In-vivo Bioassay

Whole-body Counting
Organ and Wound Counting
Calibration and QA

Learning Objectives

- Describe detectors and geometries used for whole-body counting
- Describe detectors and geometries used for organ counting
- Describe calibration and quality assurance methods

Whole Body Counting

- External measurement of photons emitted by radionuclides within the body
- Photons must have sufficient energy and abundance to escape the body
- Can also detect bremsstrahlung from energetic beta emitters
- Method of choice for most fission and activation products

Detectors

- NaI(Tl) - most common, high efficiency, poor resolution
- HPGe - increasingly common, usually in scanning geometry, high resolution offsets low efficiency for mixed radionuclides
- Phoswich - thin NaI(Tl) backed by CsI(Tl) operated in anti-coincidence, low background, high efficiency for low energy photons

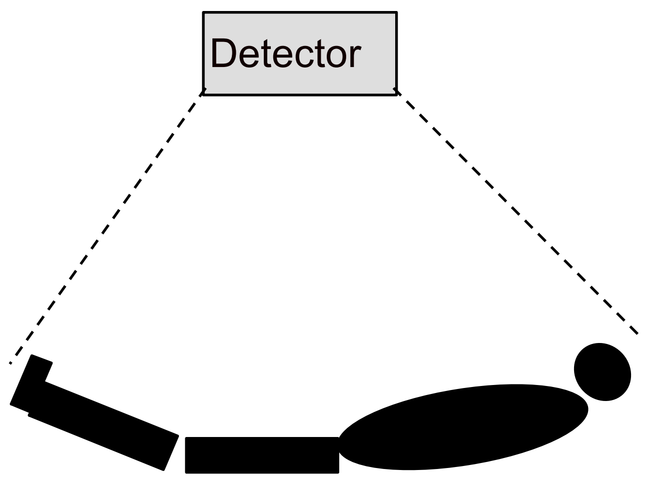
Detectors, cont.

- Proportional Counters - low background, low efficiency, but large area for low energy photons
- Si(Li) - high efficiency, low background due to high resolution for low energy
- CdTe - occasionally used for wound monitor
- $BiGeO_4$ - large volume, high efficiency, but not in routine use anywhere

WBC Geometries

- Arc - uncomfortable, least sensitive, analytical calibration, not sensitive to distribution
- Chair - fairly common, similar to arc, more sensitive, somewhat dependent on distribution
- Bed - needs many detectors or scanning geometry, can get distribution data, same geometry as stand-up

METER ARC GEOMETRY



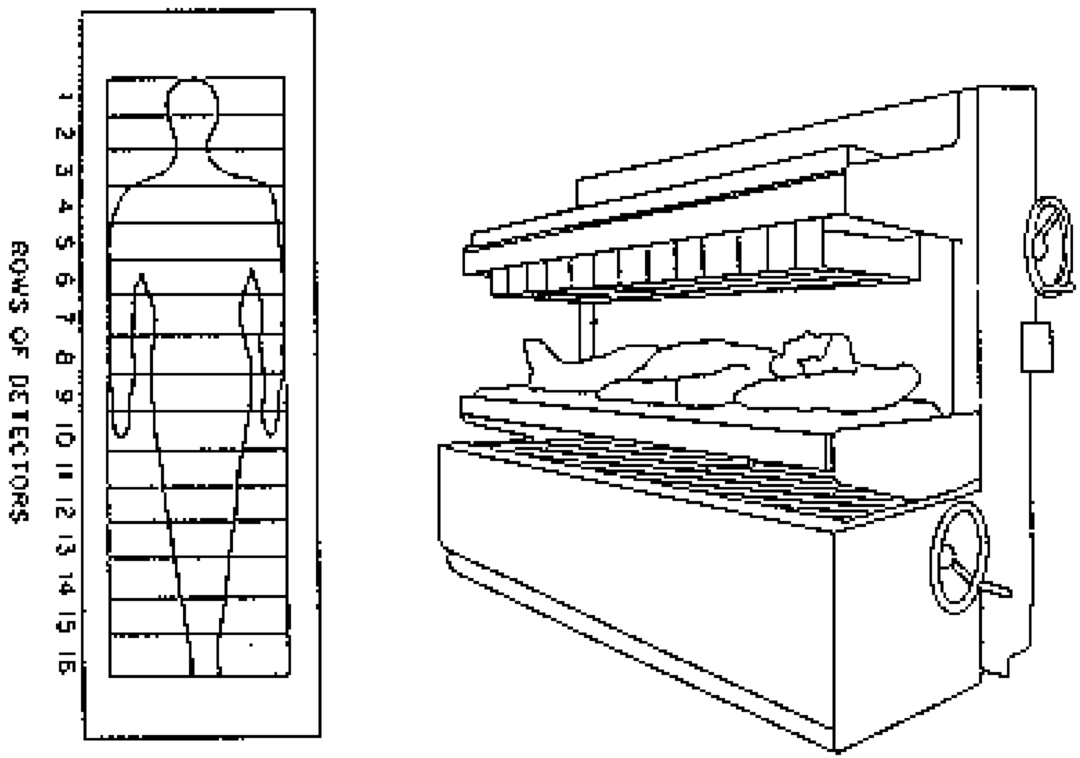
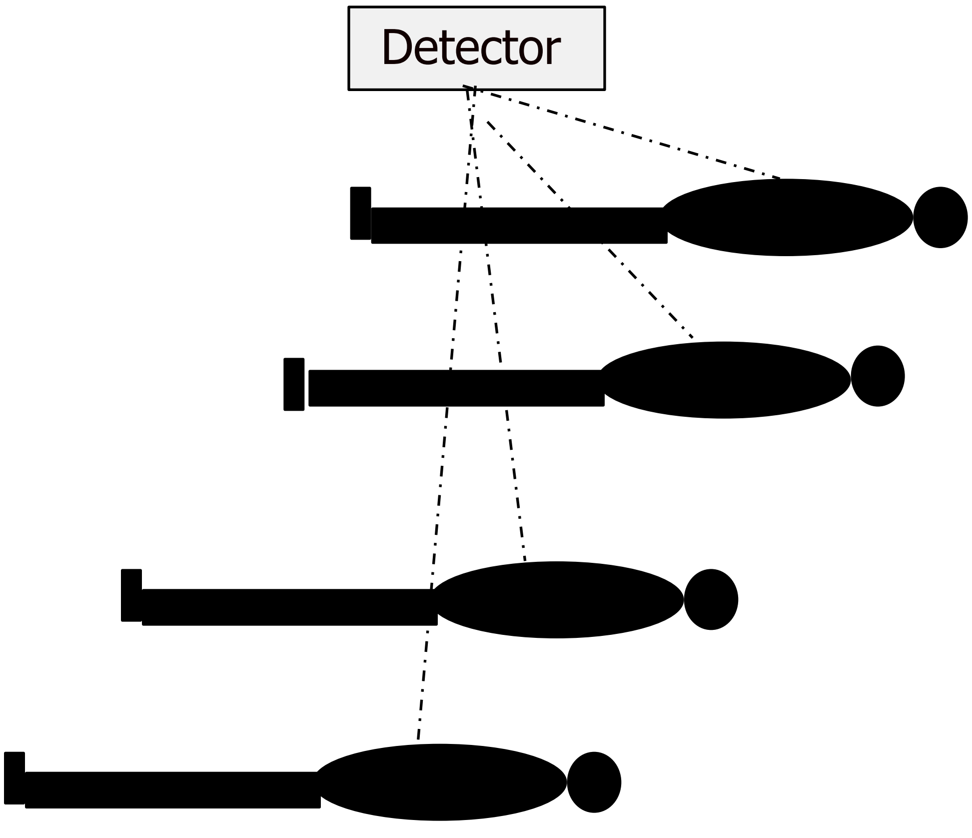


Fig. 2b. A drawing of the upgraded Brookhaven whole-body counter.
(Figure provided by Kenneth J. Ellis, Brookhaven National Laboratory)

Scanning Geometry



WBC Shielding

- Two approaches:
  - Shield everything, ie, special room
  - Shield detector, ie, “shadow shield”

Both are fairly common -- shadow shields are used more in industry for quick screening. Research facilities normally build WBC rooms.

Steel is most common shielding material.

Data Collection

- Typical configuration:
  - Detector - preamp - amplifier - discriminator - analog - to - digital - converter - multi-channel - analyzer (usually computer based)
  - Can get fancy with anti-coincidence detector, summing multiple detectors, etc.
  - Most problems usually arise in the ADC’s.
  - Dead time usually not a problem for WBC.

Data Analysis

- Usually computerized
- Peak search with digital filter
- Individual peak fitting or summing over predefined region of interest (ROI)
- Least squares fit with library of standard spectra - - only as good as standards
- Software verification extremely important, and almost always neglected - - program may be proprietary

Subject Handling

- Routine:
  - Scheduled appointments, frequency based on missed dose or work completion; shower, change into clean clothes, secure valuables; typical counting times from 10 to 40 minutes. Quick screens in 2 minutes without changing.
- Emergency:
  - Decontaminate and medical treatment first! Operator on call, rapid preliminary results.

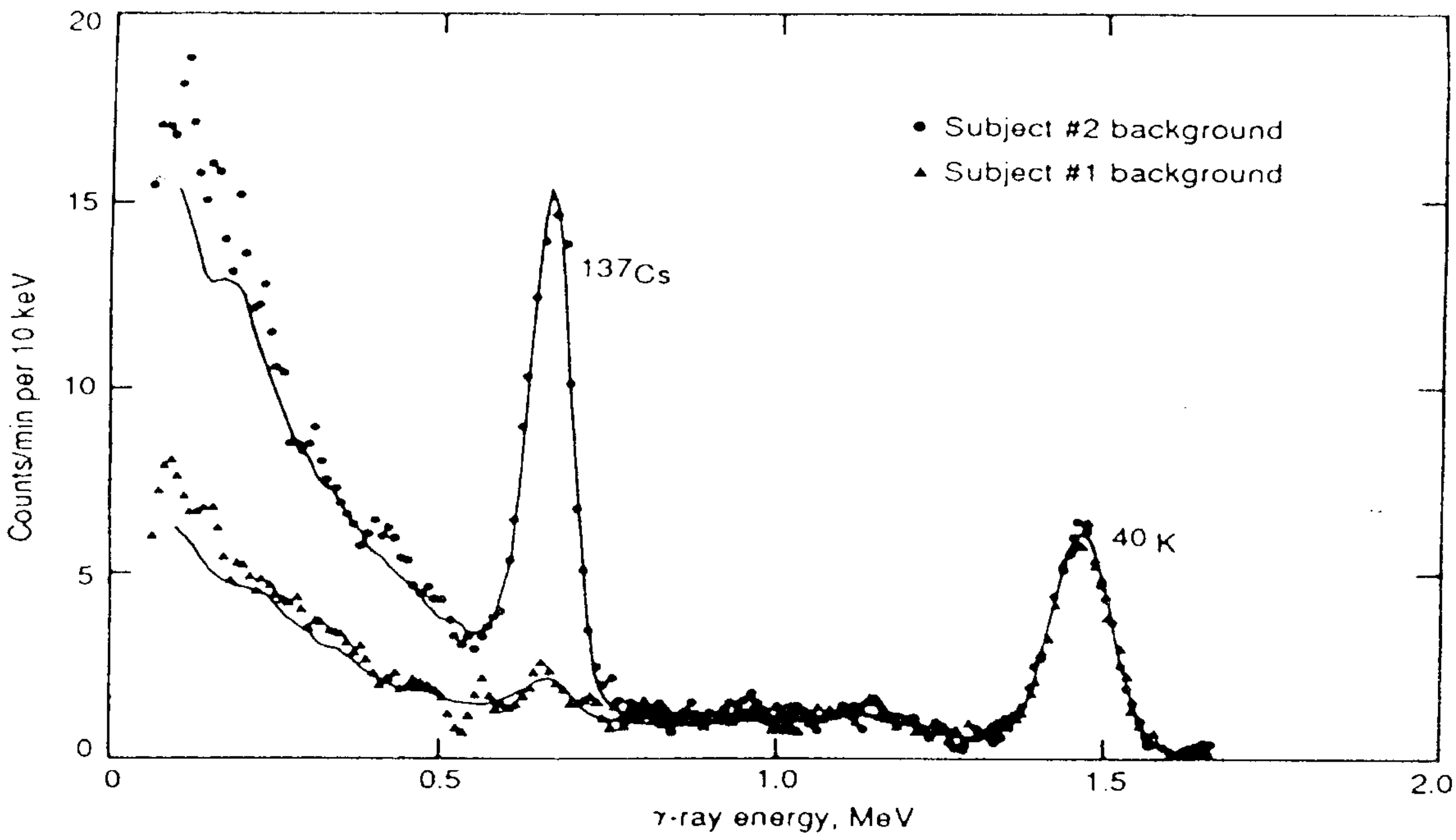
Background Components

- Cosmic ray muons and their interaction products
- Terrestrial gamma-emitting radionuclides (K-40, U-238 and Th-232 and progeny)
- Trace radioactivity in components (Co-60 in steel, U in Be, etc.)
- Natural and fallout radioactivity in subjects (K-40, Cs-137, Rn-222 and progeny)

Average Body Content of Radionuclides Measurable by Whole-Body Counting and Normally Present

Nuclide	Origin	Avg. Content, Bq (μCi)
^{40}K	Natural	3700 (0.1)
^{137}Cs	Global fallout	100 (0.003)
^{214}Pb, etc. (^{222}Rn progeny)	Natural	40 (0.001) or more

NaI(Tl) Spectra of 2 Subjects



Typical Body Content of Radionuclides not Measurable by WBC

Nuclide	Origin	Average Content, Bq (μCi)
^{3}H	Cosmic plus fallout	30 (8×10^{-4})
$^{235,238}U$	Natural	1.5 (4×10^{-5})
^{226}Ra	Natural	1 (3×10^{-5})
^{228}Ra	Natural	0.4 (1×10^{-5})
^{14}C	Cosmic plus fallout	3700 (0.1)
$^{239,240}Pu$	Global fallout	0.4 (1×10^{-5})
^{90}Sr - ^{90}Y	Global fallout	30 (7×10^{-4})
^{87}Rb	Natural	700 (0.02)

Source: Eisenbud 1987

Interferences

- Biggest problem
  - External contamination
- Surprisingly frequent
  - Nuclear medicine procedures
  - Example: Tl-202, trace contaminant in Tl-201 used for myocardial imaging
  - MDA via WBC = 1 nCi; amount injected = 0.01 mCi (0.1% of 10 mCi Tl-201)
  - T(e) = 6 d, detectable for 100 days post inj.

Sensitivities of Various Whole-body Counting Systems (Bq)

Nuclide	γ- energy, MeV	Typical MDA, 30 min	MDA BNL 15 min	MDA new 10 x 60 min
^{137}Cs	0.66	74	22	1
^{54}Mn	0.84	111	88	4
^{65}Zn	1.12	111	111	5
^{60}Co	1.33	111	140	6

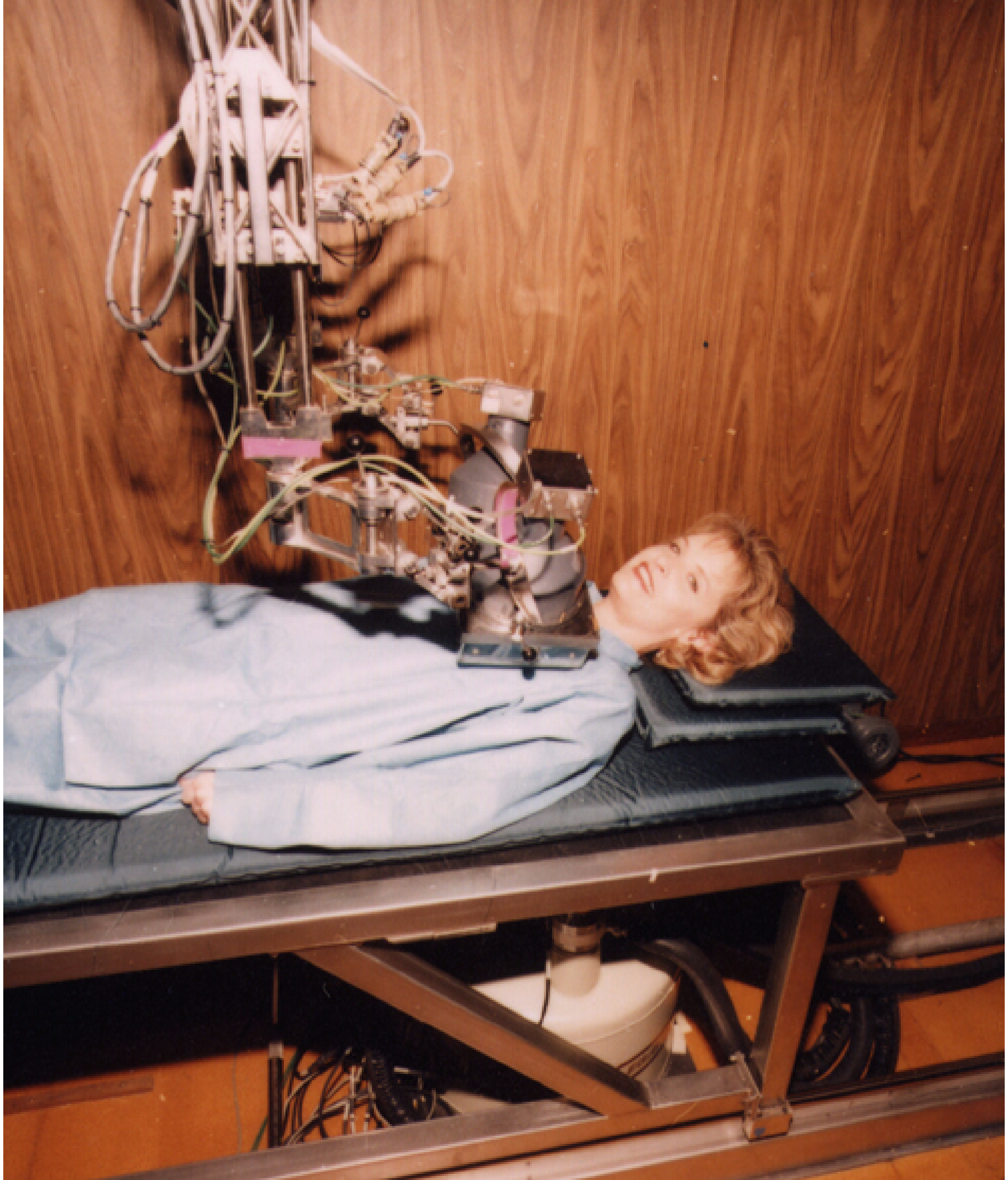
Health Physics 1991. Volume 60, Supplemental 1

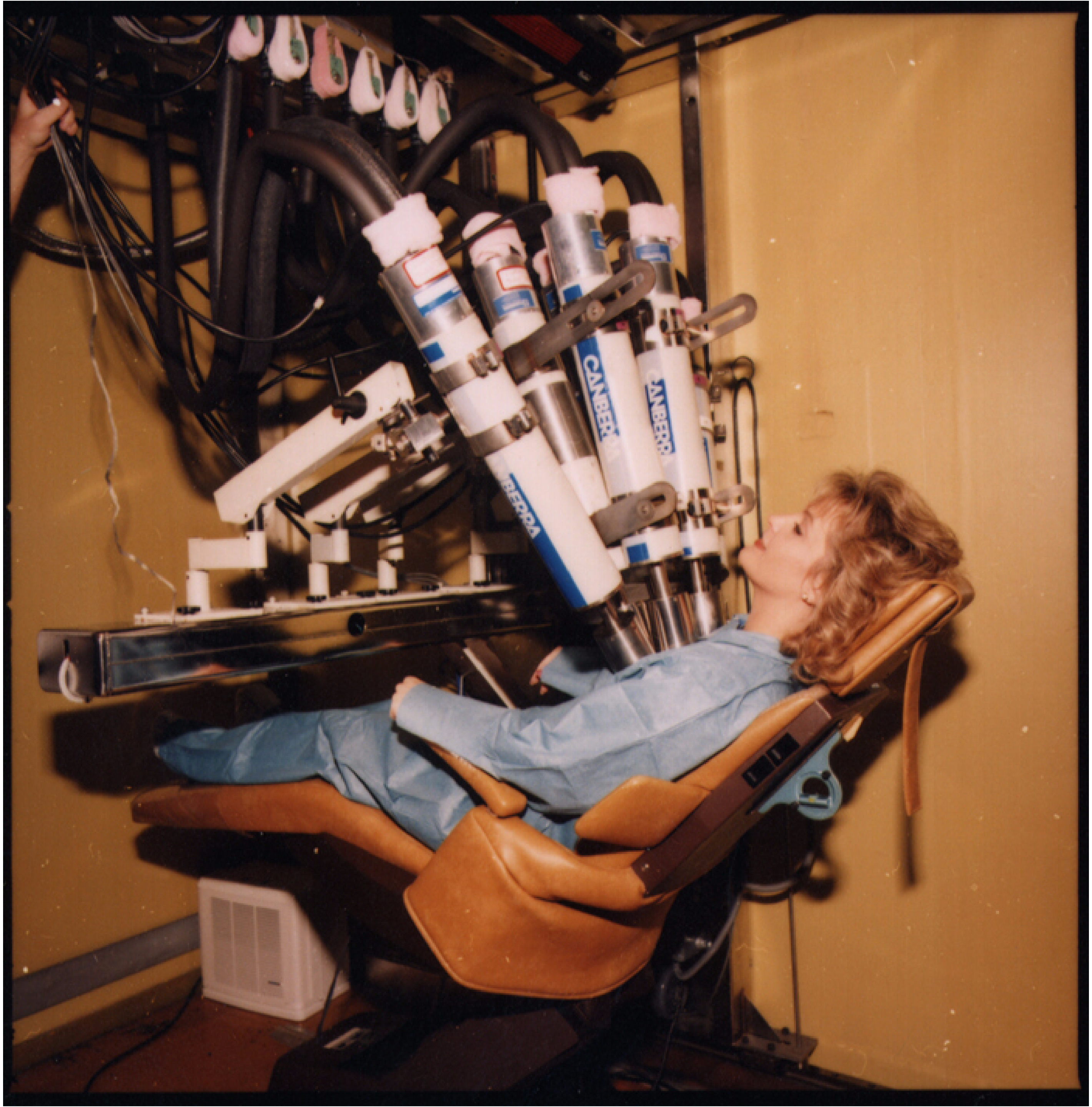
Lung Counting for Pu-239
or other low-energy emitters

- Low-energy photon emitters: 13 - - 90 keV Pu, Am, Pb-210, U
- HPGe detectors currently state-of-the-art
- Critical parameter is chest wall thickness HVL of soft tissue = 6 mm at 17 keV
- Am-241 60 keV line often used as tracer, presuming the Am/Pu ratio is known

Lung Counting (cont.)

- CWT measured ultrasonically, or correlated with height, weight, chest circumference, etc. Also need to know % adipose tissue.
- Calibration derived from Livermore phantom, verified by in-vivo tracer experiments.
- Some data show that distribution of activity in lung is particle size dependent.
- Current MDA for "pure" Pu-239 is 60 nCi, vs. ALI of 5 nCi (lung content of ~1 nCi); MDA via Am-241 is ~2 nCi.





Skull Counting

- Used for bone-seeking low-energy photon emitters, including Pu, Am and Pb-210.
- Skull represents 14% of skeletal mass and 12% of total bone surface area; must assume distribution of activity is representative of entire skeleton.
- Easy to surround skull with detectors.
- Can measure cumulative radon exposure.

Liver Counting

- Deposition site for transuranics
- Difficult for low-energy emitters due to severe attenuation
- Can count left side of abdomen for background
- Some facilities look at liver with Ge while using NaI(Ti) for WBC, in order to identify gamma emitters

Wound Counting

- Important to quantify intake, especially as regards need for medical treatment
- For low-energy photon emitters, can estimate depth by differential attenuation, so guide excision
- Usually a dedicated detector at medical facility is used
- Type(s) of detector determined by radionuclides in use at facility

Typical wound counter—NaI(Tl)

Distribution Measurements

- Gross distribution by placing counter at different locations
- Usually performed in scanning geometry
- Increased resolution from collimating detector, but much longer counting time
- Must know anatomy and physiology to interpret correctly

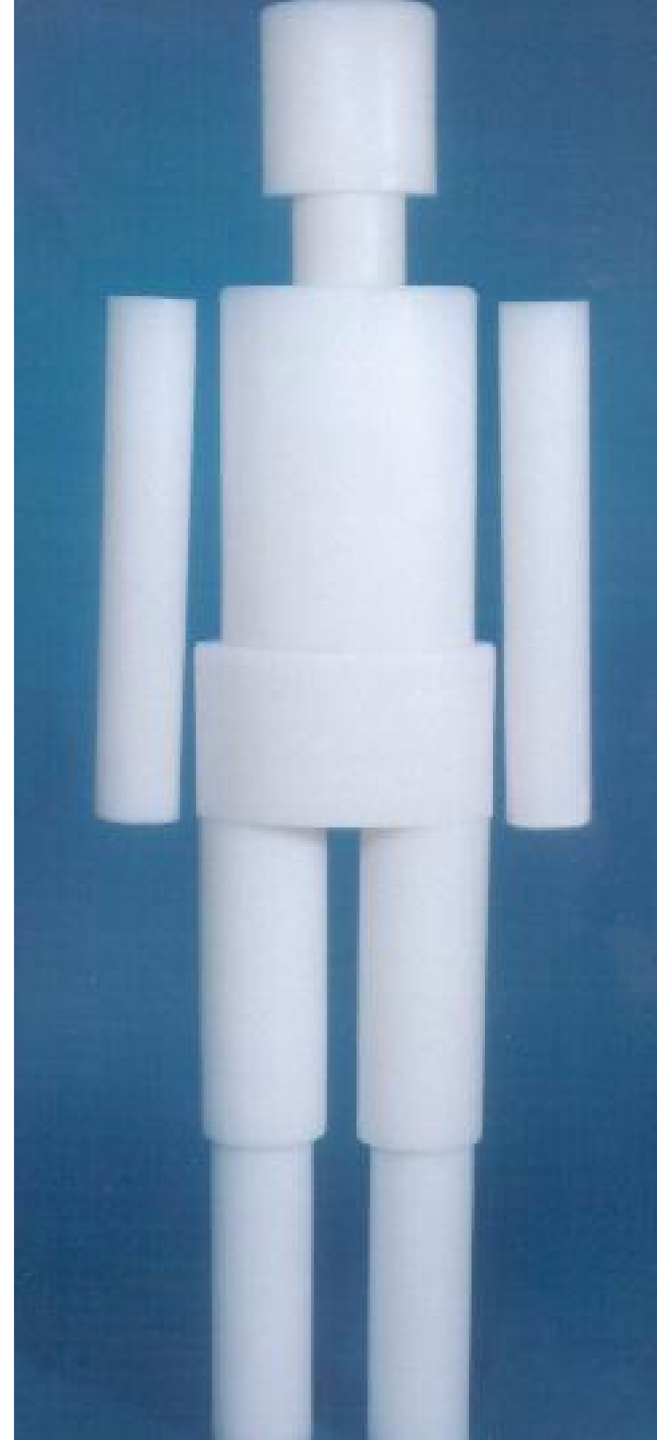
Calibration Methods

- Analytical
  - arc geometry - - can cross - - calibrate others
  - scanning bed - - mathematics very messy
- In-vivo tracer methods
  - use K-40 as internal standard
  - inject known amount of activity
  - can even use radiopharmaceuticals
- Phantoms: most common method
  - commercially available
  - homemade

Phantoms

- BOMAB - - Bottle Manikin Absorption simplest, uniform distribution, tends to leak, good for K-40, Cs-137
- REMCAL - - Radiation Equivalent Manikin Calibration more anthropomorphic, variable distribution, separate organs
- REMAB - - Radiation Equivalent Manikin Absorption more complex, adjustable distribution, separate organs, including skeleton

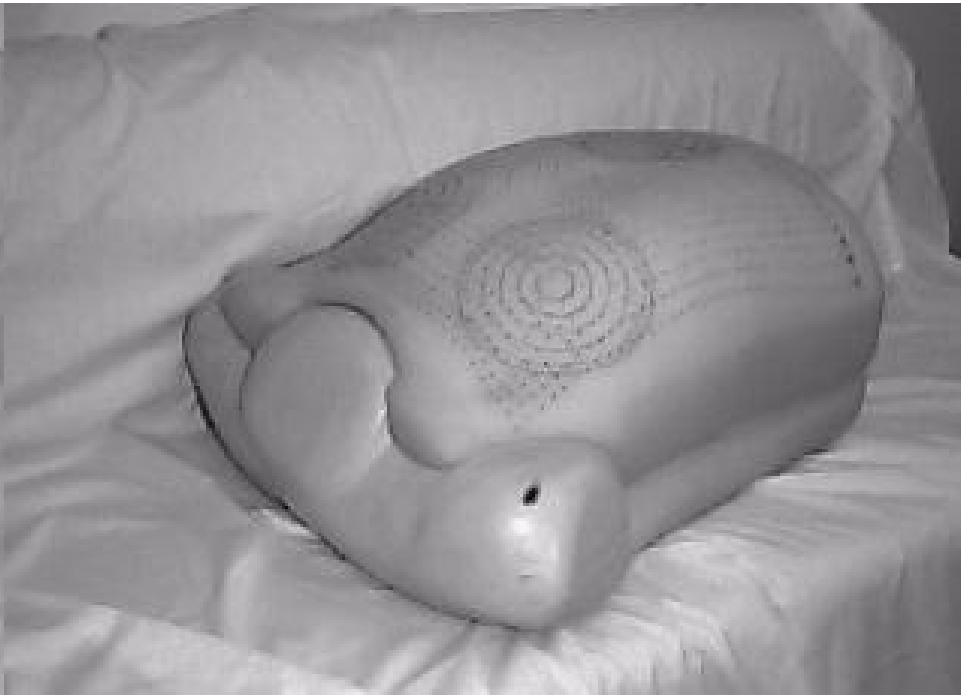
BOMAB



More Phantoms

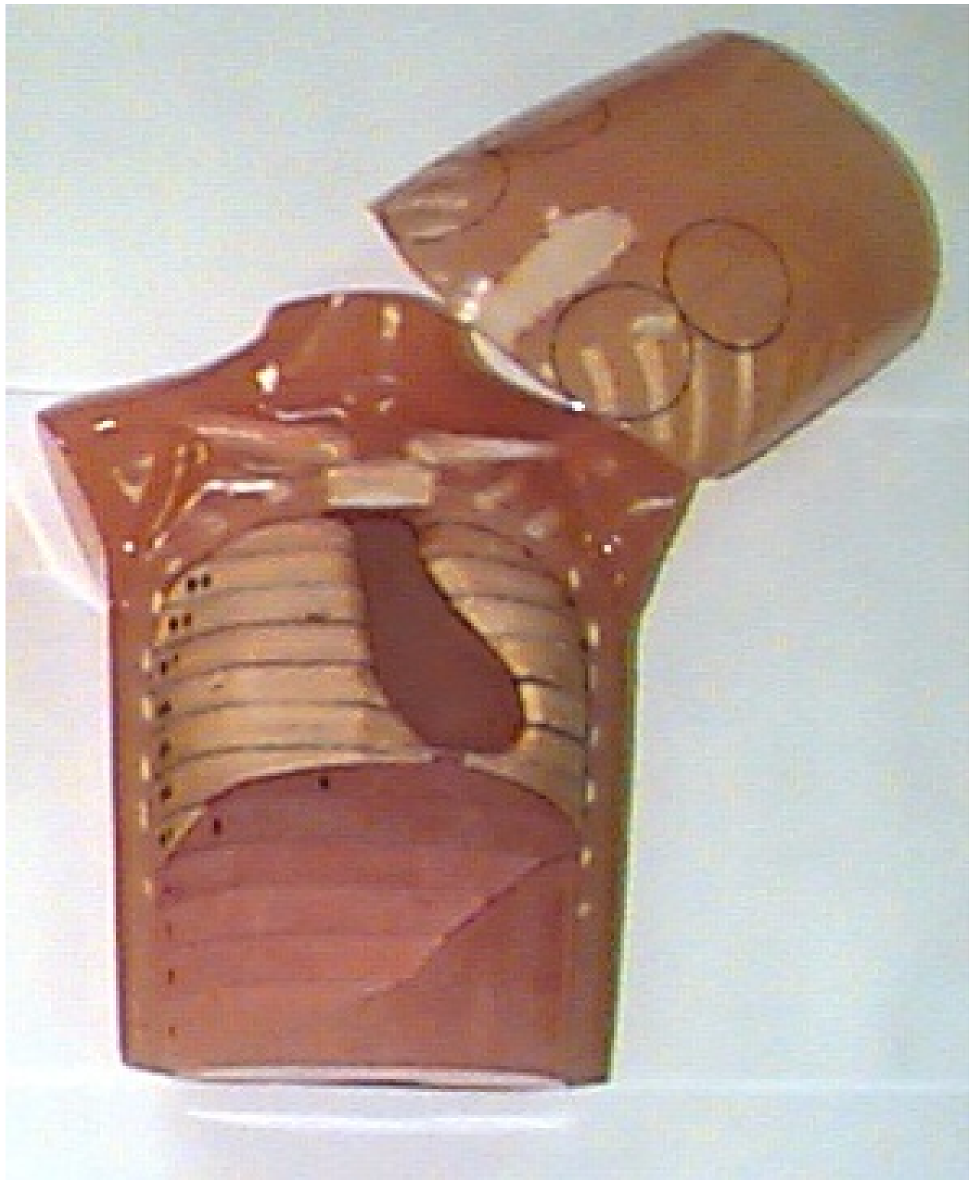
- RALPH - - Realistic Anthropomorphic Livermore Phantom - - a.k.a. Realistic Thorax Phantom designed for low-energy photon emitters in lung and liver - - add - ons for rest of body
- Specialized phantoms:
  - Skull for bone counting
  - Thyroid
  - Wound

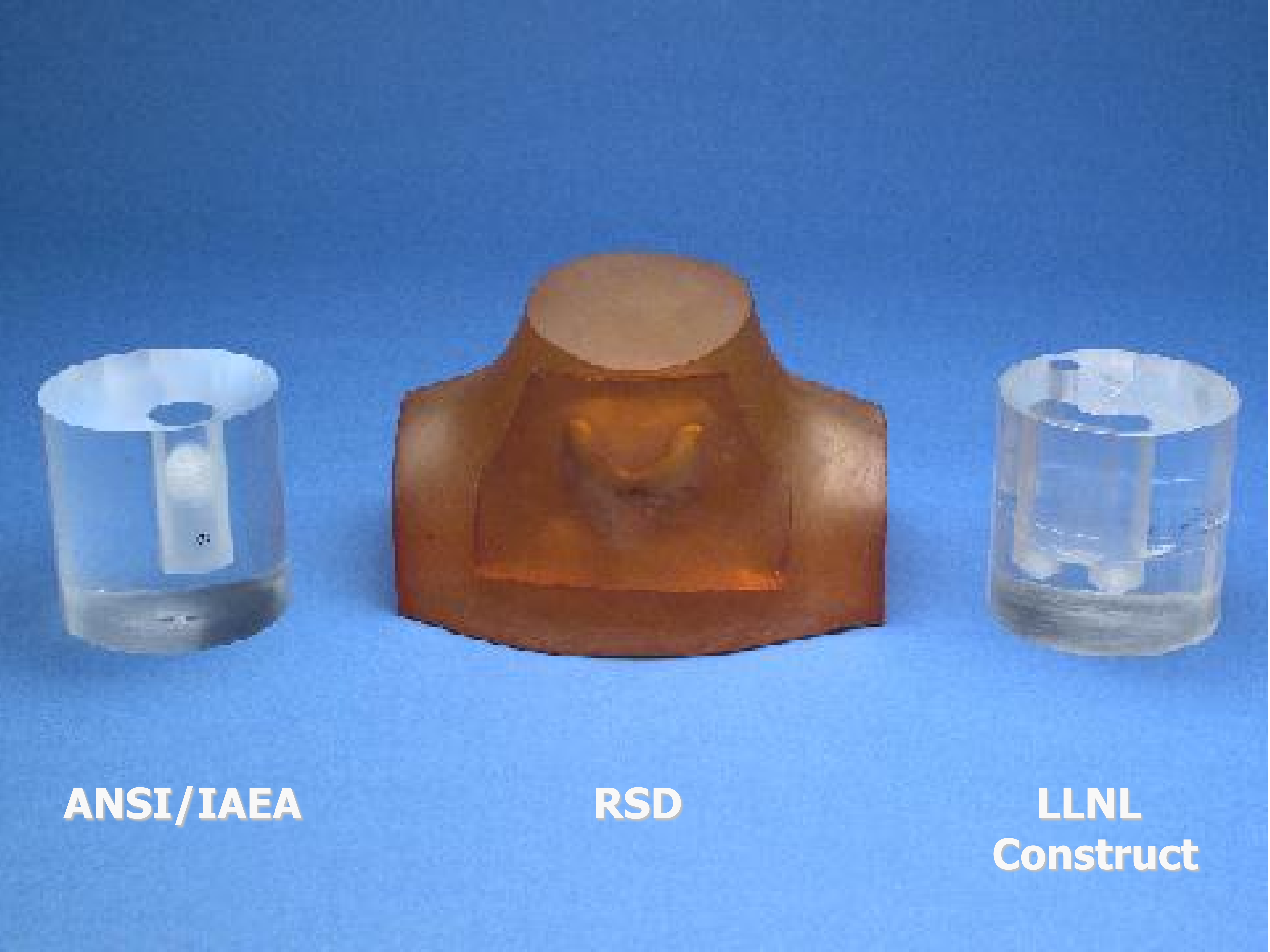
The LLNL Torso Phantom



MFP

JAERI Phantom




ANSI/IAEA
RSD
LLNL
Construct

Things to Remember

- Phantoms designed for specific purposes
- May need to correct for body size
- Radionuclide content should be traceable to NIST or other certifying organization
- Phantom calibrations should be performed once or twice a year or after significant equipment or configuration changes
- Use daily check source in fixed geometry to verify efficiency and gain

Other Calibration Methods

- K-40, internal standard - - can use to determine total body potassium, which in turn is 0.2% of body mass
- Calibrate by counting many (>20) people, average K content vs. 0.2% body mass
- Calibrate other gamma emitters by correcting for photon yield, detector efficiency, and absorption in body
- Correct only for uniform distribution

Tracer Calibration Methods

- Na-24 injection, tracer for K-40
- “Mock plutonium” for lung counter calibration - - Nb - 92m, same photon emission as Pu-239, gamma-ray tracer at 440 keV, no particulate emission, so low dose
- Radiopharmaceuticals: can be used IF you can determine amount in body at time of count from amount administered and retained

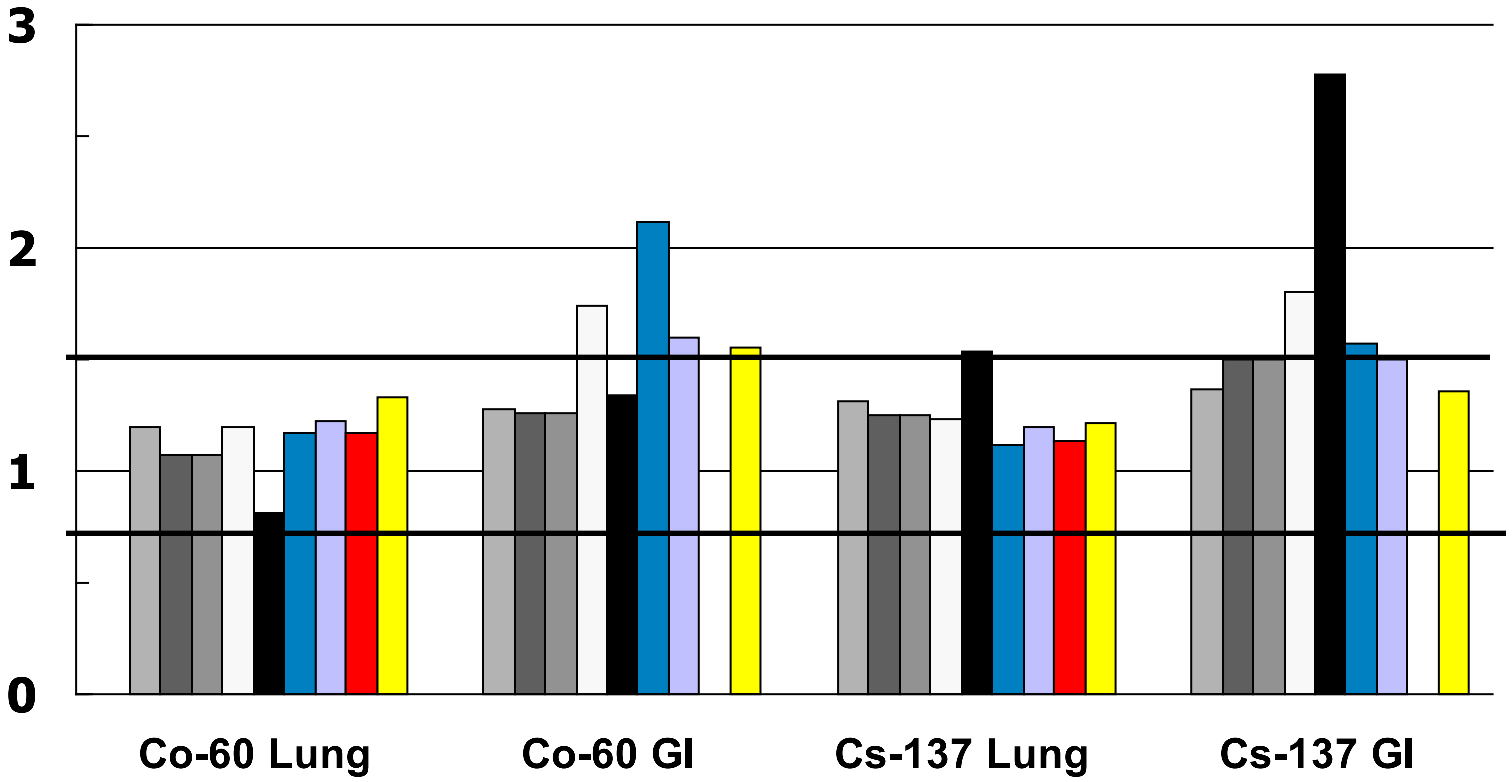
Cross-calibrations

- Numerous exercises sponsored by DOE in which point sources, phantoms and occasionally subjects have been sent around to various facilities
- Becoming codified in an in-vivo DOELAP program, and a standard phantom library
- Eventually may be a NVLAP program similar to that for external dosimetry

Quality Assurance in WBC

- Essentially the same as for in-vitro bioassay
- Documentation: technical basis document, procedure manuals, qualification records, calibration and daily check records, traceability of standards
- Configuration control: detectors, geometries, patient handling, software verification

WBC Intercomparison--Open Geometries



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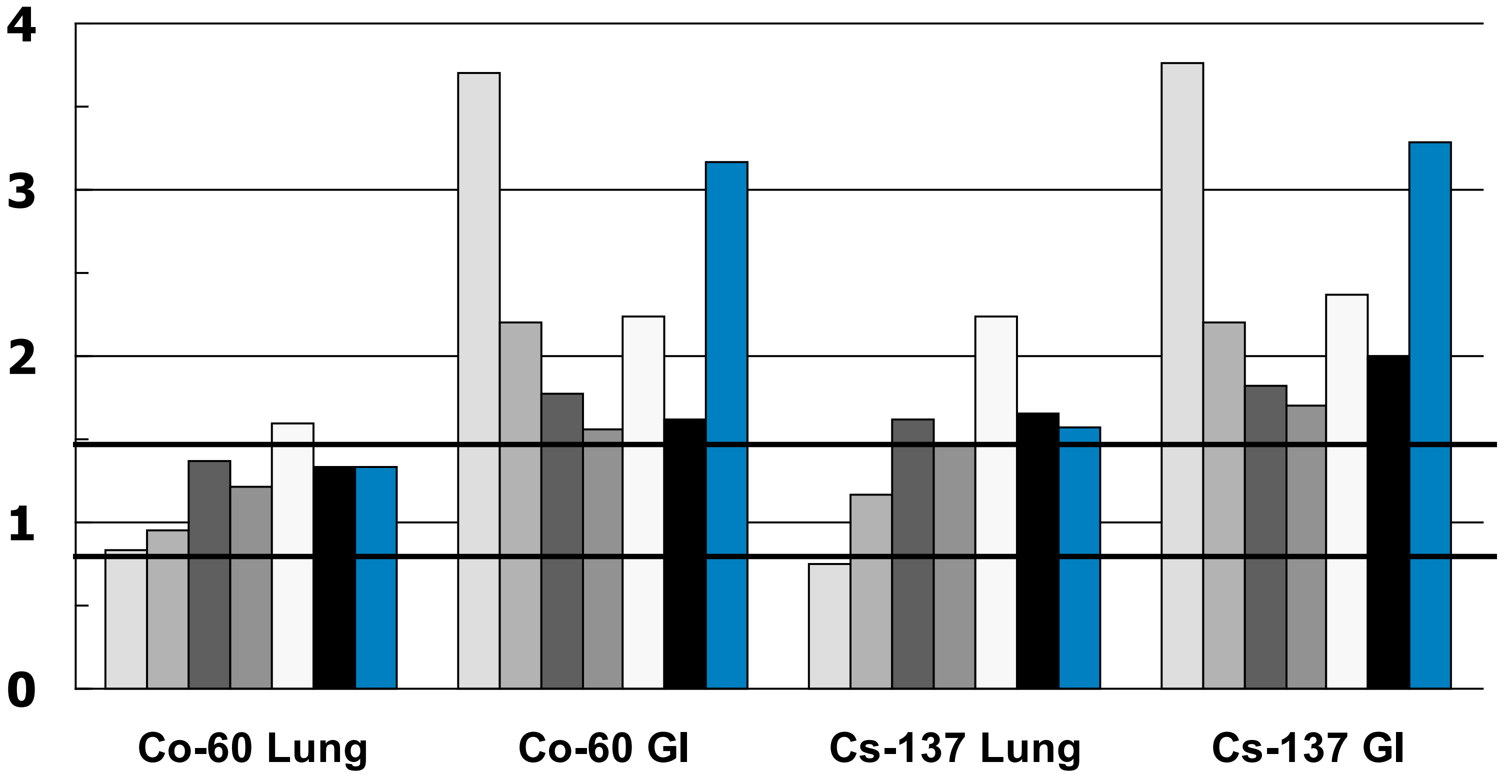
WBC Intercomparison--Closed Geometries



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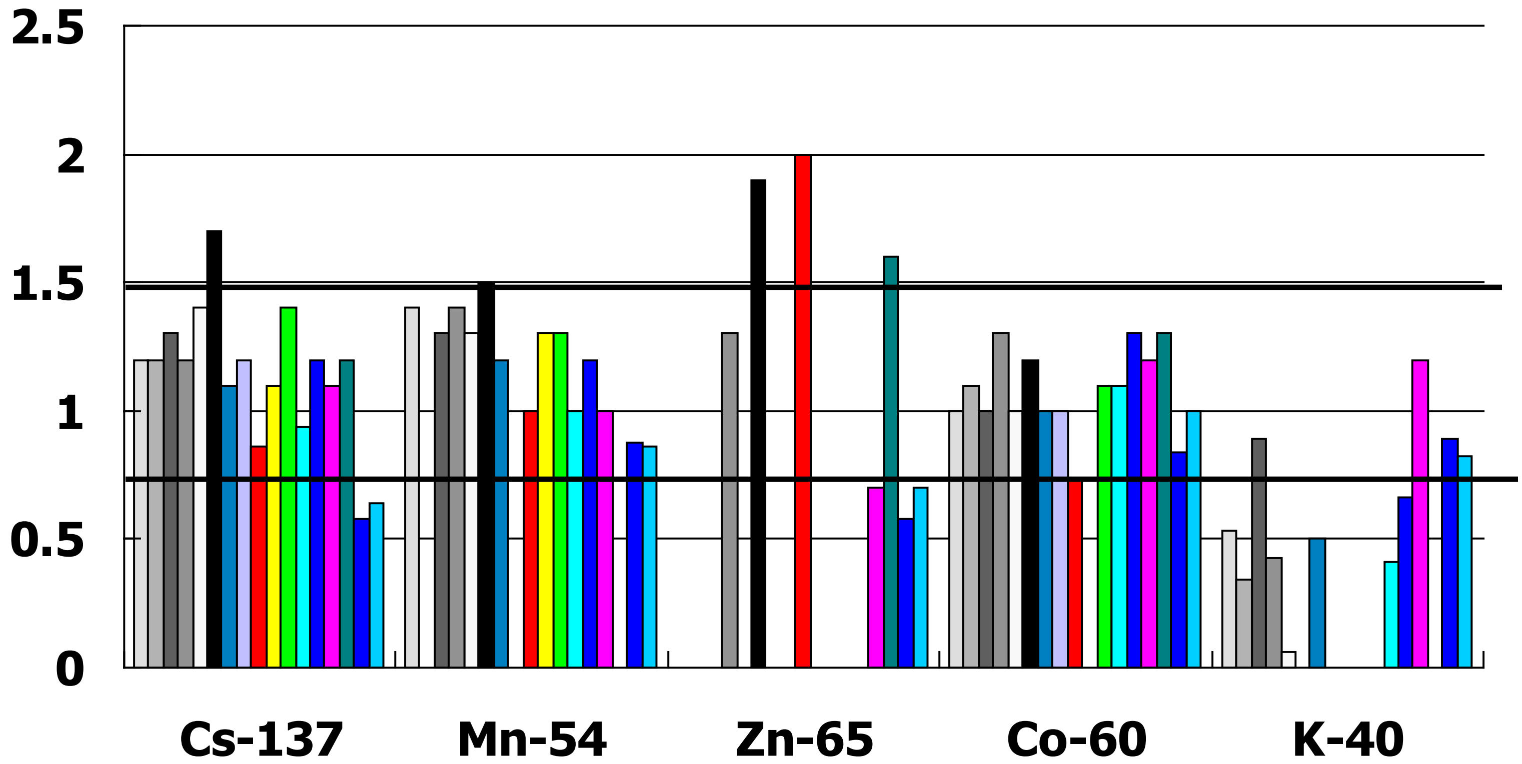
WBC Intercomparison Region III



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