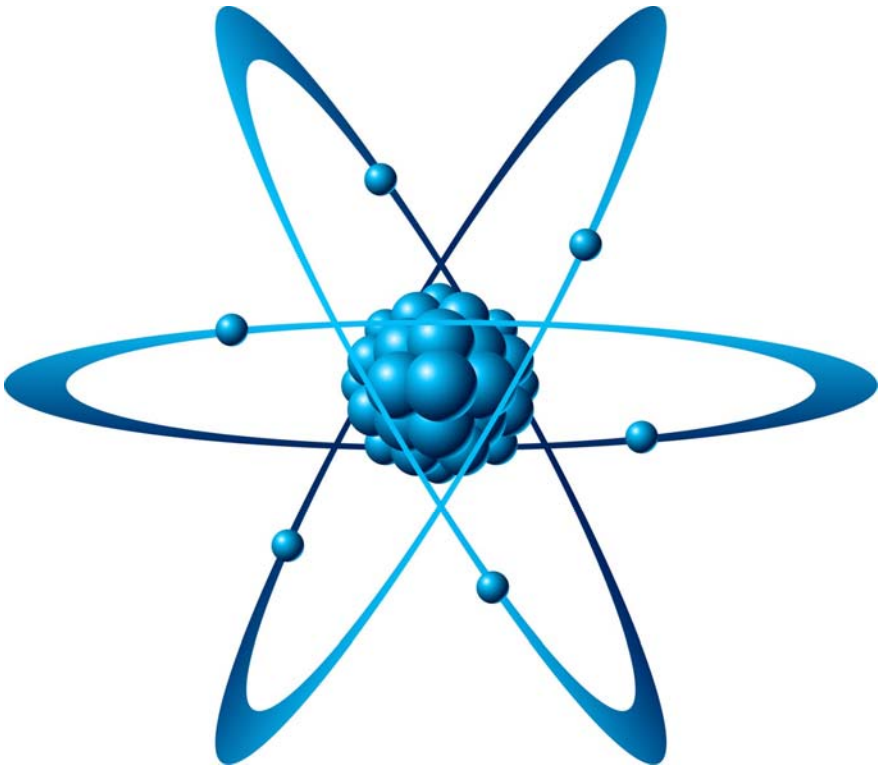
- Future X-ray backscatter AITs should have an independent mechanism to ensure that screening time does not exceed time needed to acquire the necessary images.

Summary of the NAS Study

HEALTH & SAFETY STDS	What are the relevant health and safety standards?	• American National Standards Institute / Health Physics Society (ANSI/HPS N.43.17) specifies limits for equipment for non-medical radiation applications
RADIATION EXPOSURE	Are passengers or bystanders receiving a radiation dose that exceeds relevant safety standards?	• Regardless of measurement technique or modelling approach, all measurements and computations agree dose is at least 5X below the ANSI/HPS limit. • No measurable dose for operators and bystanders.
SYSTEM DESIGN	Are the system design and operating procedures sufficient to prevent overexposure to passengers and bystanders?	• The system design and safety interlocks appear to be sufficient to prevent increase in radiation exposure. • Over-exposure would occur after 16 hours at full x-ray dose in case of machine malfunction.



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