

Internal Dose Assessment: Techniques and Example Problems

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Concepts

- Internal dose estimates – “marriage” of physical and biological quantities
- Biology – distribution and kinetics
- Physics – energy deposition patterns



Absorbed dose: $D = \frac{d\varepsilon}{dm}$

$$D = N \times DCF$$

N is the number of disintegrations that occur in a source region

DCF is the dose conversion factor, which gives the dose absorbed in a target per disintegration in a source

$$DCF (T \leftarrow S) = \frac{k \sum_i n_i E_i \phi_i (T \leftarrow S)}{m_T}$$

n_i = the fraction of disintegrations that occur with energy E_i ,

$\phi(T \leftarrow S)$ = the fraction of energy emitted in source region S that is absorbed in target region T,

m_T = the mass of target region T, and

k = a unit conversion factor.

(for example if we have energy in MeV and mass in g and we want the dose in Gy, we need to convert MeV to J, and g to kg, as $1 \text{ Gy} = 1 \text{ J/kg}$).

$$H = D Q$$

Radiation Weighting Factors	
Alpha particles	20
Beta particles (+/-)	1
Gamma rays	1
X-rays	1
Auger, conversion electrons	>1



?



MIRD

$$D_{r_k} = \sum_h \tilde{A}_h S(r_k \leftarrow r_h)$$

$$S(r_k \leftarrow r_h) = \frac{k \sum_i n_i E_i \phi_i(r_k \leftarrow r_h)}{m_{r_h}}$$

ICRP

$$H_{50,T} = \sum_S U_S SEE(T \leftarrow S)$$

$$SEE = \frac{k \sum_i n_i E_i \phi_i Q_i}{m}$$

Absorbed dose: $D = \frac{d\varepsilon}{dm}$

$$D = N \times DCF$$

N is the number of disintegrations that occur in a source region

DCF is the dose conversion factor, which gives the dose absorbed in a target per disintegration in a source

Problem #1 - First Principles

ICRP Report #23 describes Reference Man as containing 140 grams of potassium. Estimate the average beta dose rate in rad/week to the whole body, given the following information:

Reference Man	70,000 g
K-40 in potassium	0.012%
K-40 beta decay probability	90%
K-40 maximum beta energy	1.3 MeV
K-40 half-life	1.2×10^9 years

Problem #1 - First Principles

Avogadro's number	6.023×10^{23}
Energy conversion	1.6021×10^{-6} erg/MeV
Dose conversion	100 erg/g = 1 rad

First, we need to find how much activity we have, which is calculated from the number of grams, from the well-known relationship:

$$A = \lambda N$$

Problem #1 - First Principles

$$A = \left(\frac{0.693}{1.2 \times 10^9 \text{ yr}} \right) \left(\frac{1 \text{ yr}}{\pi \times 10^7 \text{ sec}} \right) (140 \text{ g K}) \times$$
$$\left(\frac{1.2 \times 10^{-4} \text{ g K} - 40}{\text{g K}} \right) \left(\frac{\text{mol K} - 40}{40 \text{ g K} - 40} \right) \left(\frac{6.023 \times 10^{23} \text{ atoms}}{\text{mol}} \right)$$

$$A = 4.65 \times 10^3 \text{ atoms/ sec} = 4.65 \times 10^3 \text{ dis/ sec}$$

Problem #1 - First Principles

$$D = \left(\frac{4.65 \times 10^3 \text{ dis}}{\text{sec}} \right) \left(\frac{6.048 \times 10^5 \text{ sec}}{\text{week}} \right) \left(\frac{1.3 \text{ MeV}}{3 \beta} \right) \times$$
$$\left(\frac{0.9 \beta}{\text{dis}} \right) \left(\frac{1.602 \times 10^{-6} \text{ erg}}{\text{MeV}} \right) \left(\frac{\text{g} - \text{rad}}{100 \text{ erg}} \right) \left(\frac{1}{70000 \text{ g}} \right)$$

$$D = 2.5 \times 10^{-4} \text{ rad/week}$$

Problem #2 - Contributions to Organ Dose

Calculate the dose to liver, spleen, and lungs from Y-90 activity in the liver and spleen as described below. To understand the contributions to the total dose to any organ, consider separately:

- a) dose from nonpenetrating radiations (nonpenetrating self-dose),
- b) dose from penetrating radiations when source and target are the same organ (penetrating self-dose),
- c) dose from penetrating radiations when source and target are not the same organ (cross-irradiation dose).

Problem #2 - Contributions to Organ Dose

Complete the data tables below to calculate the doses.

<u>Organ</u>	<u>mass (kg)</u>	<u>\tilde{A} ($\mu\text{Ci}\cdot\text{hr}$)</u>
Liver	1.91	2000
Spleen	0.183	2000
Lungs	1.00	0

For Y-90:

$$\Delta_p = 0.000 \text{ g-rad}/\mu\text{Ci-hr} \quad \Delta_{np} = 1.99 \text{ g-rad}/\mu\text{Ci-hr}$$

(p=penetrating, np=nonpenetrating)

Problem #2 - Contributions to Organ Dose

	$\phi(r_T \leftarrow \text{liver})$		$\phi(r_T \leftarrow \text{spleen})$	
<u>Target</u> (r_T)	<u>p</u>	<u>np</u>	<u>p</u>	<u>np</u>
Liver	<u>NA</u>	<u>1</u>	<u>NA</u>	<u>0</u>
Spleen	<u>NA</u>	<u>0</u>	<u>NA</u>	<u>1</u>
Lungs	<u>NA</u>	<u>0</u>	<u>NA</u>	<u>0</u>

Problem #2 - Contributions to Organ Dose

Target Organ	Source Organ				Total
	Liver		Spleen		
	p	np	p	np	
Liver	NA	2.1	NA	0	2.1
Spleen	NA	0	NA	22	22
Lungs	NA	0	NA	0	0

The liver dose is $(2000 \mu\text{Ci}\cdot\text{hr} \times 1.99 \text{ g-rad}/\mu\text{Ci}\cdot\text{hr})/1910 \text{ g} = 2.1 \text{ rad}$.

The spleen dose is $(2000 \mu\text{Ci}\cdot\text{hr} \times 1.99 \text{ g-rad}/\mu\text{Ci}\cdot\text{hr})/183 \text{ g} = 22 \text{ rad}$.

Problem #2 - Contributions to Organ Dose

Teaching Points

- Liver and spleen had equal cumulated activities. Because spleen is about 10x smaller, the dose is 10x higher (exactly true for beta emitters, results will vary for gamma emitters, but the trend will be the same).
- Units, units, units. The mass was given in kg, we needed to convert it to g. If we didn't, our answers were off by a mere factor of 1000, and our calculations would have wrongly indicated that the patient may have received an extremely high dose.

Problem #2 - Contributions to Organ Dose

Now let's repeat the problem using Tc-99m.

<u>Organ</u>	<u>mass (kg)</u>	<u>\tilde{A} ($\mu\text{Ci}\cdot\text{hr}$)</u>
Liver	1.91	2000
Spleen	0.183	2000
Lungs	1.00	0

For Tc-99m:

$$\Delta_p = 0.267 \text{ g-rad}/\mu\text{Ci-hr} \quad \Delta_{np} = 0.0342 \text{ g-rad}/\mu\text{Ci-hr}$$

(p=penetrating, np=nonpenetrating)

Problem #2 - Contributions to Organ Dose

	$\phi(r_T \leftarrow \text{liver})$		$\phi(r_T \leftarrow \text{spleen})$	
<u>Target</u> (r_T)	<u>p</u>	<u>np</u>	<u>p</u>	<u>np</u>
Liver	<u>0.162</u>	<u>1</u>	<u>0.0071</u>	<u>0</u>
Spleen	<u>0.00062</u>	<u>0</u>	<u>0.072</u>	<u>1</u>
Lungs	<u>0.0098</u>	<u>0</u>	<u>0.0085</u>	<u>0</u>

Problem #2 - Contributions to Organ Dose

Target Organ	Source Organ				Total
	Liver		Spleen		
	p	np	p	np	
Liver	0.045	0.036	0.002	0	0.083
Spleen	0.0018	0	0.21	0.37	0.59
Lungs	0.0052	0	0.0045	0	0.0097

Problem #2 - Contributions to Organ Dose

Teaching Points

- Again, with equal cumulated activities in liver and spleen, roughly a 10 fold difference in dose, due to the mass difference.
- Now lung gets a dose, even with no assigned activity. This is due to penetrating dose from the liver and spleen, i.e. photons that originate in these organs but deposit dose in the lungs.

Problem #3 - Calculation of MIRD S-value for average organ dose

We can calculate an S-value for liver self-irradiation from Tc-99m by combining the appropriate decay data with calculated absorbed fractions. Here is the decay scheme for Tc-99m (data from the RADAR web site, www.doseinfo-radar.com):

			Radiation
	Rad.	Energy	Intensity
	Type	(keV)	(%)
Tc-99m	E-CE-M	1.6286	74.6
6.01 h	E-AU-L	2.17	10.2
	E-AU-K	15.5	2.07
	E-CE-K	119.467	8.8
	E-CE-K	121.59	0.55
	E-CE-L	137.4685	1.07
	E-CE-L	139.59	0.172
	E-CE-M	139.967	0.194
	E-CE-N+	140.443	0.0374
	E-CE-M	142.09	0.034
	G-X-L	2.42	0.48
	G-X-K α 2	18.2508	2.1
	G-X-K α 1	18.3671	4.02
	G-X-K β	20.6	1.2
	G	140.511	89.06
	G	142.63	0.0187



MIRD System

One more definition.

Recall that:

$$S = \frac{k \sum_i n_i E_i \phi_i}{m}$$

So we can define:

$$\Delta_i = k n_i E_i$$

And then say that:

$$S = \frac{\sum_i \Delta_i \phi_i}{m}$$

What is the value of k?

$$\frac{3.7 \times 10^4 \text{ dis}}{s - \mu\text{Ci}} \frac{3600 \text{ s}}{h} \frac{1.6 \times 10^{-6} \text{ erg}}{\text{MeV}} \frac{g - \text{rad}}{100 \text{ erg}} = 2.13$$

<u>Emission</u>	<u>n</u>	<u>E</u>	<u>k n E</u>	<u>φ</u>	<u>k n E φ</u>
γ 2:	0.891	0.1405	0.267	0.162	0.0432
K _{α1} x-ray	0.04	0.0184	0.0016	0.82	0.0013
K _{α2} x-ray	0.021	0.0182	0.0008	0.82	0.00066
K _{β1} x-ray	0.012	0.0206	0.0003	0.78	0.00041
"Nonpen"	--	--	0.0321	1.0	0.0321
				<u>TOTAL =</u>	<u>0.078</u>

E is in units of MeV/dis, so k n E φ has units of g-rad/μCi-hr.

Problem #3 - Calculation of MIRD S-value for average organ dose

The S-value is simply the sum of the values in the fifth column (units g-rad/ μ Ci-hr) divided by the mass of the liver, 1910 g:

$$S(\text{liver} \leftarrow \text{liver}) = 0.078/1910 = \underline{4.1 \times 10^{-5} \text{ rad}/\mu\text{Ci-hr}}$$

Problem #4 - Dose to One Organ

Data extrapolated from an animal study yield the following parameters for a new compound tagged to Tc-99m:

Liver	$f_1 = 0.3$	$T_{e1} = 0.5$ hours
	$f_2 = 0.1$	$T_{e2} = 5.5$ hours
Kidneys	$f = 0.2$	$T_e = 1.2$ hours

where f is the fraction of injected activity (note that only 60% of the injected activity is accounted for by considering only these two organs). Let's calculate the dose to the liver.

Problem #4 - Dose to One Organ

$$S(\text{liver} \leftarrow \text{liver}) = 4.6 \times 10^{-5} \text{ rad}/\mu\text{Ci-hr}$$

$$S(\text{liver} \leftarrow \text{kidneys}) = 3.9 \times 10^{-6} \text{ rad}/\mu\text{Ci-hr}$$

Assume $A_0 = 1 \text{ mCi} = 1000 \mu\text{Ci}$; then,

$$\begin{aligned} \tilde{A}(\text{liver}) &= 1.443 \cdot 1000 \mu\text{Ci} (0.3 \cdot 0.5 \text{ hr} + 0.1 \cdot 5.5 \text{ hr}) = \\ &1010 \mu\text{Ci-hr} \end{aligned}$$

$$\tilde{A}(\text{kidneys}) = 1.443 \cdot 1000 \mu\text{Ci} \cdot 0.2 \cdot 1.2 \text{ hr} = 350 \mu\text{Ci-hr}$$

Problem #4 - Dose to One Organ

$$D(\text{liver}) = 1010 \mu\text{Ci-hr} \cdot 4.6 \times 10^{-5} \text{ rad}/\mu\text{Ci-hr} + \\ 350 \mu\text{Ci-hr} \cdot 3.9 \times 10^{-6} \text{ rad}/\mu\text{Ci-hr}$$

$$D(\text{liver}) = 0.0465 \text{ rad} + 0.0014 \text{ rad} = 0.048 \text{ rad.}$$

Note that the liver contributes 97% of its total dose. Dividing by the injected activity, the dose, given these input assumptions, is 0.048 rad/mCi. So, if we redesigned the study to use 3 mCi, the liver absorbed dose would be 3 mCi x 0.048 rad/mCi = 0.14 rad.

Problem #5 - Dose to Several Organs

In MIRD Dose Estimate Report No. 12 (Thomas et al. 1984), the following residence times are found for intravenous administration of Tc-99m DTPA:

Kidneys	0.092 hr
Urinary Bladder	0.84 hr (2.4 hr voiding intervals)
	1.72 hr (4.8 hr voiding intervals)
Remainder of Body	2.84 hr

Problem #5 - Dose to Several Organs

$$D = \tau S$$

$$D = \begin{bmatrix} \tau_{kid_1} & \tau_{blad_1} & \tau_{RB_1} \\ \tau_{kid_2} & \tau_{blad_2} & \tau_{RB_2} \end{bmatrix} X$$

$$\begin{bmatrix} S(kid \leftarrow kid) & S(ov \leftarrow kid) & S(mar \leftarrow kid) & S(test \leftarrow kid) & S(blad \leftarrow kid) & S(TB \leftarrow kid) \\ S(kid \leftarrow blad) & S(ov \leftarrow blad) & S(mar \leftarrow blad) & S(test \leftarrow blad) & S(blad \leftarrow blad) & S(RB \leftarrow blad) \\ S(kid \leftarrow RB) & S(ov \leftarrow RB) & S(mar \leftarrow RB) & S(test \leftarrow RB) & S(blad \leftarrow RB) & S(TB \leftarrow RB) \end{bmatrix}$$

Problem #5 - Dose to Several Organs

$$D = \begin{bmatrix} 0.092 & 0.842 & 2.84 \\ 0.092 & 1.72 & 2.84 \end{bmatrix} \begin{bmatrix} 1.9 \times 10^4 & 1.1 \times 10^6 & 3.8 \times 10^6 & 8.8 \times 10^8 & 2.8 \times 10^7 & 2.1 \times 10^6 \\ 2.6 \times 10^7 & 7.3 \times 10^6 & 1.6 \times 10^6 & 4.7 \times 10^6 & 1.6 \times 10^4 & 1.9 \times 10^6 \\ 1.4 \times 10^6 & 2.4 \times 10^6 & 2.9 \times 10^6 & 1.7 \times 10^6 & 1.9 \times 10^6 & 2.0 \times 10^6 \end{bmatrix}$$

$$D = \begin{bmatrix} D_{kid_1} & D_{ov_1} & D_{mar_1} & D_{test_1} & D_{blad_1} & D_{TB_1} \\ D_{kid_2} & D_{ov_2} & D_{mar_2} & D_{test_2} & D_{blad_2} & D_{TB_2} \end{bmatrix}$$

$$D = \begin{bmatrix} 2.2 \times 10^{-5} & 1.3 \times 10^{-5} & 1.0 \times 10^{-5} & 8.8 \times 10^{-6} & 1.4 \times 10^{-4} & 7.5 \times 10^{-6} \\ 2.2 \times 10^{-5} & 1.9 \times 10^{-5} & 1.2 \times 10^{-5} & 1.3 \times 10^{-5} & 2.8 \times 10^{-4} & 9.1 \times 10^{-6} \end{bmatrix}$$

(units are rad/mCi)

Problem #6 - Effective Dose

Dose Equivalent

<u>Organ</u>	<u>rem</u>	<u>mSv</u>
Liver	0.048	0.48
Kidneys	0.030	0.30
Ovaries	0.015	0.15
Testes	0.011	0.11
Red Marrow	0.022	0.22
Bone Surfaces	0.025	0.25
Thyroid	0.002	0.02

Problem #6 - Effective Dose

<u>Organ</u>	<u>Weighting Factor</u>	<u>Dose Equivalent (mSv)</u>	<u>Weighted Dose Equivalent (mSv)</u>
Liver	0.06	0.48	0.0288
Kidneys	0.06	0.30	0.0180
Ovaries	0.25	0.15	0.0375
Red Marrow	0.12	0.22	0.0264
Bone Surfaces	0.03	0.25	0.0075
Thyroid	0.03	0.02	0.0006
		TOTAL	0.1188

Problem #6 - Effective Dose

So we would conclude that the H_e for this compound is 0.12 mSv (0.012 rem or 12 mrem).

This means that if the whole body were uniformly irradiated to receive 0.12 mSv, the individual would receive the same risk (of fatal cancer or genetic defects) as from 0.48 mSv to the liver, 0.30 mSv to the kidneys, etc.



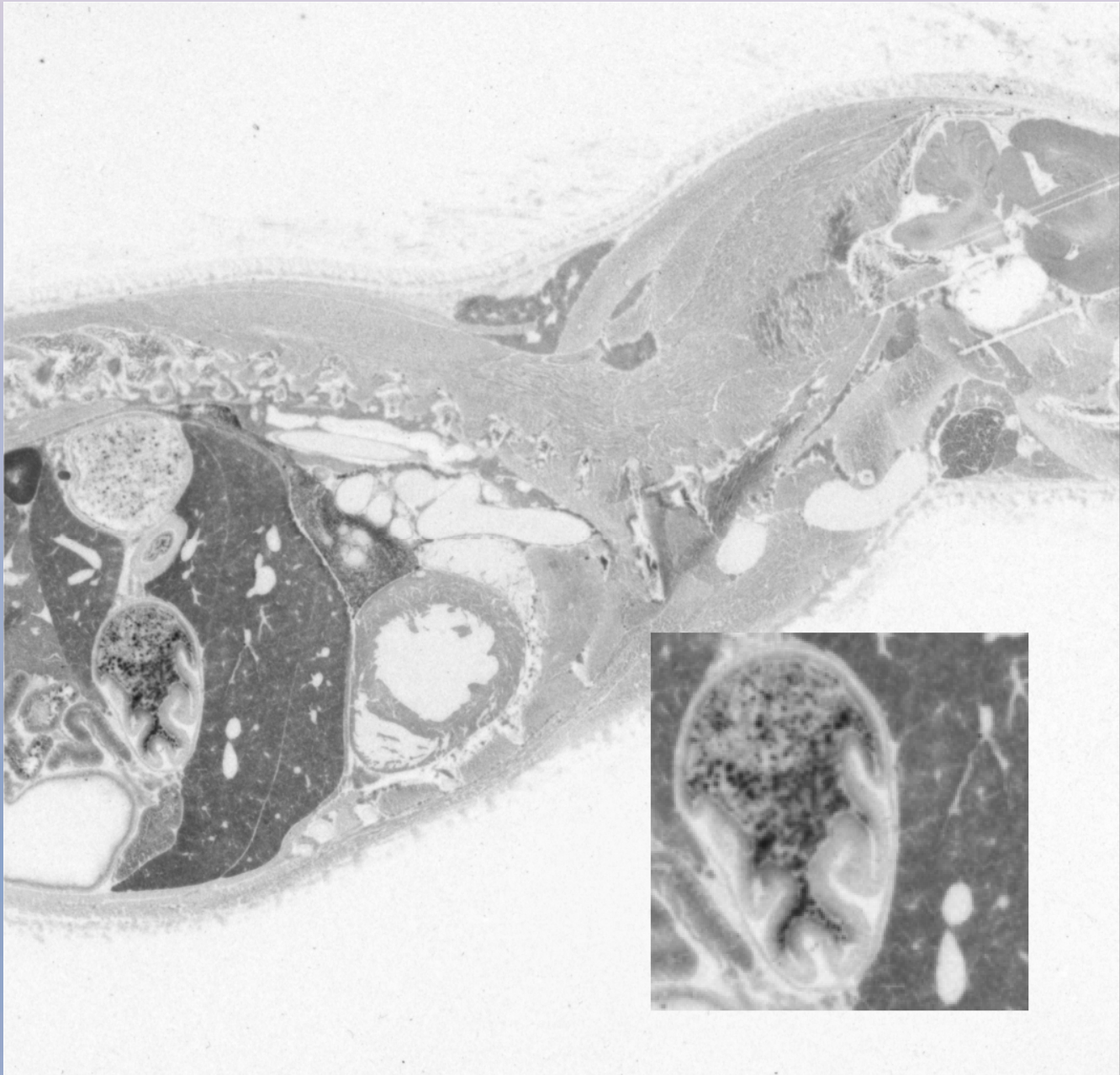
B I O L O G Y

Determination of Kinetic Data

- Preclinical:
 - Choice of animal species
 - Choice of analytical method
 - Execution of experiments
 - Extrapolation of results
 - Kinetic analysis
- Clinical:
 - Execution of experiments
 - Kinetic analysis

Animal Data Collection Methods

- Autoradiography
 - Animals are sacrificed and frozen into a block of carboxymethyl cellulose (CMC).
 - Slices are cut with a Cryostat Microtome where the knife cuts approximately 30 μm slice of the animal.
 - The sections are then freeze dried and attached to x-ray film for exposure.



Animal Data Collection Methods

- Necropsy
 - Animals are sacrificed, then frozen and individual organs and tissues are dissected out from the carcass.
 - These are assayed for radioactivity content, typically using scintillation detectors.
- Imaging
 - microPET and microSPECT methods
 - Region of Interest (ROI) analysis of images, as in humans.

The elephantine fallacy

(Harwood, Science 1963)

- Investigators wanted to study the reaction of a male elephant to LSD, to simulate rage behavior.
- They calculated the dose, based on the amount that puts a cat into a rage, and had multiplied it by the ratio of the animal weights and arrived at a value of 297 mg of LSD to be given to the elephant.

The elephantine fallacy

- The elephant immediately started trumpeting and running around, then he stopped and swayed; five minutes after the injection he collapsed, went into convulsions, defecated, and died.
- The authors concluded that elephants are peculiarly sensitive to LSD.

Some Possible Calculations of a Suitable Dose of LSD to Give to an Elephant

Based on the body weight of the elephant and the dose effective in cats.	297 mg
Based on the metabolic rates of the elephant and the cat.	80 mg
Based on the body weight of the elephant and the human.	8 mg
Based on the metabolic rates of the elephant and the human.	3 mg
Based on the brain sizes of the elephant and the human.	0.4 mg

Animal Data Extrapolation Methods

- Direct Use (i.e. no extrapolation)
 - %/organ in the animal = %/organ in the human
- Concentration equivalence
 - %/g in animal = %/g in human
- Concentration/Body weight equivalence
 - % - kg/g in animal = % - kg/g in human
 - (organ mass in g)/(body weight in kg) used as scaling factor.

Mass scaling

$$\left(\frac{\%}{g} \right) \times \text{body mass (kg)} \equiv \frac{\% - \text{kg}}{g} \quad \leftarrow \text{Animal}$$

$$\frac{\% - \text{kg}}{g} \times \frac{\text{organ mass (g)}}{\text{body mass (kg)}} \equiv \frac{\%}{\text{organ}} \quad \leftarrow \text{Human}$$

	Spleen				
ANIMAL	1 hr	3 hr	6 hr	16 hr	24 hr
%ID/organ	3.766	3.520	2.803	1.009	0.581
(%ID/g)	37.84	36.33	30.56	11.18	5.66
HUMAN					
%ID/organ	3.232	3.103	2.611	0.955	0.483

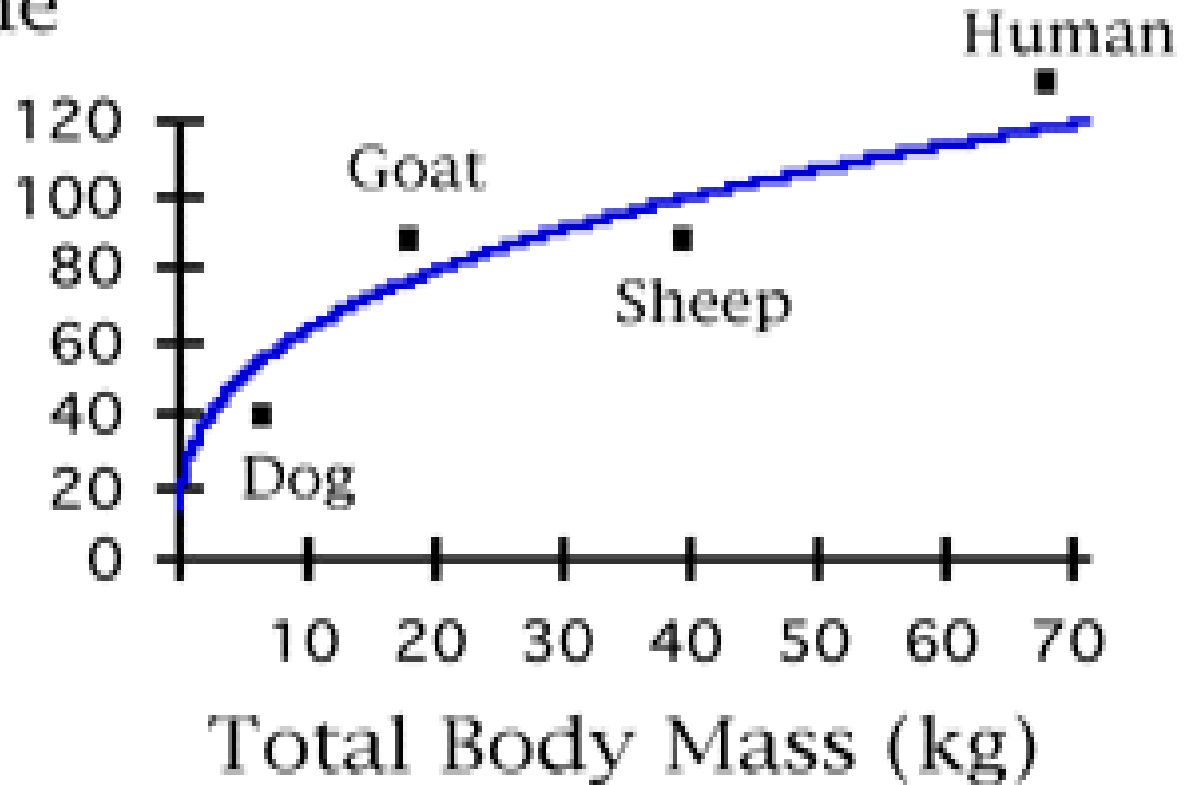
Mass and time scaling

$$t_a = t_h \left[\frac{m_h}{m_a} \right]^{0.25}$$

Animal Data	5 min	15 min	30 min	60 min	1.5 h
	0.3	0.32	0.48	0.49	0.32
Extrapolated Human Data	22 min	1.1 h	2.2 h	4.3 h	6.5 h
	0.26	0.28	0.42	0.43	0.28

Allometric Scaling

Half Time
(hr)



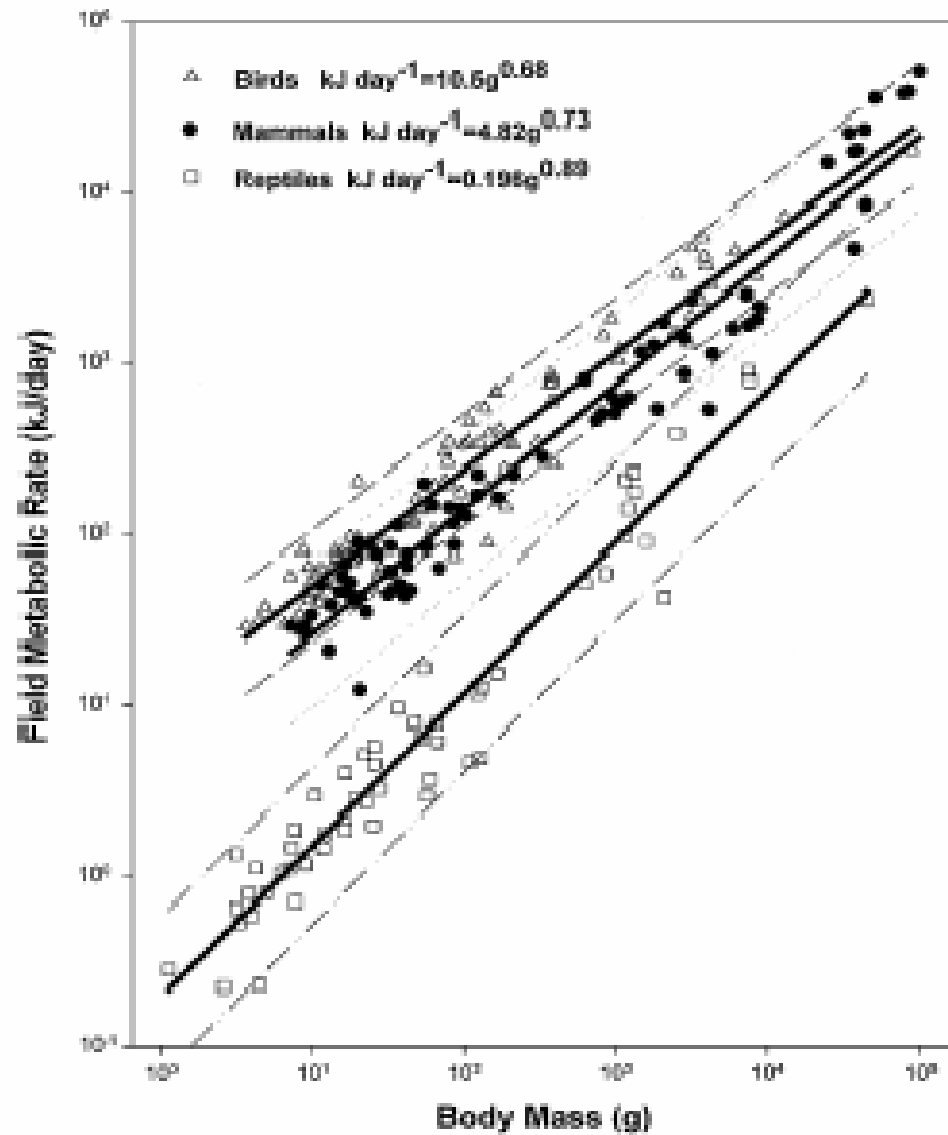
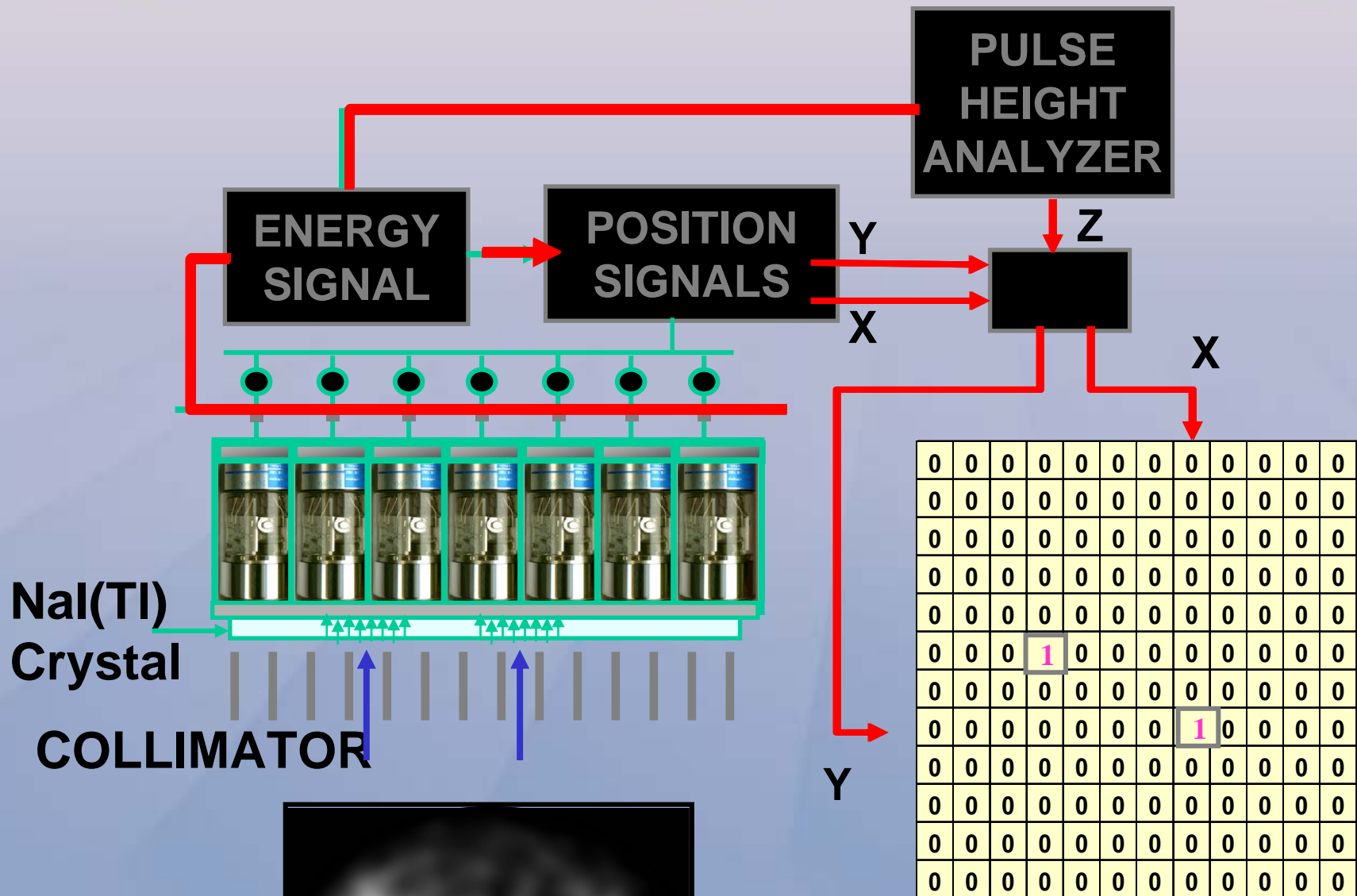


Figure 1 Allometry of field metabolic rate in terrestrial vertebrates. (Solid lines) least-squares linear regression lines for birds, mammals, and reptiles (see Equations 1, 17, and 32 in Table 2); (dashed or dotted lines) 95% confidence intervals of the prediction for each line.

Acquisition of Kinetic Data

- Gamma camera – setup, calibration, quality control issues
- Choice of regions of interest
- Number and spacing of data points
- Treatment of kinetic data
 - Kinetic model form, parameters
 - Application to dose calculation models



**PULSE
HEIGHT
ANALYZER**

**ENERGY
SIGNAL**

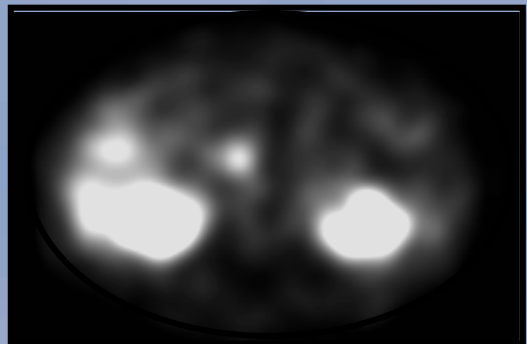
**POSITION
SIGNALS**

**NaI(Tl)
Crystal**

COLLIMATOR

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
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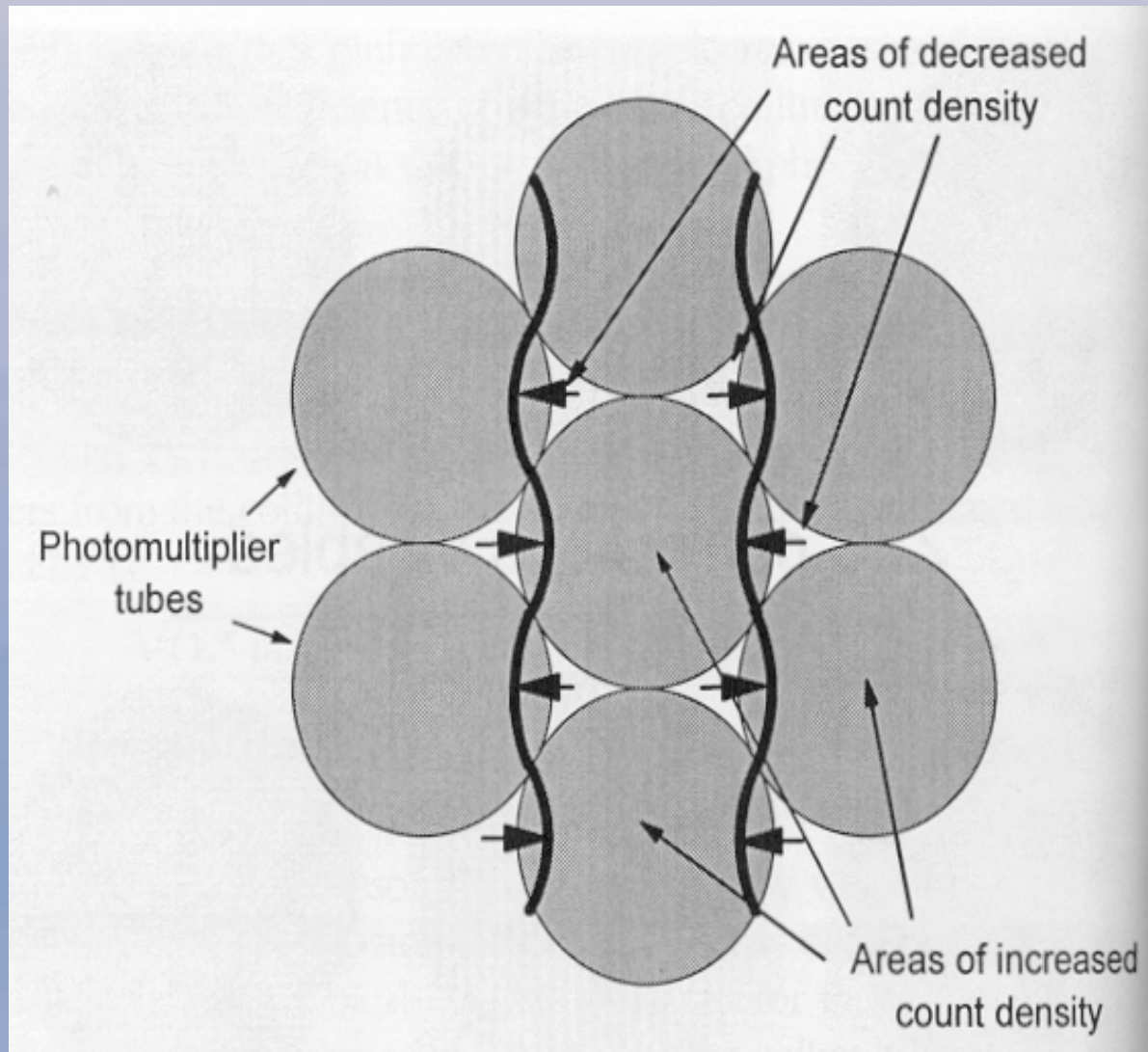
Image Frame



Gamma Camera System Performance

- Spatial resolution – point or line sources used to study the FWHM (function of nuclide, collimator, distance).
- Linearity – flood or bar sources – map of correction factors is developed.
- Energy resolution
- Flood field uniformity

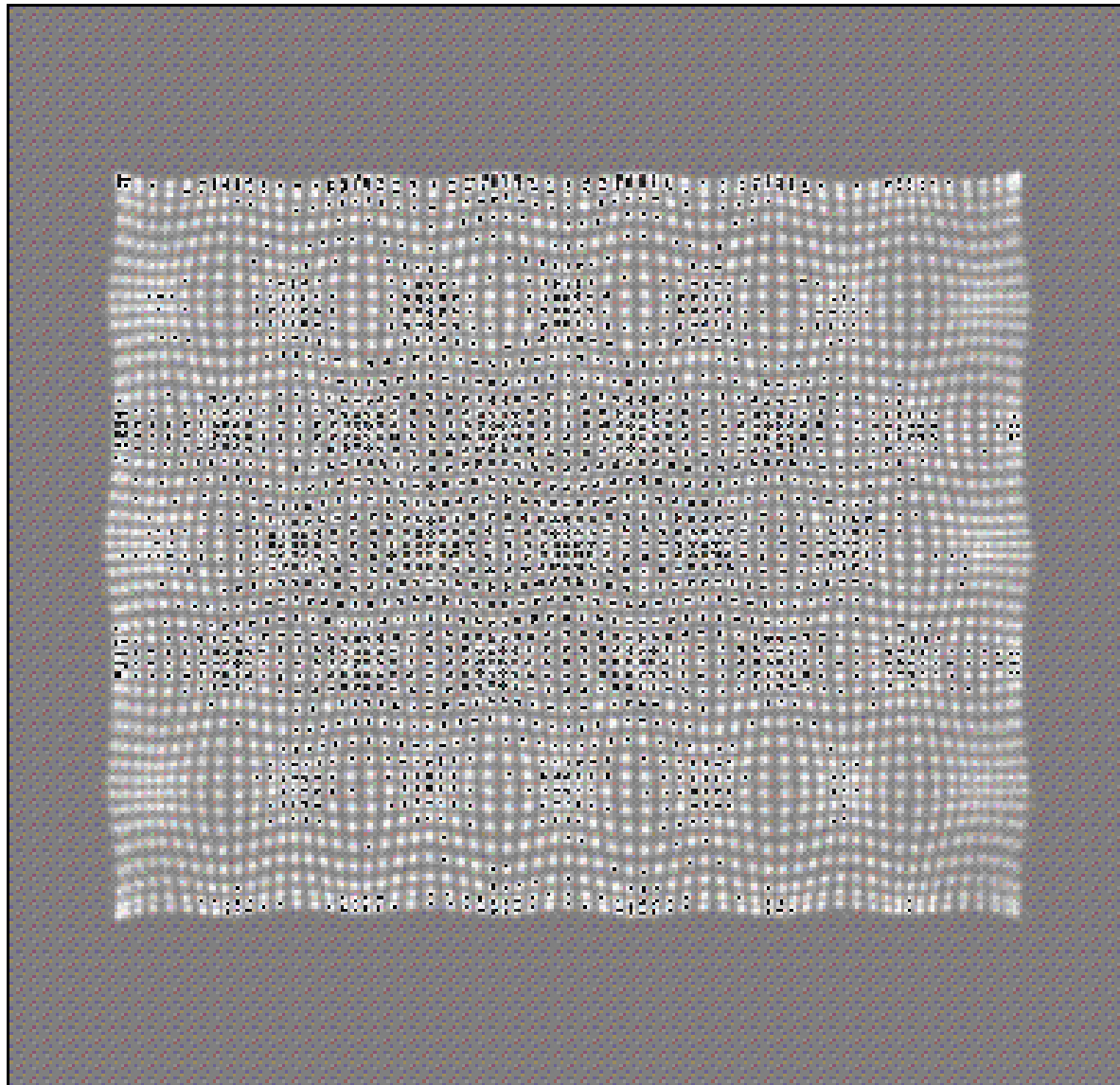
Non-linearity --> Non-Uniformity



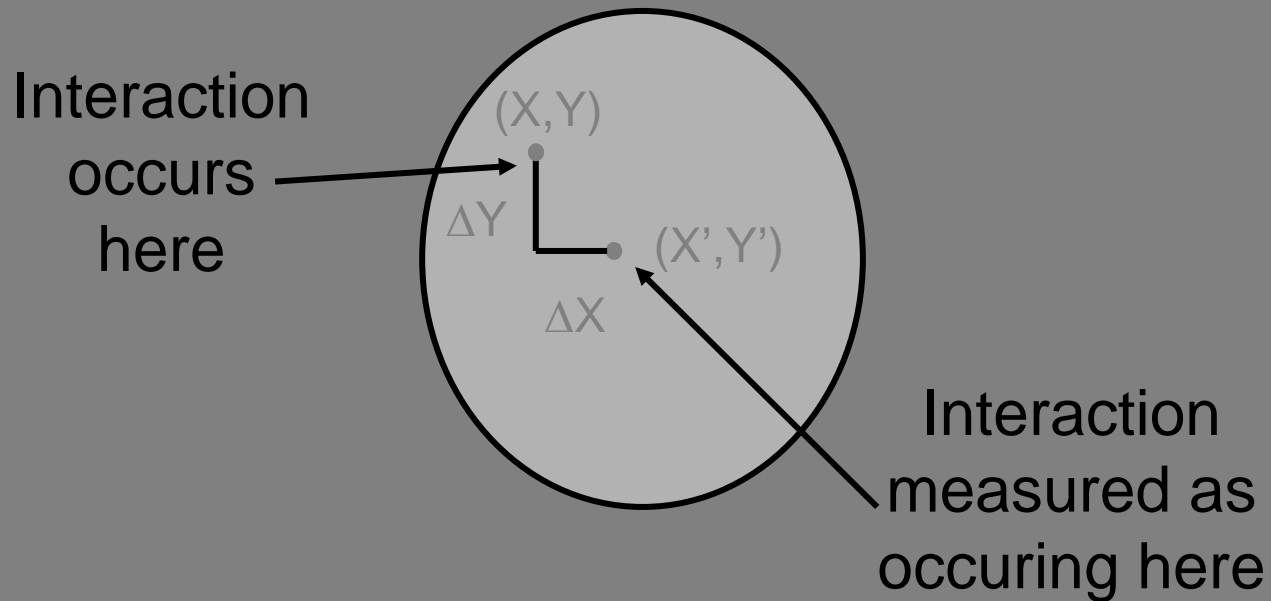
Lincorr.img (33.3%)



1024x1024 pixels; 16-bit grayscale; 2048K



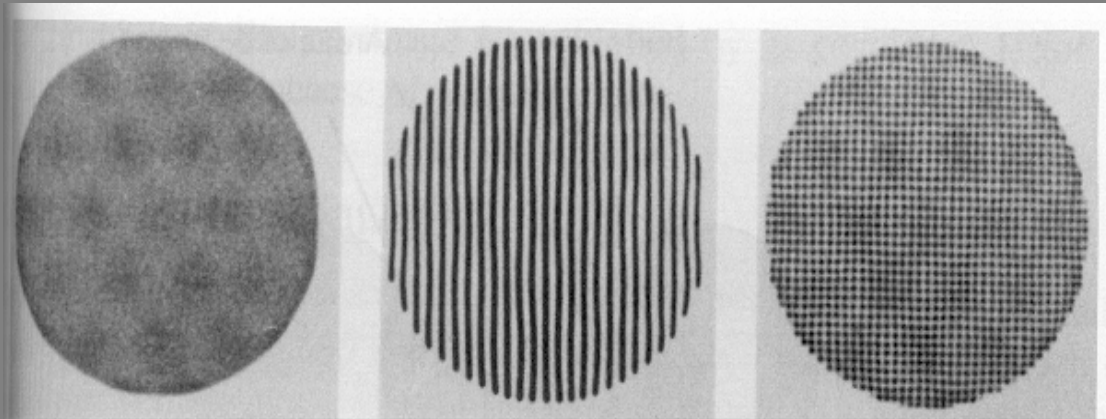
Linearity Correction



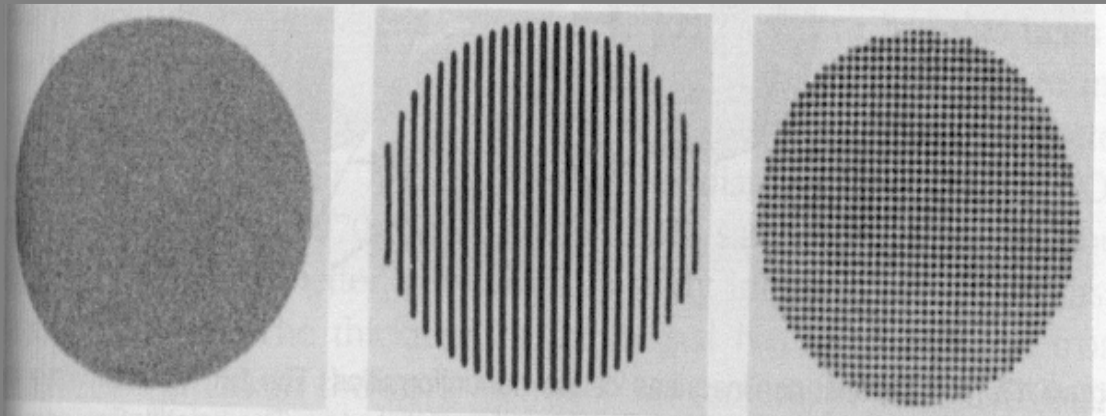
$$X = X' + \Delta X$$

$$Y = Y' + \Delta Y$$

Energy and Linearity Corrections

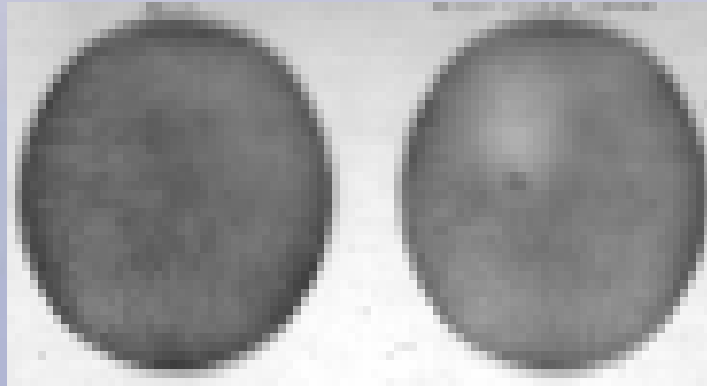


ZLC Circuitry Disabled



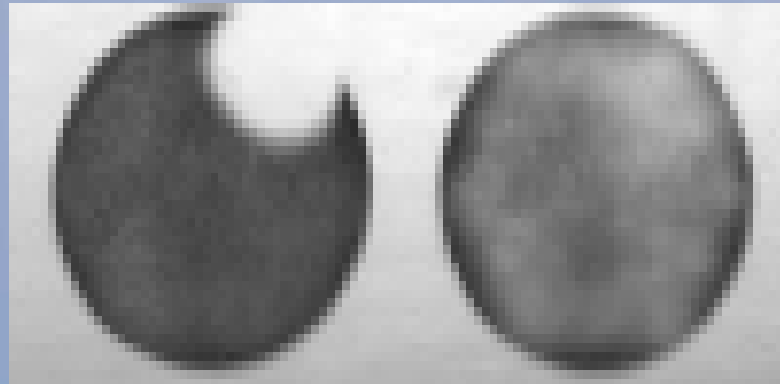
ZLC Circuitry Enabled

Intrinsic Uniformity Evaluation



OK

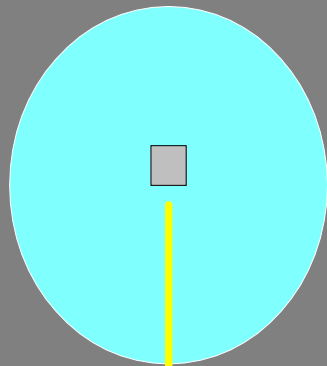
Drifting PMT



PMT Out

Off Peak

Sensitivity Correction



← High Count Flood

95	100
100	105

Sensitivity
Map

1.05	1.00
1.00	0.95

Sensitivity
Correction

100	100
100	100

Corrected
Image

Gamma Camera System Performance

- Sensitivity – counts/disintegration.
- Possible dead time losses.
- QA
 - Daily
 - Energy (+/- 2 keV)
 - Uniformity
$$\frac{(\text{Max} - \text{Min})}{(\text{Max} + \text{Min})} \times 100$$

Should be <5%
 - Weekly
 - Linearity, distortion, spatial resolution

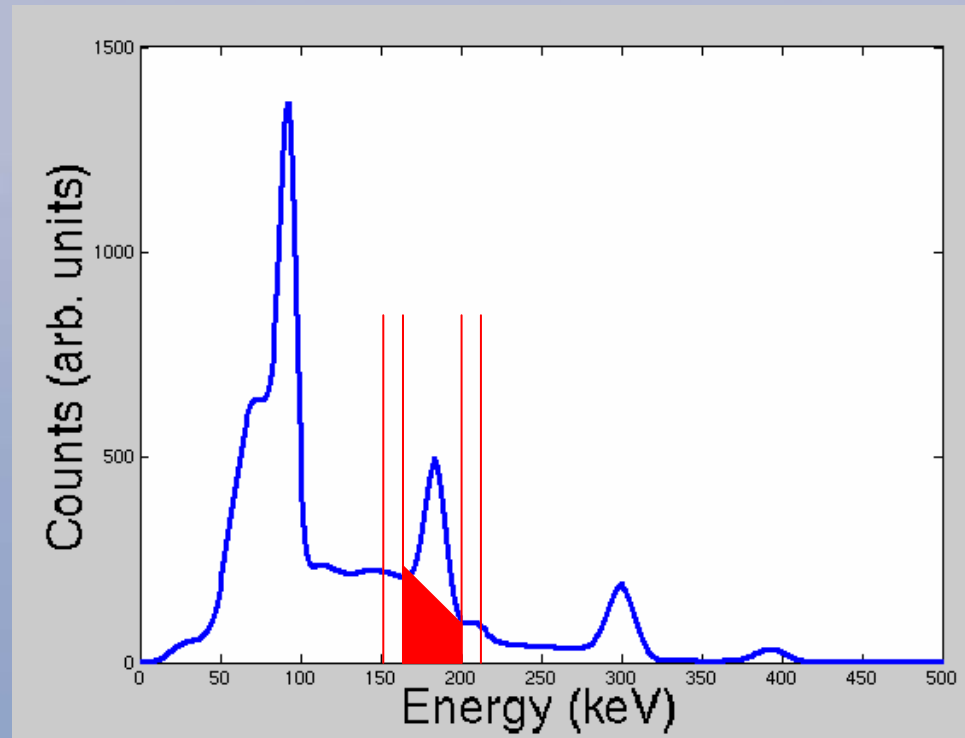
Gamma Camera Data: Activity Calibration Factor

- Objects are at unknown depth in body.
- We obtain a projection image. We need to correct for attenuation.
- Geometric mean method, in principle, removes depth dependence.

$$A_{ROI} = \sqrt{\frac{I_A I_P}{e^{-\mu_e t}}} \frac{f_j}{C}$$

Gamma Camera Data: Scatter Correction

- Activity in our region of interest has counts from Compton scattered events – from the actual photopeak and possibly from higher energy peaks.
- Use of lower and upper “scatter windows” in the acquisition are used to correct for this.



06048bp.img (75%)



256x1024 pixels; 8-bit grayscale; 256K

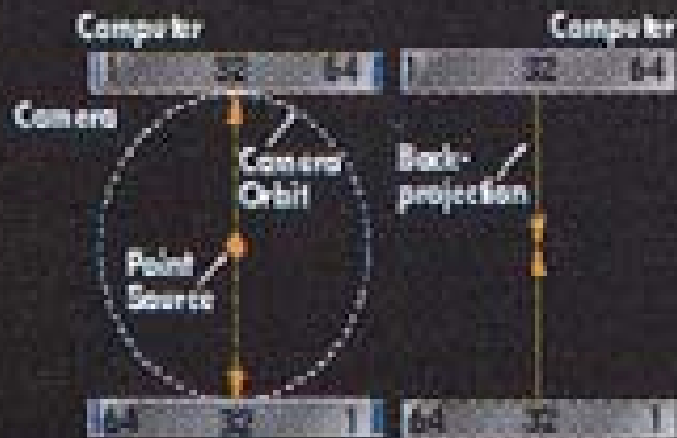


SPECT Quality Control

- Daily camera quality control
- Axis of Rotation (COR)
- Uniformity Correction (Sensitivity Maps)
- Head Tilt
- Patient Motion

Center of Rotation (COR)

Properly Calibrated
Acquisition Reconstruction



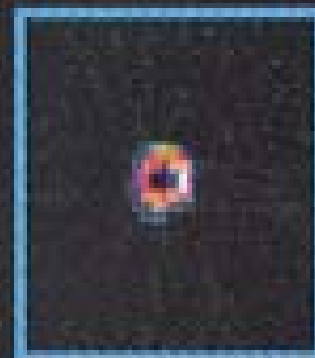
Poorly Calibrated
Acquisition Reconstruction



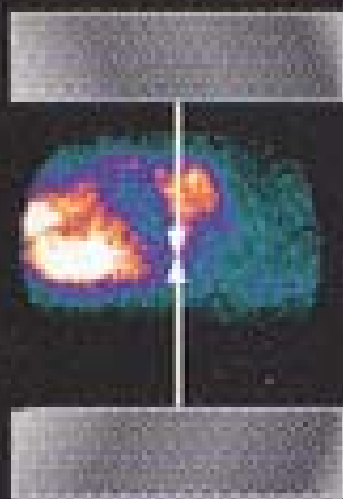
QUALITY
CONTROL



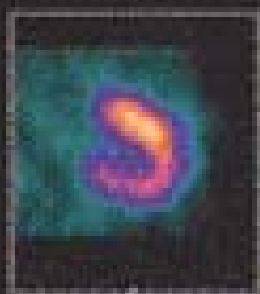
Without proper center of rotation calibration the SPECT image of a point source acquired with a 360° orbit will be blurred or, if the calibration is bad enough as a ring!



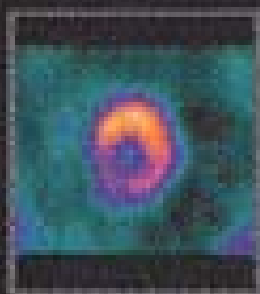
Camera Head Not Level



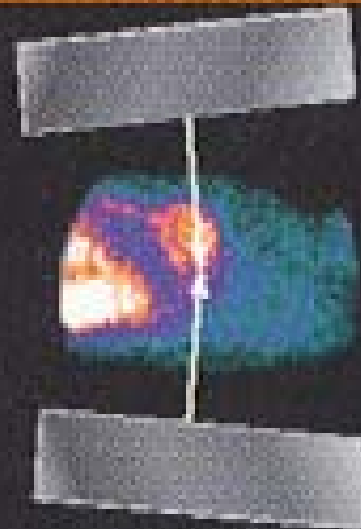
Level



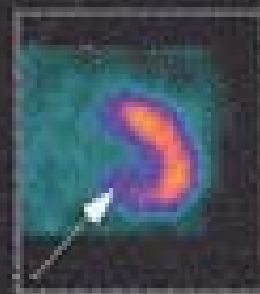
Vertical
Long Axis



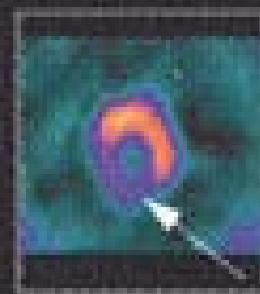
Short
Axis



Tilted



Vertical
Long Axis

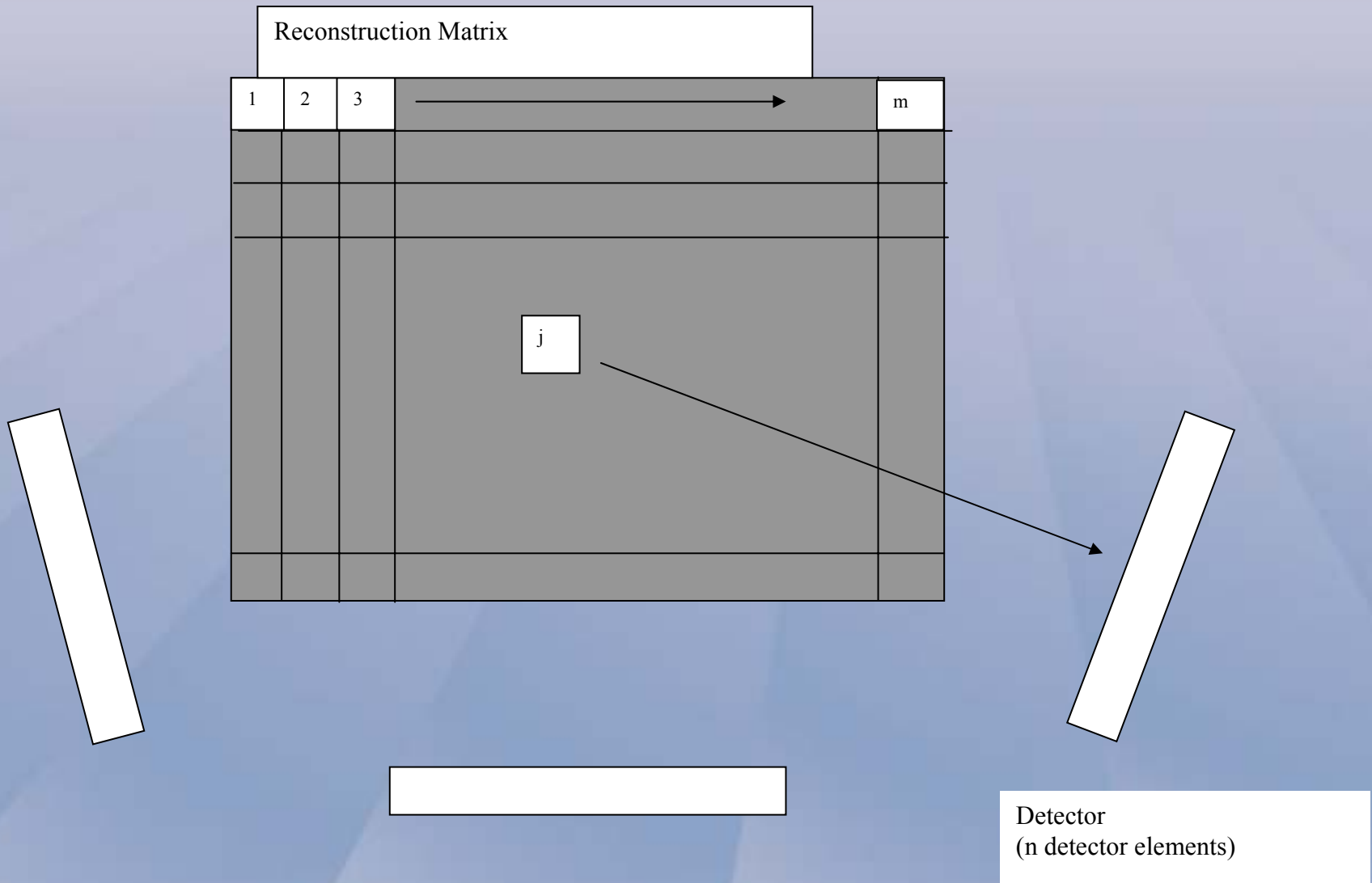


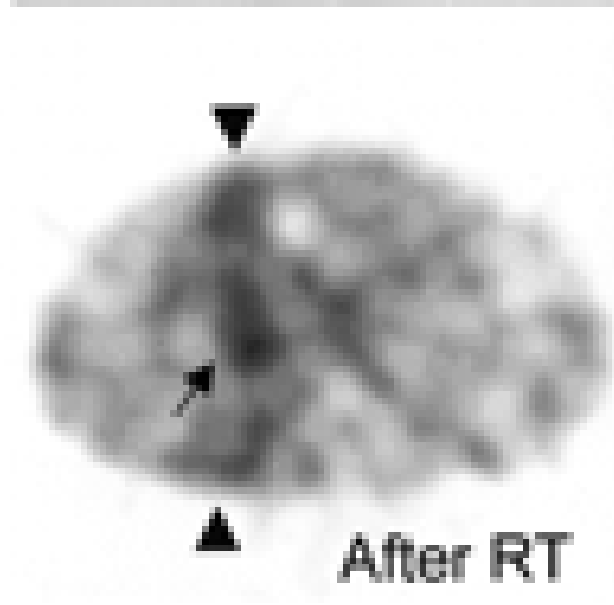
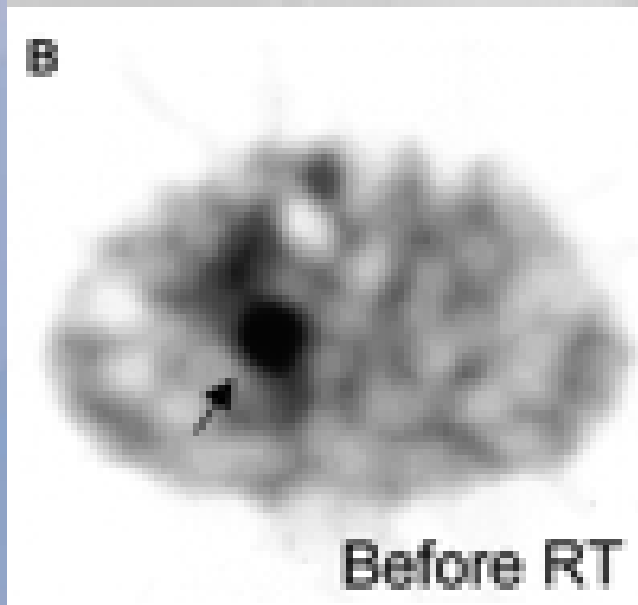
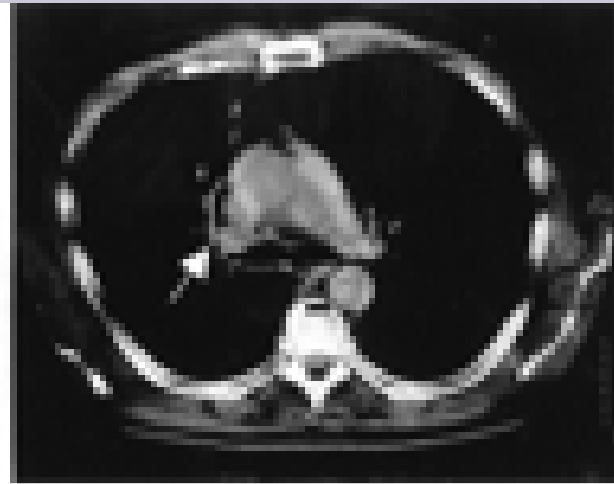
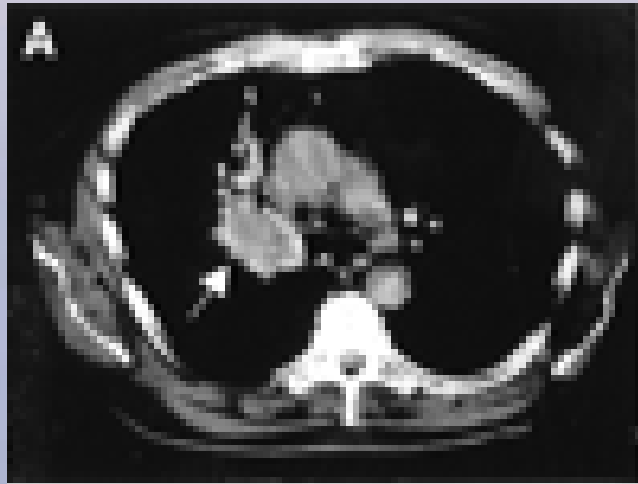
Short
Axis

—▶ Artfactual loss of counts

QUALITY
CONTROL

SPECT Image Reconstruction





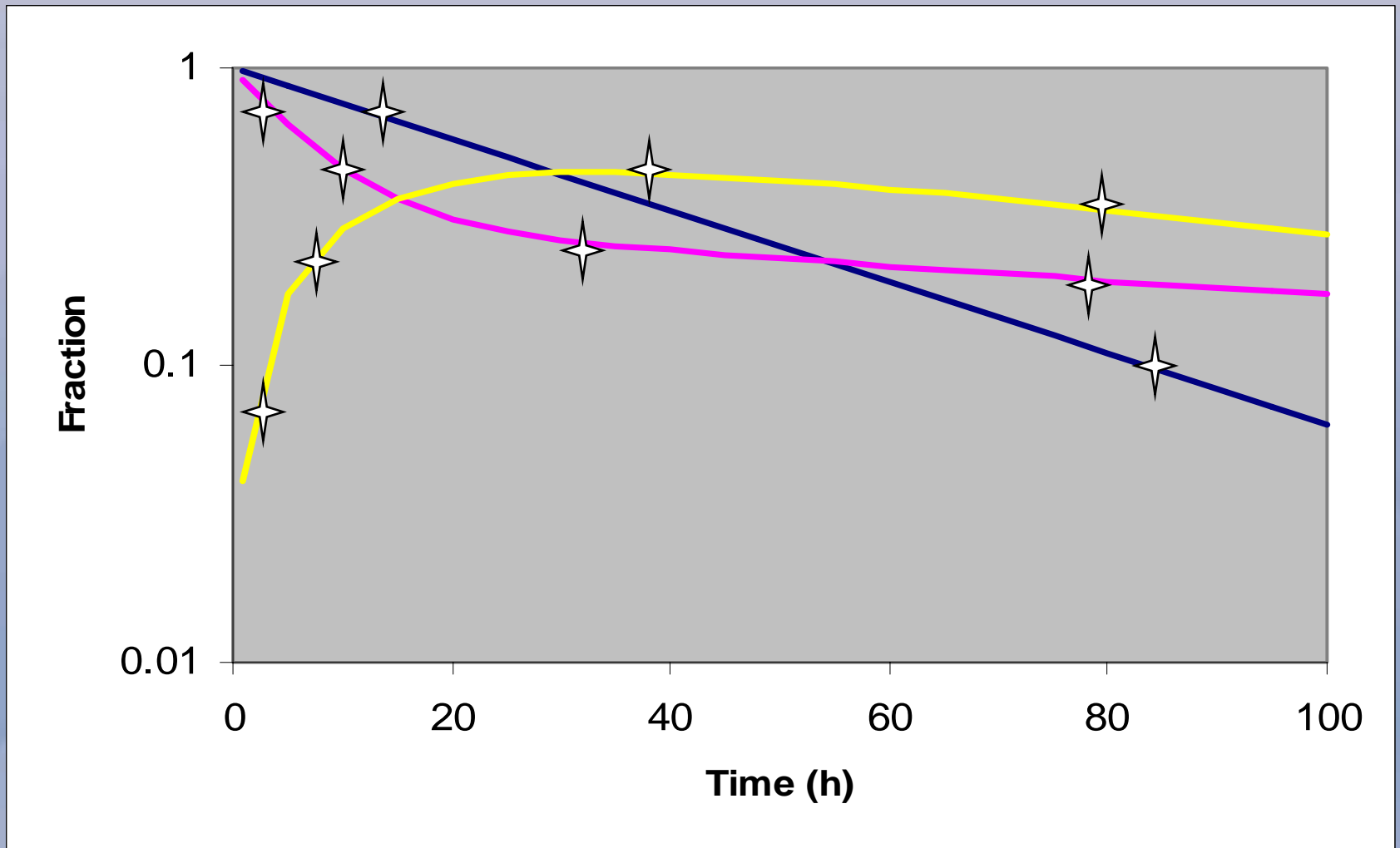
MicroPET scanner
(Concorde
Microsystems Inc.)

From
[http://www.crump.ucla.edu/
user-
files/resprojects/microPET/](http://www.crump.ucla.edu/user-files/resprojects/microPET/)

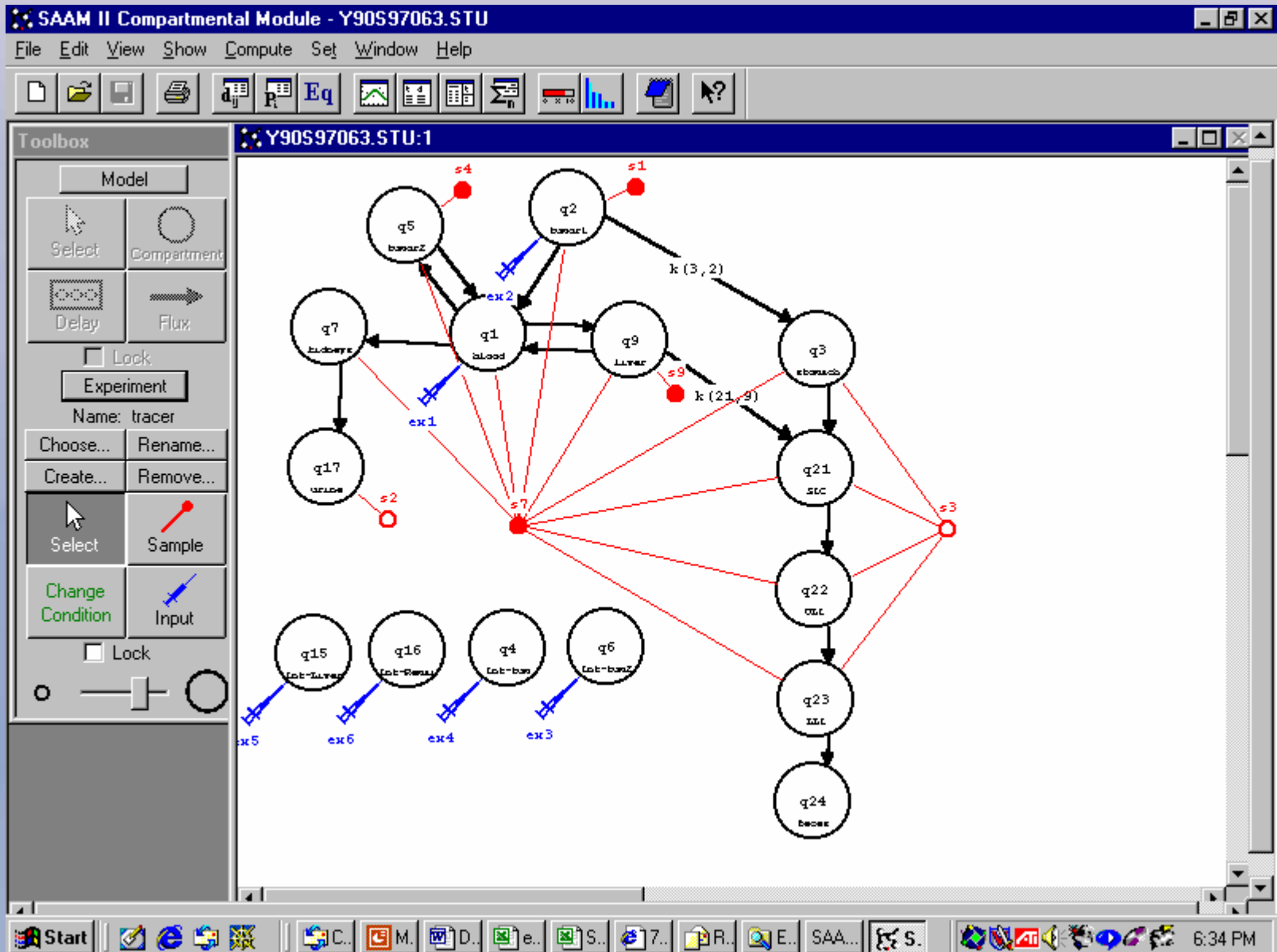


Metabolic Models: Patient-specific kinetic modeling

MIRD 16: Number and spacing of time points

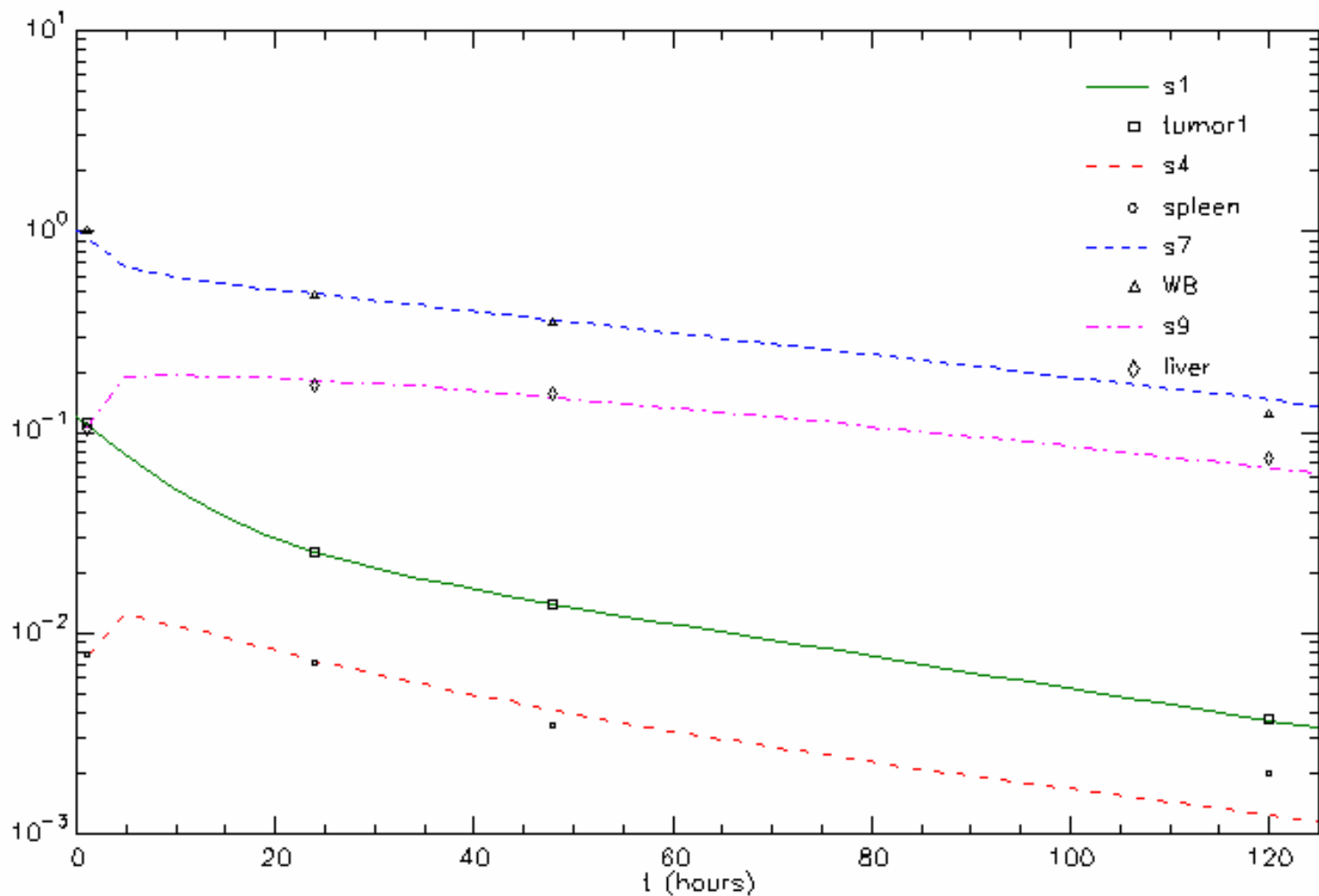


Use of SAAM II for Biokinetic Analysis





To Plot

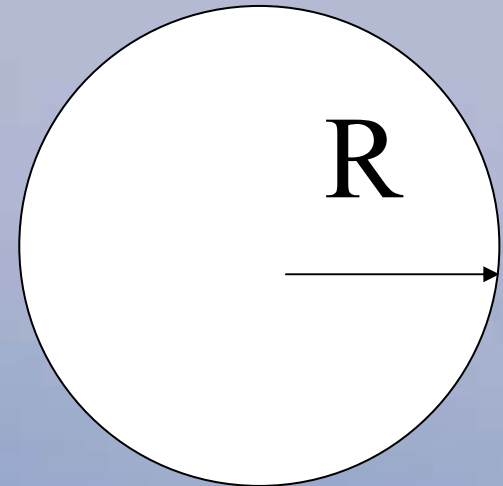


A photograph of a physics laboratory. The room is filled with various pieces of scientific equipment, including what appears to be a large particle detector or a complex experimental setup. The lighting is somewhat dim, with a warm, golden glow from the right side. The word "PHYSICS" is overlaid in a white, serif font across the center of the image.

PHYSICS

Evolution of Physical Models

$$\phi = (1 - e^{-\mu R})$$



1. Sphere – ICRP II (1959)

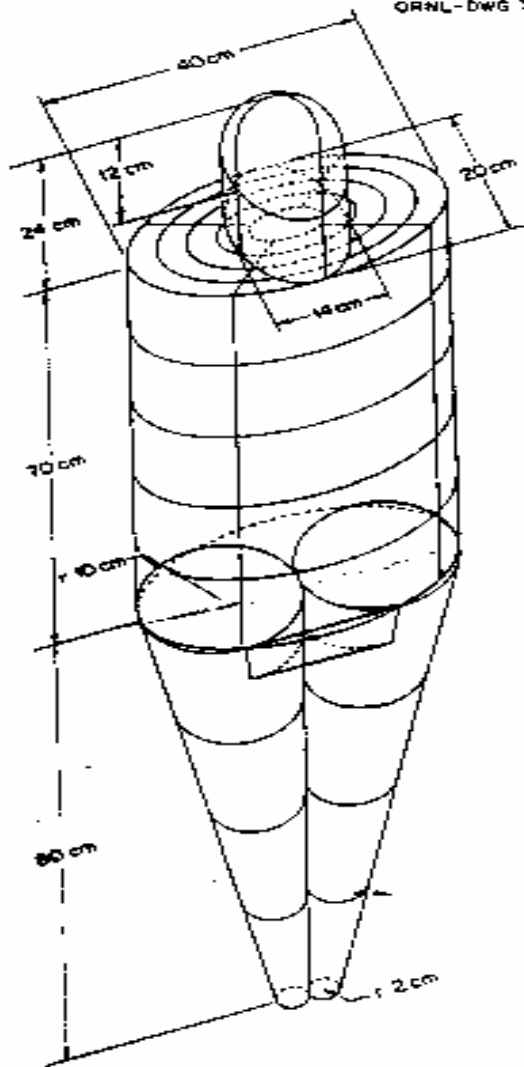


Fig. A-1. The adult human phantom.

ORGANS NOT SHOWN

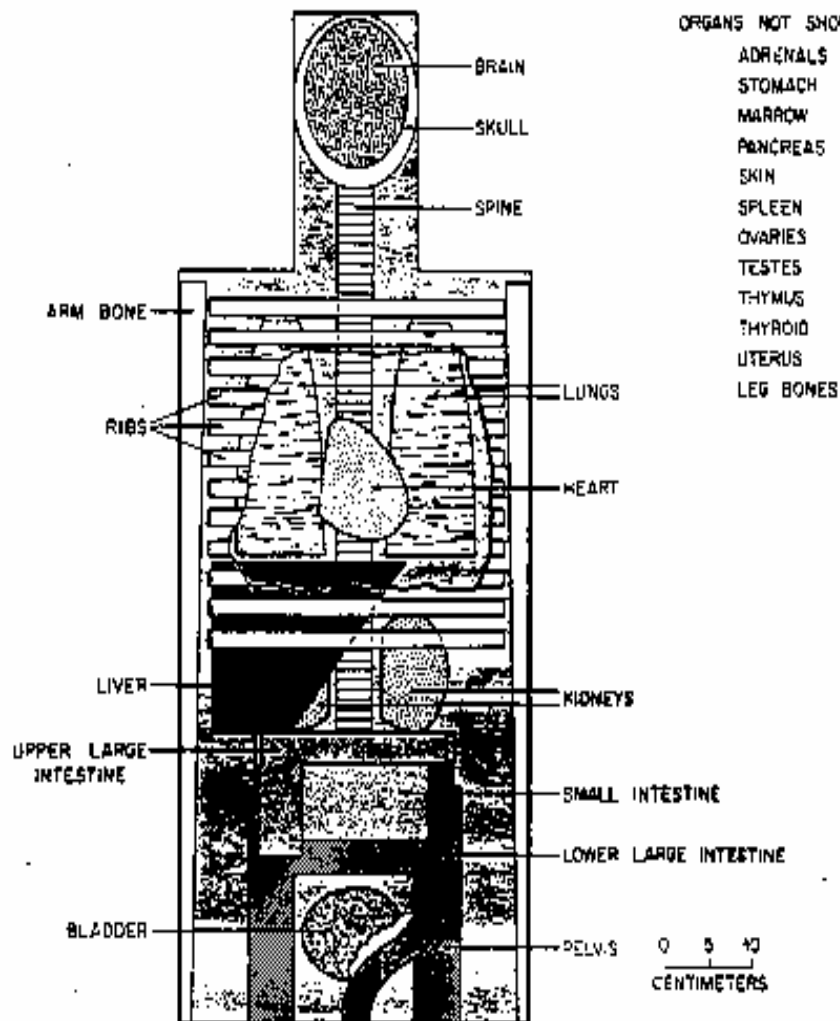
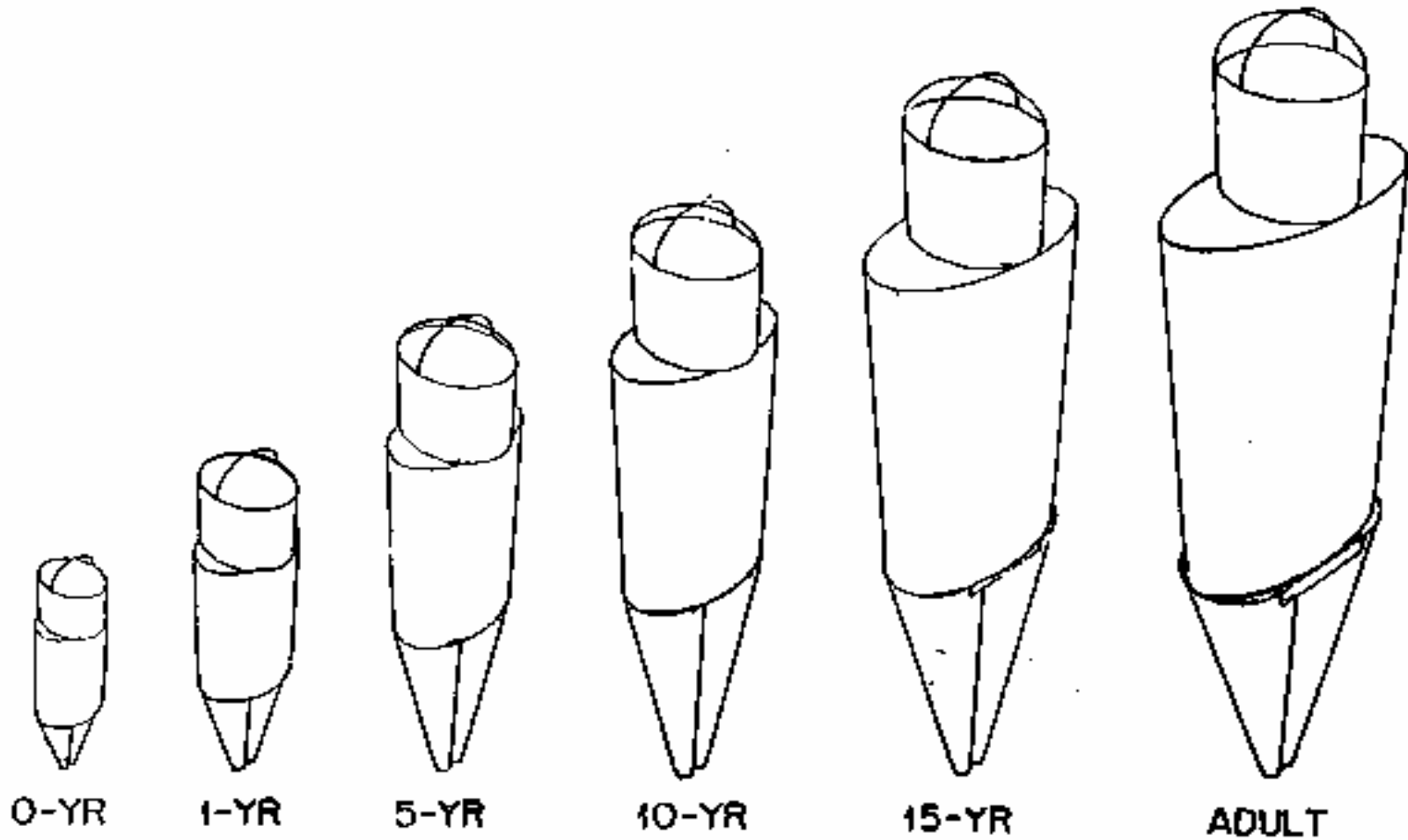


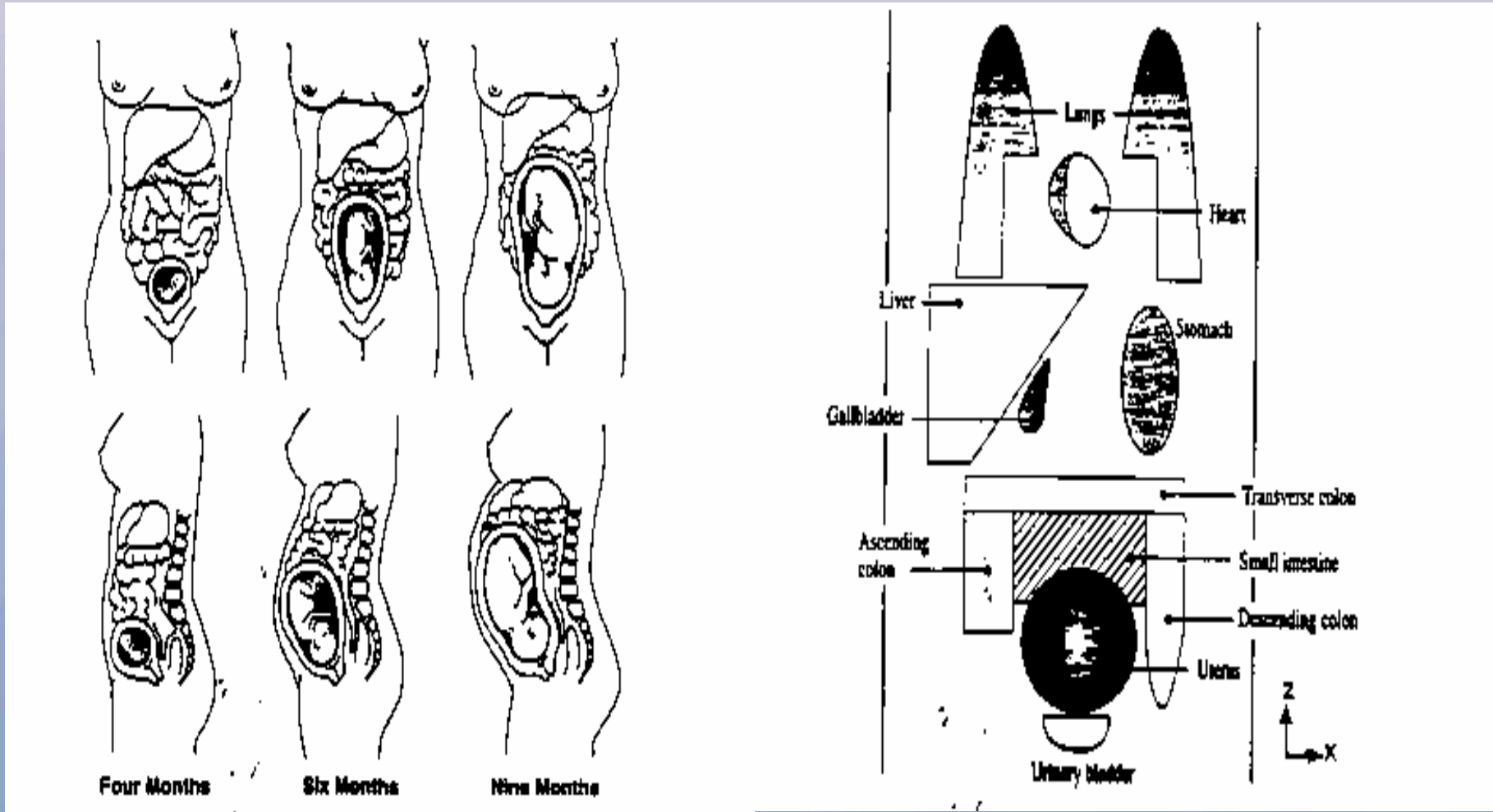
Fig. A-2. Anterior view of the principal organs in the head and trunk of the phantom used for MIRD Pamphlet No. 5.

2. Adult equation-based model (MIRD/ICRP - 1975)



3. Equation-based models of children and adults (Cristy/Eckerman, 1987)

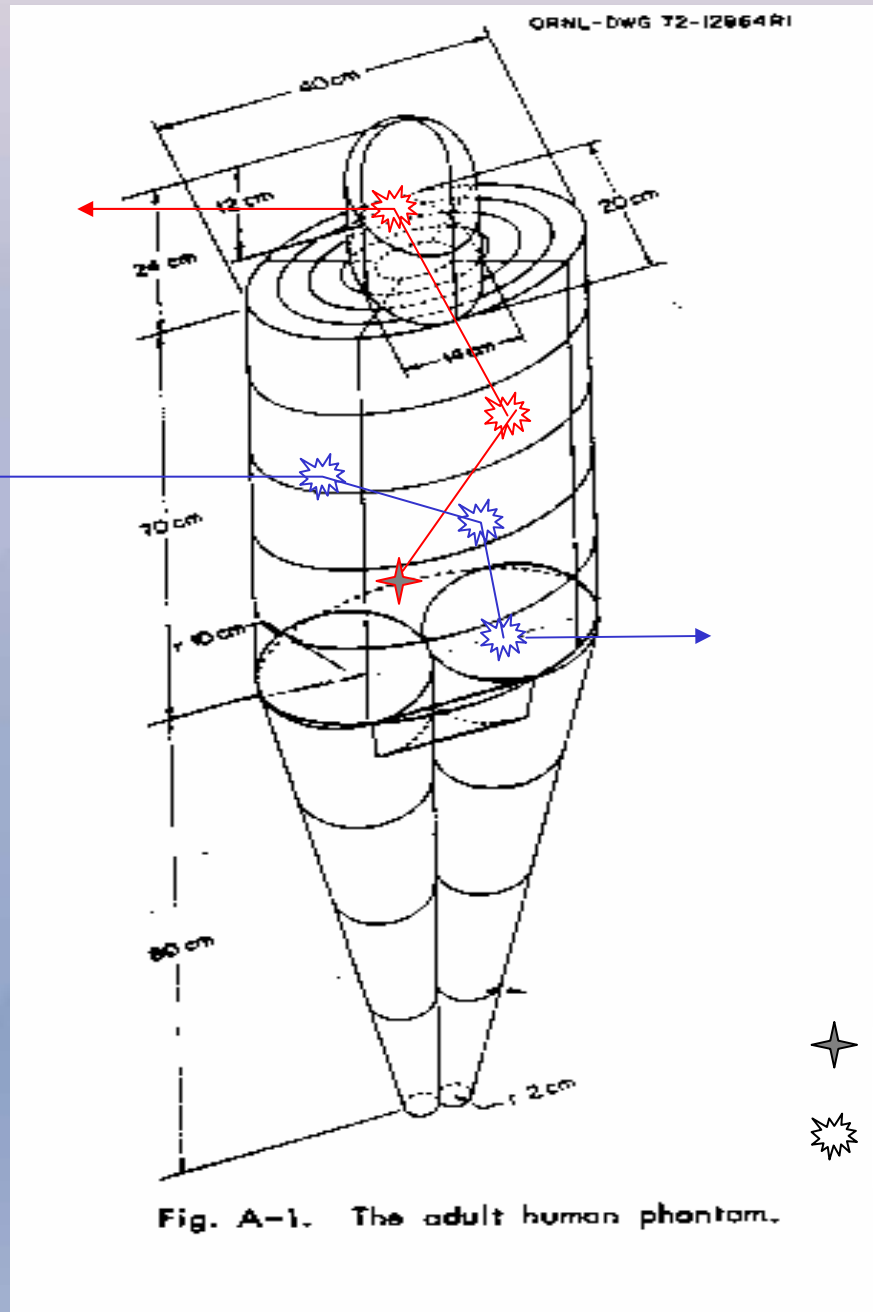
4. Equation-based models of the pregnant woman (Stabin et al. 1995)



Sketches of the woman at various stages of gestation

Geometrical model for the 3 month pregnant woman

The Monte Carlo process:



Tables of DCFs

- Precalculated
- Lookup tables
- Software programs (e.g. MIRDOSE)
- Kinetic data + DCFs =

“A Perfect Marriage”

Software Tools: Nuclear Medicine Internal Dosimetry

- CAMIRD → MIRDDOSE → OLINDA
- MABDOSE
- RADAR

File Help

Elements	Nuclides
Tellurium	87-Y-39
Thallium	88-Y-39
Thulium	90-Y-39
Tin	
Tungsten	
Vanadium	
Xenon	
Ytterbium	
Yttrium	

Phantoms

<input checked="" type="checkbox"/> Adult (70 kg)	<input type="checkbox"/> Adult Female - Nonpregnant
<input type="checkbox"/> 15-year-old (57 kg)	<input type="checkbox"/> 3-month Pregnant Woman
<input type="checkbox"/> 10-year-old (32 kg)	<input type="checkbox"/> 6-month Pregnant Woman
<input type="checkbox"/> 5-year-old (19 kg)	<input type="checkbox"/> 9-month Pregnant Woman
<input type="checkbox"/> 1-year-old (9.8 kg)	
<input type="checkbox"/> Newborn (3.4 kg)	

Residence Times (hr)

<input type="checkbox"/> Adrenals	.122	<input checked="" type="checkbox"/> Kidneys	0.61	<input checked="" type="checkbox"/> Testes
<input type="checkbox"/> Brain	23.6	<input checked="" type="checkbox"/> Liver		<input type="checkbox"/> Thymus
<input type="checkbox"/> Breasts	3.97	<input checked="" type="checkbox"/> Lungs		<input type="checkbox"/> Thyroid
<input type="checkbox"/> Gallbladder Contents		<input type="checkbox"/> Muscle	.45	<input checked="" type="checkbox"/> Urin. Bl. Contents
1.31 <input checked="" type="checkbox"/> LLI Contents		<input type="checkbox"/> Ovaries		<input type="checkbox"/> Uterus
1.61 <input checked="" type="checkbox"/> SI Contents		<input type="checkbox"/> Pancreas		<input type="checkbox"/> Fetus
<input type="checkbox"/> Stomach Contents	4.57	<input checked="" type="checkbox"/> Red Marrow		<input type="checkbox"/> Placenta
1.14 <input checked="" type="checkbox"/> ULI Contents		<input type="checkbox"/> Cortical Bone	33	<input checked="" type="checkbox"/> Remainder of Body
4.98 <input checked="" type="checkbox"/> Heart Contents		<input type="checkbox"/> Trabecular Bone		
<input type="checkbox"/> Heart Wall	1.19	<input checked="" type="checkbox"/> Spleen		

Use ICRP 30 GI tract model?

Use Dynamic Bladder Model?

Nodule Module

Sphere Size:

Sphere Diameter:

Self-dose S-value:

Control Panel

Label for Program Output:



Radiation Dose Estimates for the REFERENCE ADULT for 90-Y-39 22404Y

TARGET ORGAN	Total Dose mGy/MBq	Dose rad/mCi	Primary Contributor	Contribution	Secondary Contributor	Contribution
Adrenals	2.63E-01	9.72E-01	Rem. Body	100.0%	Liver	0.0%
Brain	2.63E-01	9.72E-01	Rem. Body	100.0%	Red Marrow	0.0%
Breasts	2.63E-01	9.72E-01	Rem. Body	100.0%	Lungs	0.0%
Gallbladder Wall	2.63E-01	9.72E-01	Rem. Body	100.0%	Liver	0.0%
LLI Wall	2.60E+00	9.61E+00	LLI	94.9%	Rem. Body	5.1%
Small Intestine	1.16E+00	4.28E+00	Small Int.	88.6%	Rem. Body	11.4%
Stomach	2.63E-01	9.72E-01	Rem. Body	100.0%	ULI	0.0%
ULI Wall	1.45E+00	5.38E+00	ULI	91.0%	Rem. Body	9.0%
Heart Wall	3.09E+00	1.14E+01	Heart	95.7%	Rem. Body	4.3%
Kidneys	2.20E-01	8.13E-01	Kidneys	100.0%	Rem. Body	0.0%
Liver	6.65E+00	2.46E+01	Liver	100.0%	Rem. Body	0.0%
Lungs	2.14E+00	7.91E+00	Lungs	100.0%	Rem. Body	0.0%

SOURCE ORGAN	Residence Time (hr)
LLI	1.31E+00
Small Intestine	1.61E+00
ULI	1.14E+00
Heart Contents	4.98E+00
Kidneys	1.22E-01
Liver	2.36E+01

Dynamic Bladder Model?

Yes No

ICRP 30 GI Model?

Yes No

Back to Input Form

Methods

- MIRDose → OLINDA
- Several new features have been added to the software:
 - The ability to handle alpha emitters
 - The ability to fit biokinetic data using multiple exponentials
 - Decay data were derived directly from the existing on-line decay databases (instead of from older published compendia).

Methods

- Many existing models were retained:
 - Ten standard whole body phantoms (Cristy/Eckerman adult and pediatrics, Stabin et al. adult woman and pregnant females)
 - Eckerman bone and marrow model
 - Static dynamic bladder model
 - ICRP 30 GI tract model

Methods

- Several new physical models have been incorporated:
 - Stabin prostate gland model
 - Watson and Stabin peritoneal cavity model
 - MIRD head and brain model
 - MIRD multipart kidney model
 - New SAFs for electrons and photons in small spheres (Stabin and Koninjenberg 1999)

Methods

- New capabilities or fixes were added:
 - Kinetic modeling module, for fitting organ kinetic data to multiple exponential models.
 - The ability to adjust organ masses to patient-specific values, with SAFs adjusted for photon and electron self-dose.
 - Assigned quality factors are user-adjustable.
 - Inappropriate contributions from “remainder of body” to marrow were eliminated.

Methods

- The code was rewritten in Java:
 - To rewrite the code in structured format, which is more logical and modular
 - To permit the use of the code on many machine platforms
- The code is written to fit within the new RADAR internet-based system of tools for internal and external dose assessment.



Main Input Form

Nuclide Input Form

Models Input Form

Kinetics Input Form

Help Form

- Adult Male
- Adult Female
- 15-year-old
- 10-year-old
- 5-year-old
- 1-year-old
- Newborn
- 3 month pregnant woman
- 6 month pregnant woman
- 9 month pregnant woman

Prostate Gland

Peritoneal Cavity

Spheres

Head Model

Kidney Model

The previously used quantity of residence time was confusing to many users. This was only a measure of the number of disintegrations occurring in a source organ. This code works with the number of disintegrations per unit activity administered (uCi-hr/uCi or Bq-hr/Bq), either entered directly, or as calculated from formulas. This is mathematically equivalent to residence times, but is perhaps easier to understand. You may also enter data from a kinetic model, involving values of activity and half-lives, and fit them to a function.

Enter the number of disintegrations for the source organs, or use some of the special options below.

Note: for the Tot Body/Rem. Body field - enter value for Rem. Body if any other organ has been chosen.

Adrenals	0.0000	Ovaries	0.0000
Brain	0.0000	Pancreas	0.0000
Breasts	0.0000	Red Mar.	0.0000
GB Cont	0.0000	CortBone	0.0000
LLI Cont	0.0000	TrabBone	0.0000
SI Cont	0.0000	Spleen	0.0000
StomCont	0.0000		
ULI Cont	0.0000	Thymus	0.0000
HeartCon	0.0000	Thyroid	0.0000
Hrt Wall	0.0000	UB Cont	0.0000
Kidneys	0.0000	Uterus	0.0000
Liver	0.0000		
Lungs	0.0000		
Muscle	0.0000	Tot Body/Rem Body	0.0000

Get setup (stp) file

- Bone Activity on Bone Surfaces
- Bone Activity in Bone Volume

Voiding Bladder Model

ICRP GI Model

Fractions and Half-times

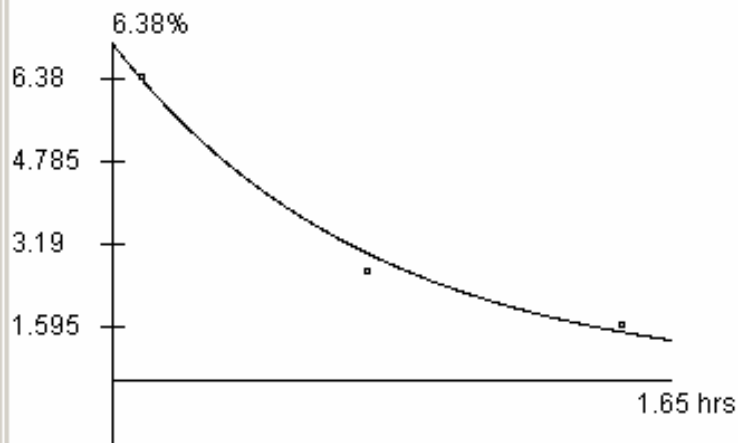
Fit data to Model

Show me some examples

Clear All Data

$$\text{Activity}(t) = A \cdot \exp(-at) + B \cdot \exp(-bt) + C \cdot \exp(-ct)$$

Title :



Time (Hr)	Obsvd %ID	Model %ID	Model/Obv	Weight
8.30E-2	5.80E+0	5.75E+0	9.91E-1	1.0
7.50E-1	2.10E+0	2.41E+0	1.15E+0	1.0
1.50E+0	1.10E+0	9.11E-1	8.28E-1	1.0
				1.0
				1.0
				1.0
				1.0
				1.0
				1.0
				1.0
				1.0

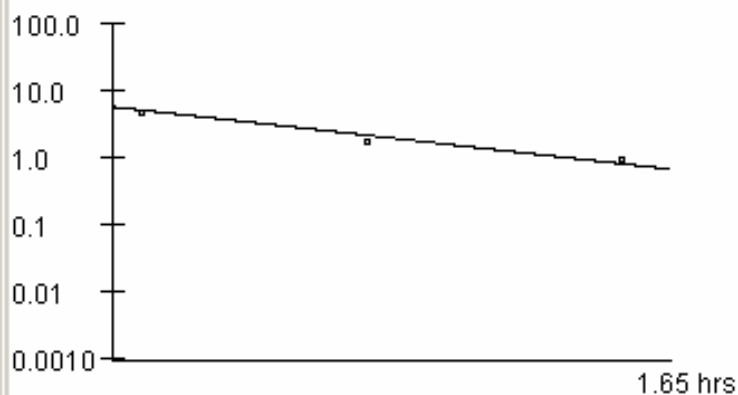
Squared Error =
 R Squared =
 Iteration = of

Phys Half Life (Hrs) =
 Num Disintegrations =
 Integral Start Time =
 Integral End Time =

- ULI
- Heart Contents
- Heart Wall
- Kidneys
- Liver**

Data are decay corrected

A
 B
 C
 a
 b
 c



OLINDA - Organ Level INTERNAL Dose Assessment Code (copyright Vanderbilt University, 2003)

NOTE: This code gives doses for stylized models of average individuals - results should be applied with caution to specific subjects.

NOTE: Users should always carefully check input data (shown below) and critically review the reported results.

Organ Doses (mSv/MBq), Nuclide: I-131 (8.02E00 day), Adult Male

Target Organ	Alpha	Beta	Photon	Total	EDE Cont.	ED Cont.
Adrenals	0.00E000	3.15E-02	1.81E-01	2.13E-01	0.00E000	1.06E-03
Brain	0.00E000	3.15E-02	2.43E-02	5.57E-02	0.00E000	2.79E-04
Breasts	0.00E000	3.15E-02	5.83E-02	8.97E-02	1.35E-02	4.49E-03
Gallbladder Wall	0.00E000	3.15E-02	2.84E-01	3.15E-01	0.00E000	0.00E000
LLI Wall	0.00E000	5.86E-01	1.18E-01	7.03E-01	4.22E-02	8.44E-02
Small Intestine	0.00E000	1.74E-01	1.18E-01	2.92E-01	0.00E000	1.46E-03
Stomach Wall	0.00E000	3.15E-02	1.06E-01	1.37E-01	0.00E000	1.65E-02
ULI Wall	0.00E000	3.49E-01	1.58E-01	5.07E-01	3.04E-02	2.53E-03
Heart Wall	0.00E000	4.93E-01	2.15E-01	7.09E-01	4.25E-02	0.00E000
Kidneys	0.00E000	2.08E-02	1.35E-01	1.55E-01	0.00E000	7.77E-04
Liver	0.00E000	1.56E000	5.60E-01	2.12E000	1.27E-01	1.06E-01

Modify Input Data

Next Phantom

Previous Phantom

See Source Organ Contributions

Main Menu

Exit

 Input Data:



Phantom organ masses (g) for the Adult Male

** = Modified by user

Hit <ret> to see changes immediately, or just DONE at end

Next Phantom	Previous Phantom
--------------	------------------

16.3	Adrenals
1420.0	Brain
351.0	Breasts
10.5	Gallbladder Wall
167.0	LLI Wall
677.0	Small Intestine
158.0	Stomach Wall
220.0	ULI Wall
316.0	Heart Wall
299.0	Kidneys
1910.0	Liver
1000.0	Lungs
28000.0	Muscle
8.71	Ovaries

94.3	Pancreas
1120.0	Red Marrow
120.0	Osteogenic Cells
3010.0	Skin
183.0	Spleen
39.1	Testes
20.9	Thymus
20.7	Thyroid
47.6	Urinary Bladder Wall
79.0	Uterus
0.0	Fetus
0.0	Placenta
73700.0	Total Body

Alpha Weight Factor

Beta Weight Factor

Photon Weight Factor

5.0

1.0

1.0

Multiply all masses by:

1.0

Reset organ values

DONE