Comparison of “whole-body” counting efficiencies for BOMAB and realistic phantoms: VIP-Man, NORMAN, and CNMAN

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Talk based on “An analysis of dependency of counting efficiency on worker anatomy for *in vivo* measurements: whole-body counting”
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Introduction

- **<u>Accurate</u> measurements of radioactive materials retained in the human body are important for:**

Radiation Protection

Nuclear Medicine Imaging

- **Most direct measurements for γ-ray emitting nuclides are made by <u>Whole-Body Counting</u>!**

What is Whole-Body Counting (WBC)?

- Detectors placed near the surface of the human body for γ-ray spectroscopy.

Efficiency Calibration
(energy, source-detector geometry, counting system)

Detector Response ⟷ *Retained Activity*

Efficiency Calibration

- **Calibrations are typically performed using physical phantoms spiked with known activity.**
- **Accuracy depends on the likeness between the physical phantom and the contaminated human subject.**
- **BOttle Manikin ABsorption Phantom (BOMAB):**

  -*de facto* calibration standard in U.S.

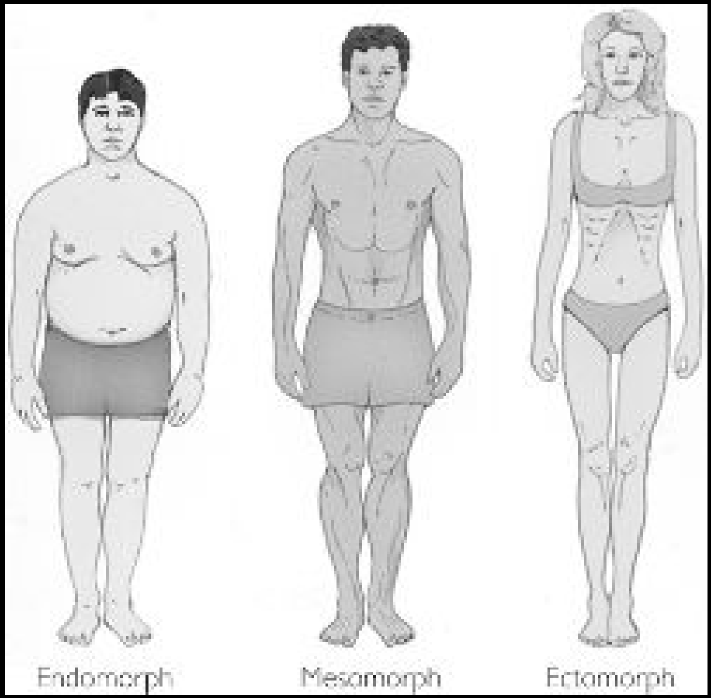
  -10 hollow, cylindrical bottles
  -polyethylene plastic
  -radioactive solutions (H_20)

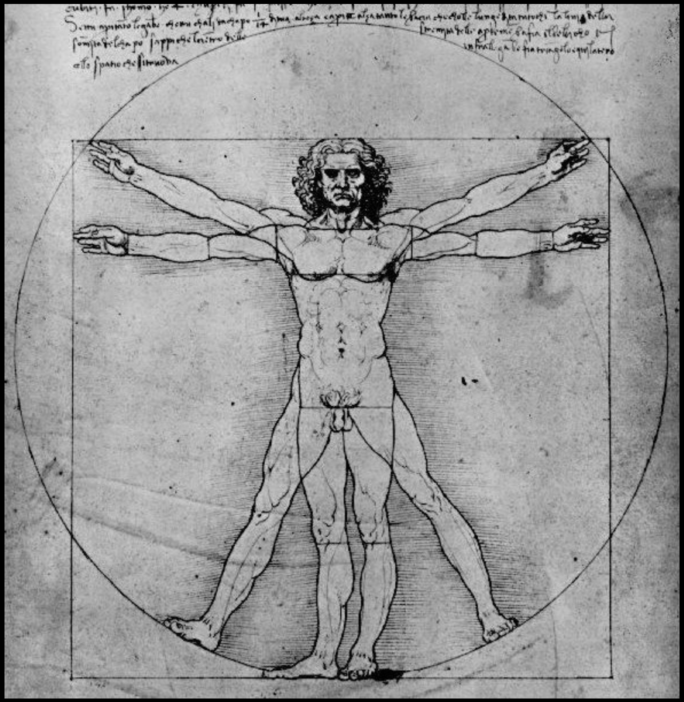
  -limited size range available

  -no bones or internal organs

Objective

- **As people come in all shapes and sizes, the purpose of this study is to improve the understanding of how human anatomy effects whole-body counting efficiency.**





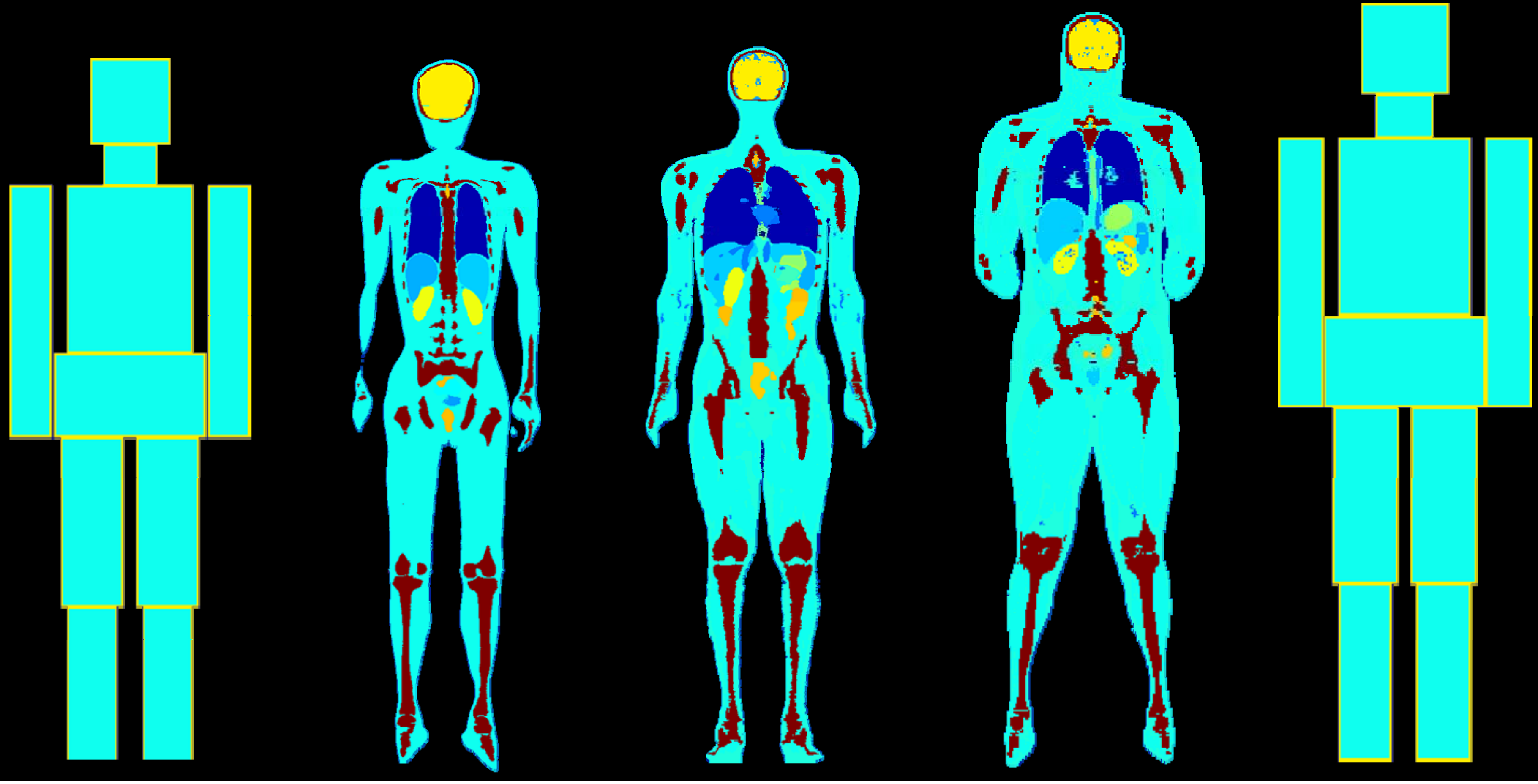
Method

- Experimental methods would be expensive and time consuming.

- Monte Carlo methods are a practical alternative.

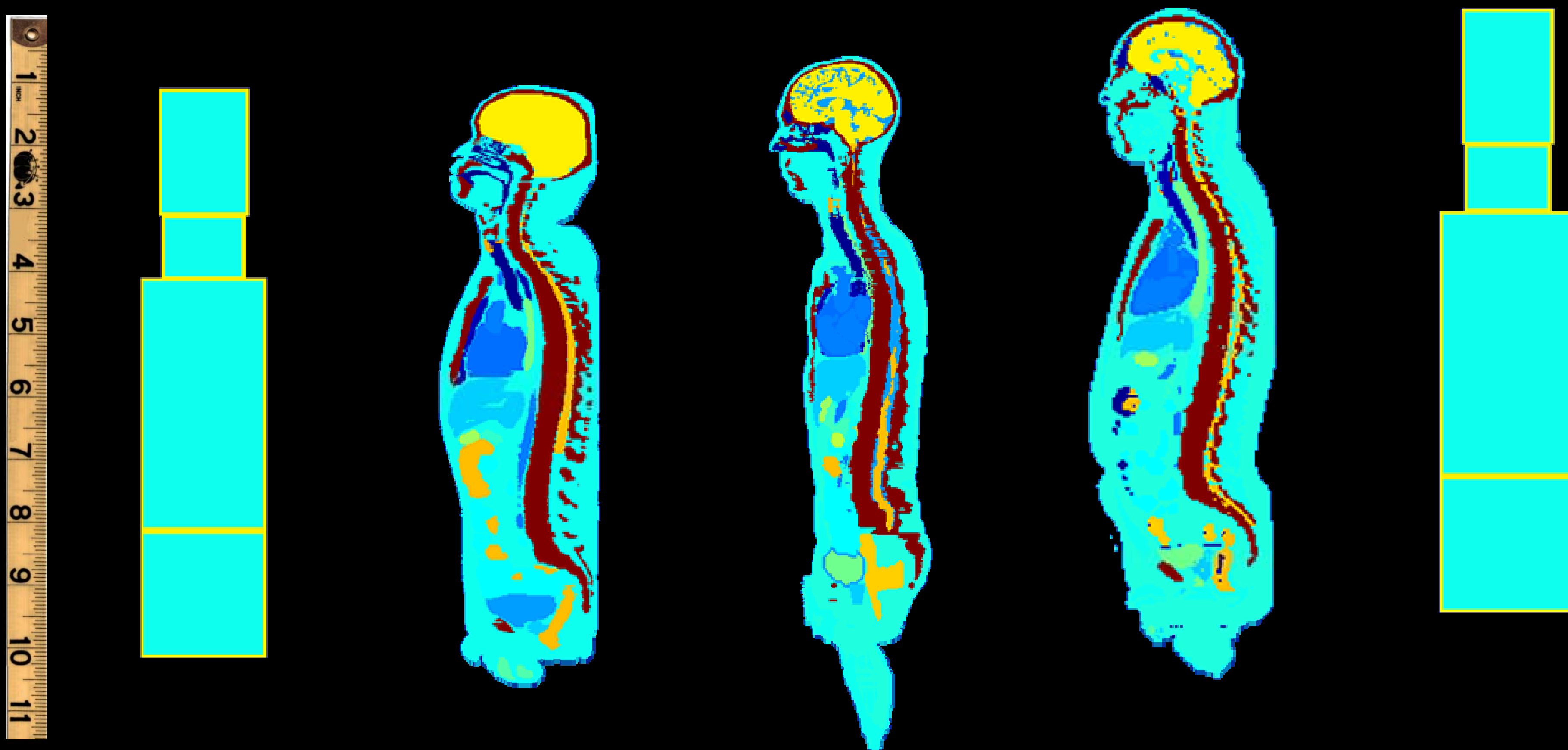
- Virtual WBC simulations performed for 2 BOMAB phantoms and 3 image-based voxel phantoms. The systematic difference in counting efficiency was examined.

Five Virtual Phantoms



	Ref. BOMAB	CNMAN	NORMAN	VIP-Man	95% BOMAB
Reference	ANSI N13.35	Zhang et al 2007	Dimbylow 1997	Xu et al 2000	ANSI N13.35
Image Type	Math Equations	Photographs	MRI	Photographs	Math Equations
Resolution		1.7 x 1.7 x 2 mm^3	2 x 2 x 2 mm^3	4 x 4 x 4 mm^3	

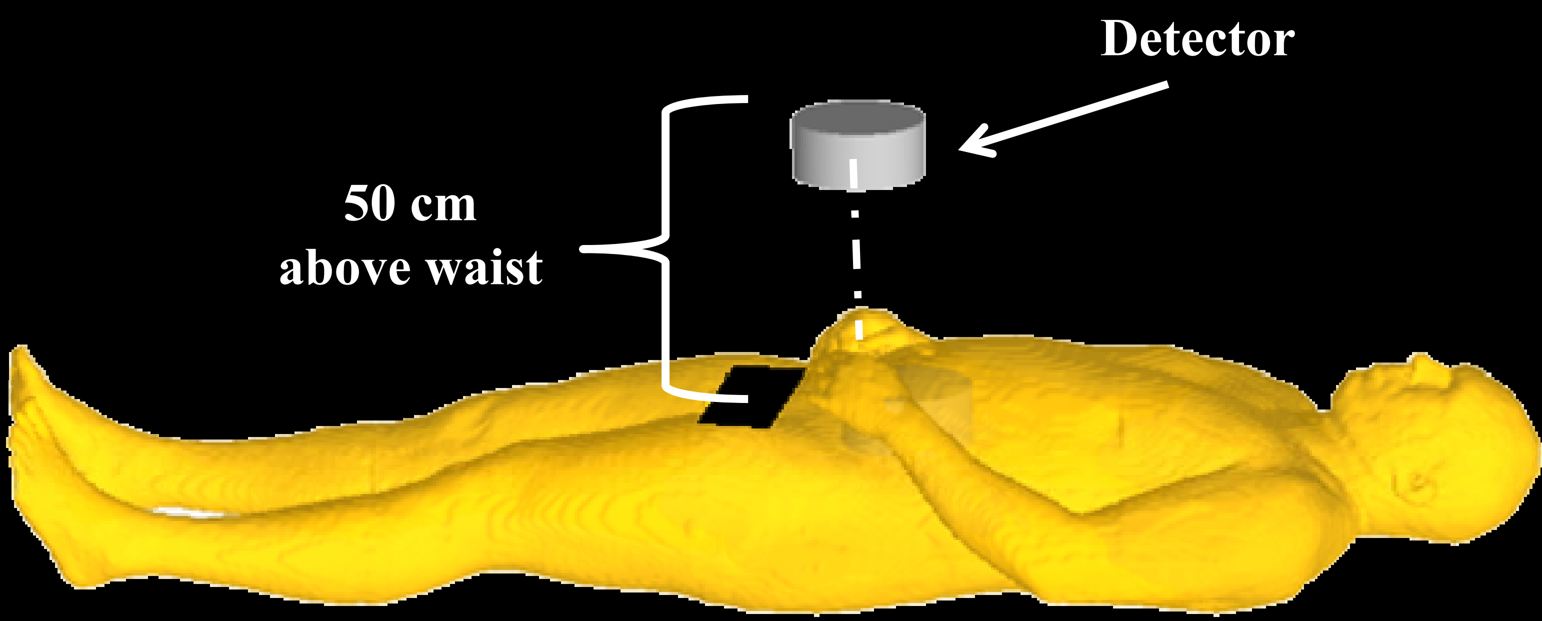
Body Height & Weight Data



	Ref. BOMAB	CNMAN	NORMAN	VIP-Man	95% BOMAB
Height	170 cm	170 cm	176 cm	186 cm	184 cm
Weight	68.1 kg	54.5 kg	68.2 kg	103.1 kg	86.6 kg

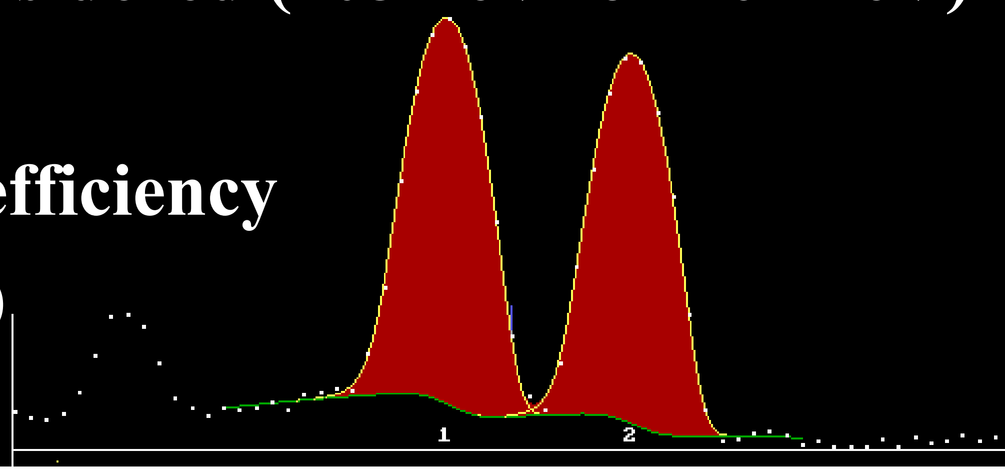
Methods: Gamma Spectrometer Modeling

- Cylindrical N-type LO-AX HPGe detector from China Institute for Radiation Protection
- Crystal is 70 mm in diameter, 30 mm in length
- Capable of measurements in range of 3 to 2000 keV
- Need reference counting position for comparison



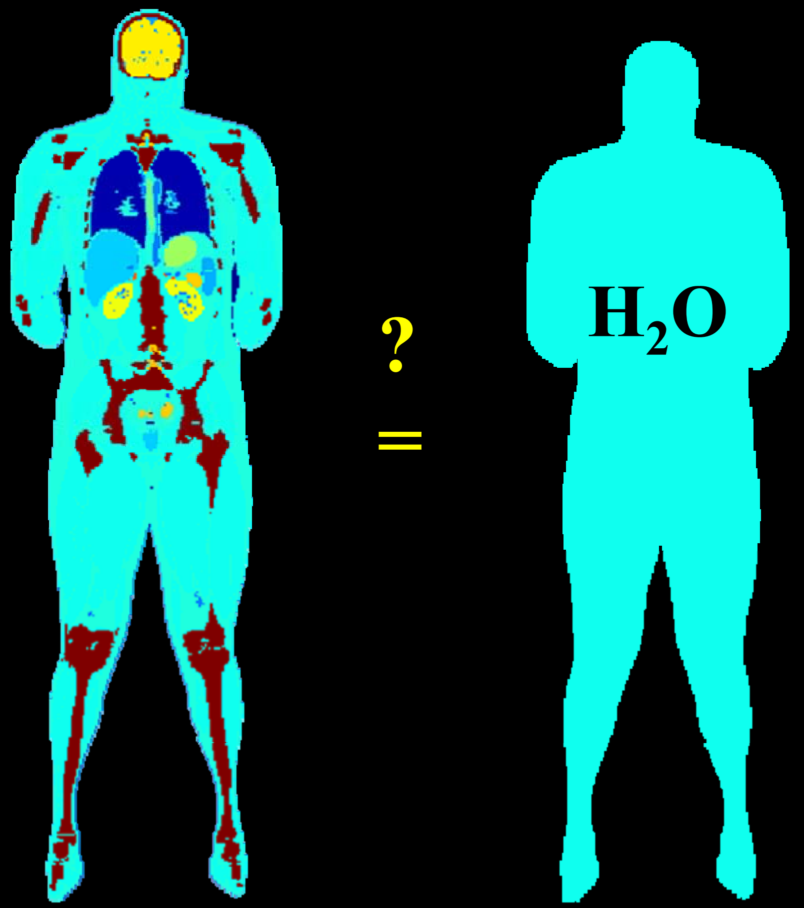
Methods: Monte Carlo Simulation

- Radiation transport simulation used to compare the whole-body counting efficiencies of the 5 phantoms
  - MCNPX 2.5.0
- Assume homogeneous body contamination scenario with gamma emitting nuclides:
  - ^{155}Eu, ^{57}Co, ^{125}Sb, ^{226}Ra, ^{152}Eu , ^{133}Ba, ^{137}Cs , ^{210}Po, ^{54}Mn, ^{154}Eu, ^{60}Co, ^{40}K
  - 14 gamma energies considered (105 keV to 1461 keV)
- Pulse Height (F8) tally
- Calculate full energy peak efficiency
- Statistical error < 3% (k=1)

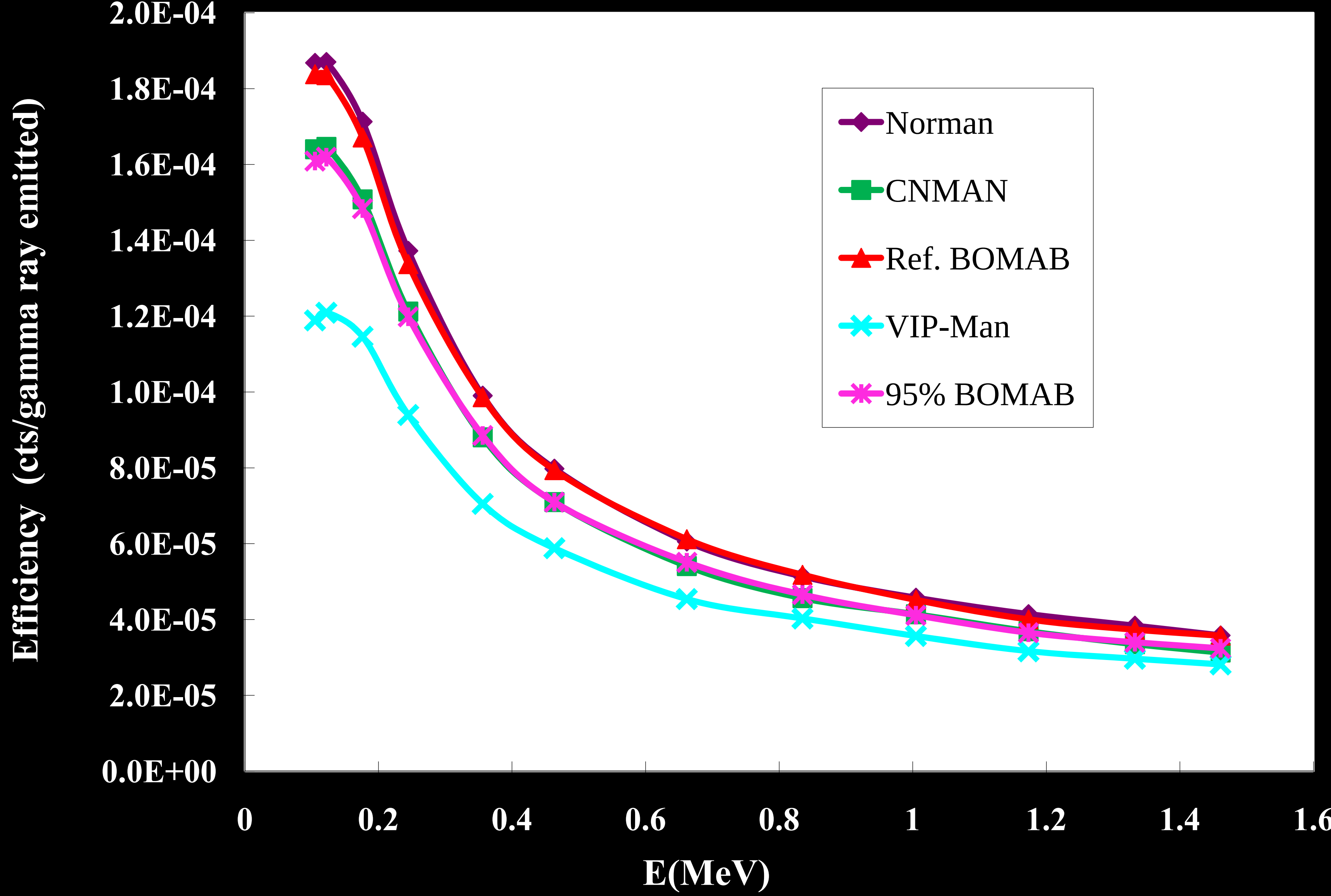


Methods: Water-Filled Phantom Simulations

- Investigation of the effect of tissue homogeneity on efficiency for the three voxel phantoms
- Density and material composition for all organs and tissues (except skin) changed to water
- Similar body shape to original heterogeneous model, but have a simple BOMAB-like internal anatomy

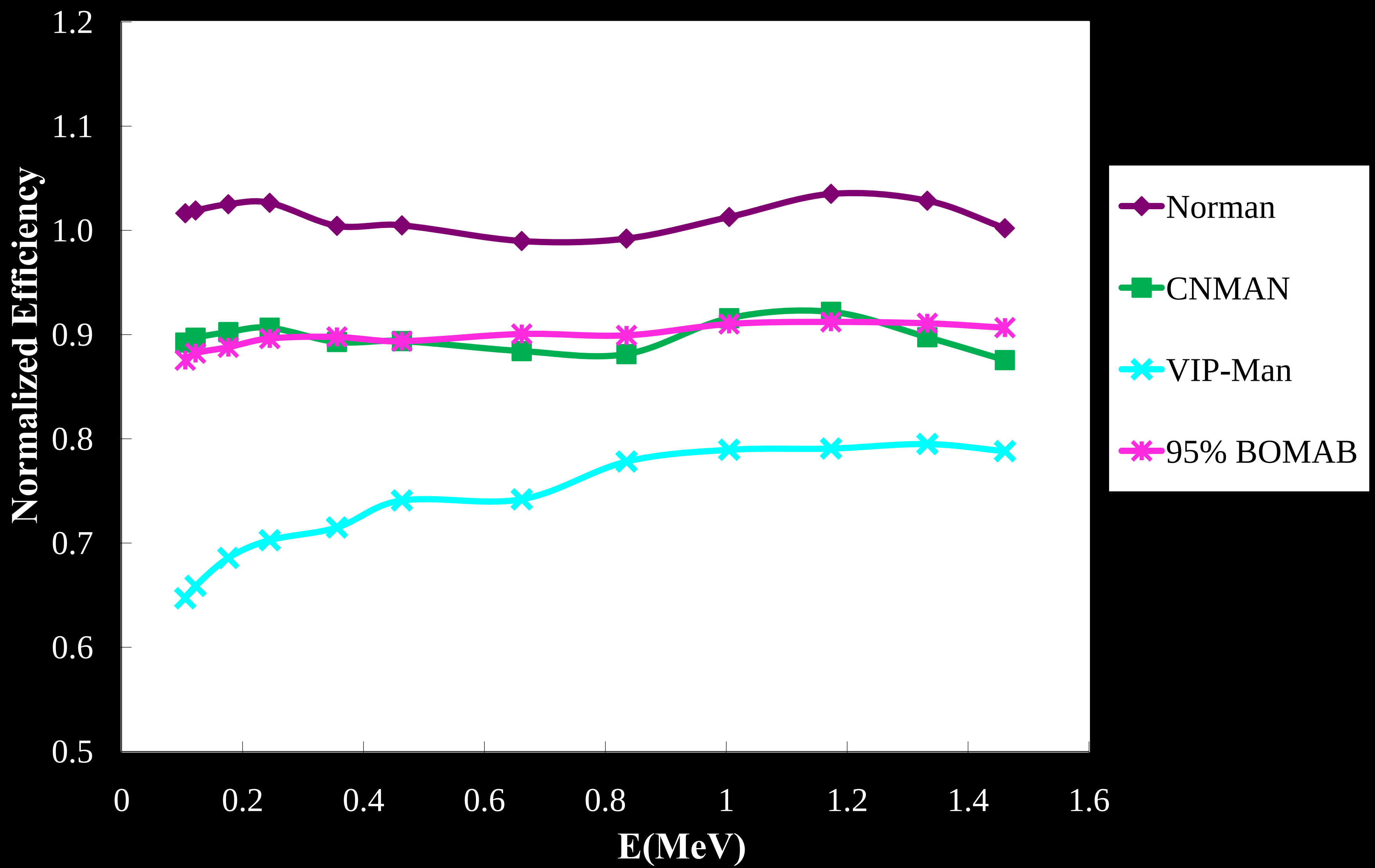


Efficiency Curves for the Five Phantoms



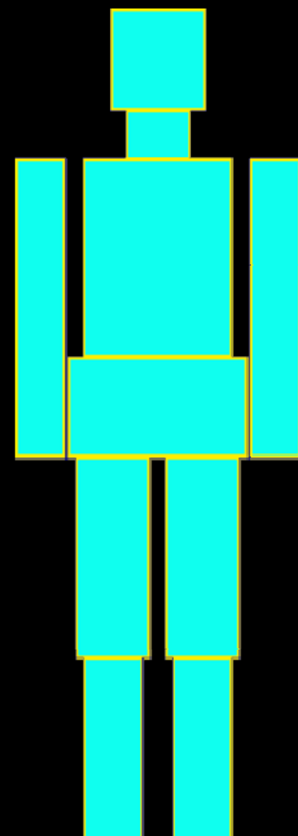
Normalized Efficiency Curves

(relative to the Reference BOMAB, the *de facto* standard)



NORMAN vs. Reference BOMAB

- **Normalized efficiency factors for NORMAN ranged from 0.99 to 1.04 across energy range studied.**
- **Agreement attributed to similar heights and weights.**



Efficiencies

≈

Ref. BOMAB

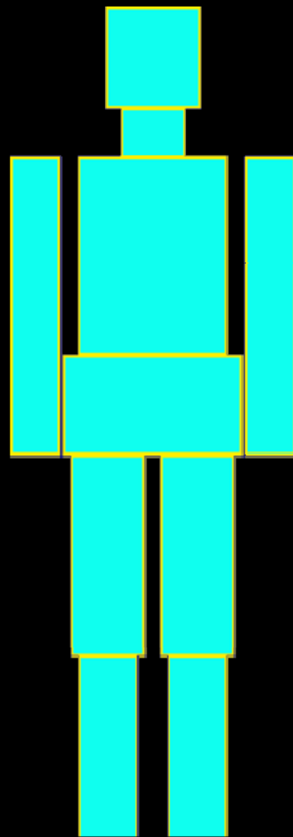
170 cm
68.1 kg

NORMAN

176 cm
68.2 kg

VIP-Man vs. Reference BOMAB

- **VIP-Man's efficiencies are 20% to 35% lower than the Ref. BOMAB.**
- **VIP-Man has greatest height, weight, and body volume.**



Efficiencies

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Ref. BOMAB

170 cm
68.1 kg

VIP-Man

186 cm
103.1 kg

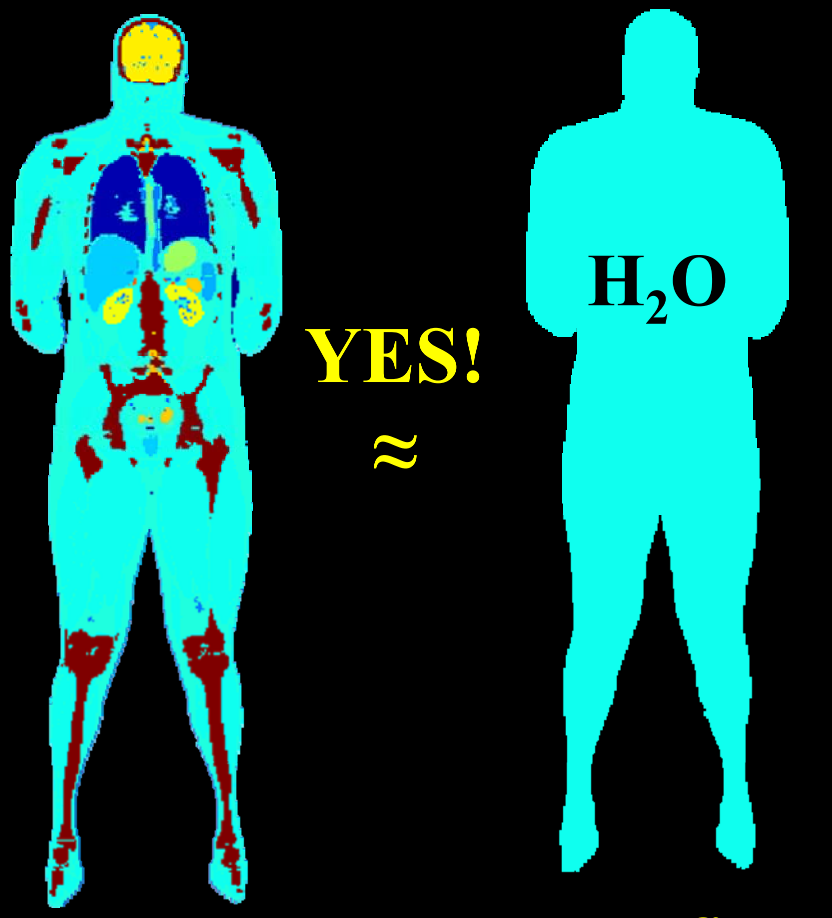
General Counting Efficiency Trends

- Similar height and weight → similar counting efficiencies.

- Counting efficiencies decrease as body weight and volume increase because of increased photon attenuation.

Results: Water Filled Phantoms

- The efficiencies of the water-filled VIP-Man, CNMAN, and NORMAN phantoms differed by less than 3% from their respective heterogeneous counterparts (energy range 100 to 1300 keV).
- Statistical error is ≈ 2%
- Effect of tissue heterogeneity is negligible compared to height & weight factors described previously

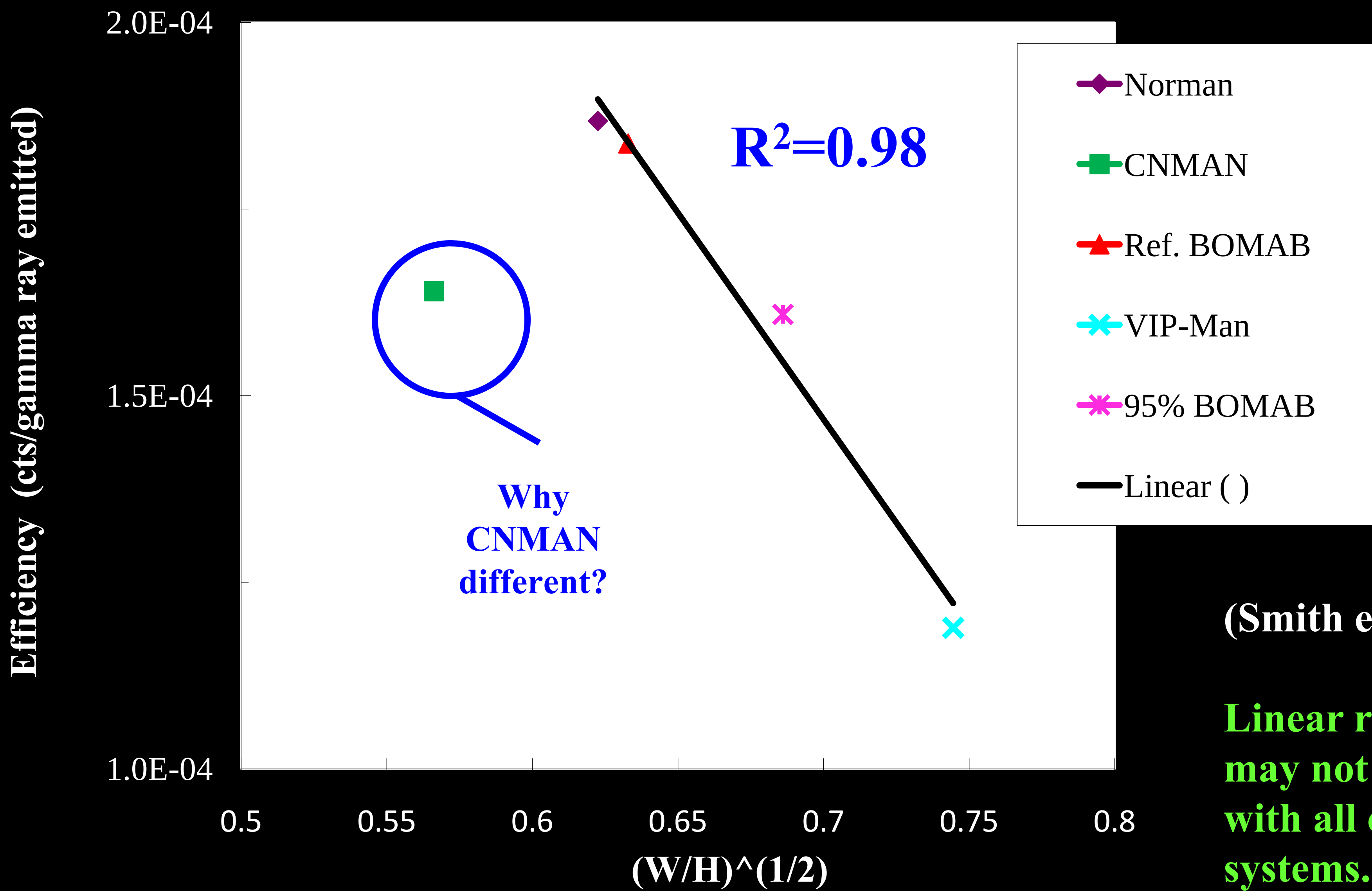


VIP-Man

Water-filled VIP-Man

Linear Regressions in Variable $(W/H)^{1/2}$

Energy = 105 keV, Similar trends for different energies

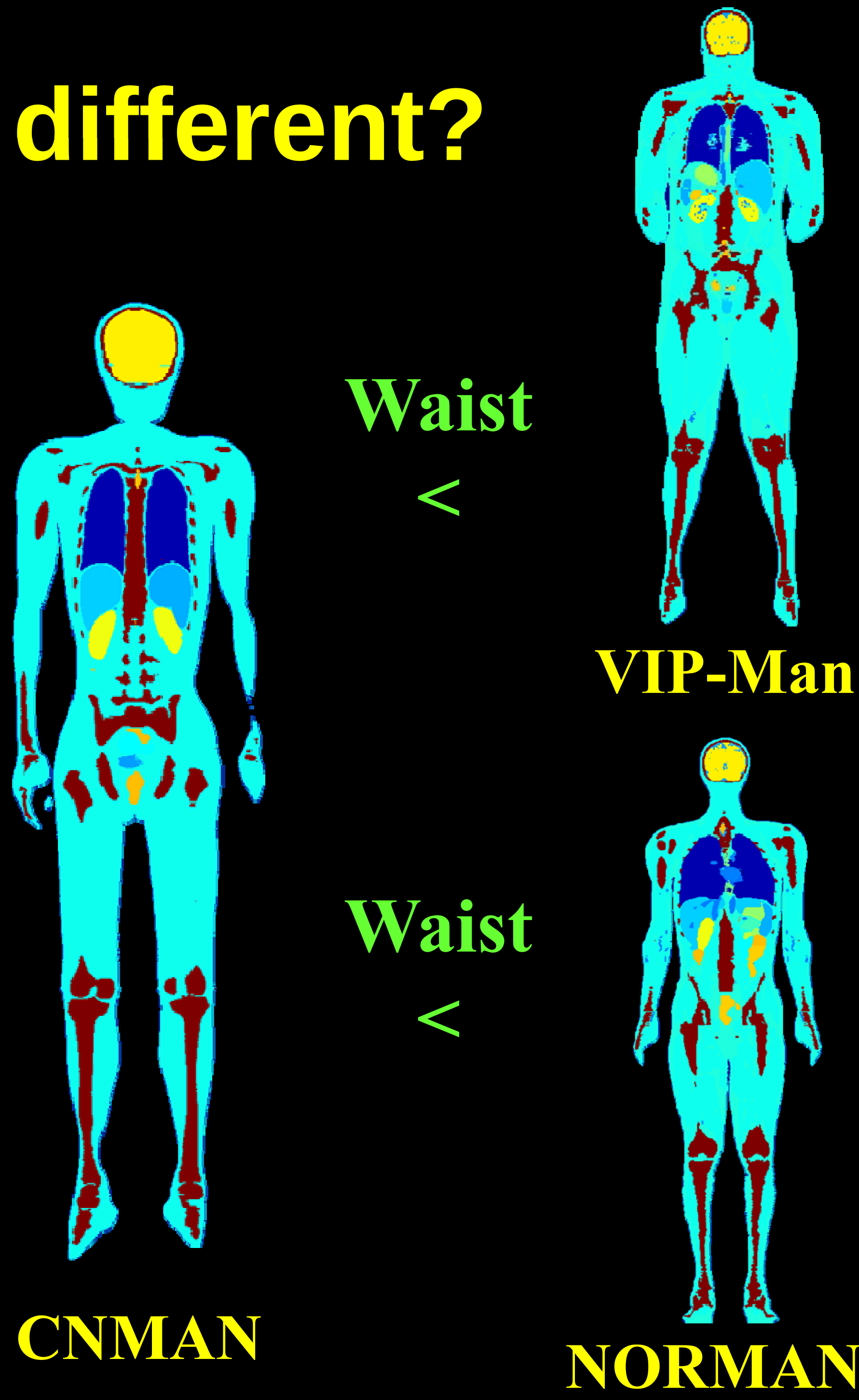


(Smith et al 1979)

Linear regression may not be found with all counting systems.

Why is CNMAN different?

- CNMAN's counting efficiency is less than would be expected by the trend line because differences in body proportions.
- Detectors placed near waist, and CNMAN has noticeably smaller waist.
- Detectors effectively further from the radionuclides.



Conclusions

- **Virtual whole-body counting simulations performed on 2 BOMAB and 3 image-based voxel phantoms. Different body shapes results in distinct efficiency curves.**

- **In general, phantoms have *similar WBC efficiencies* if *height and weight are similar***

- **If two phantoms have *similar heights, but differ in weight*, efficiencies might vary about 10% - 26% → well within proposed -25% to 50% accuracy range (ANSI 13.30).**

Conclusions

- **However, height & weight are not sufficient to completely explain WBC efficiency (e.g. CNMAN); they are only convenient ways to characterize the true dependent variable: *body shape*.**

- **Homogeneous water-filled VIP-Man, NORMAN, & CNMAN had *similar* counting efficiencies to their heterogeneous counterparts.**

- **Confirms that an appropriately sized, shaped BOMAB phantom may be sufficient for WBC calibrations if the *assumption of homogeneous contamination* is acceptable.**

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Future

- We hope to continue the whole-body comparisons with additional imaged-based voxel phantoms. Many phantoms have been developed, but few compared.
- Consider non-homogeneous contamination scenarios (e.g. bone-seeking radionuclides).
- Investigate different counting systems.

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