Three Dimensional Dosimetry Analyses In Radionuclide Therapy Using IDL And MCNP-based Software Tools

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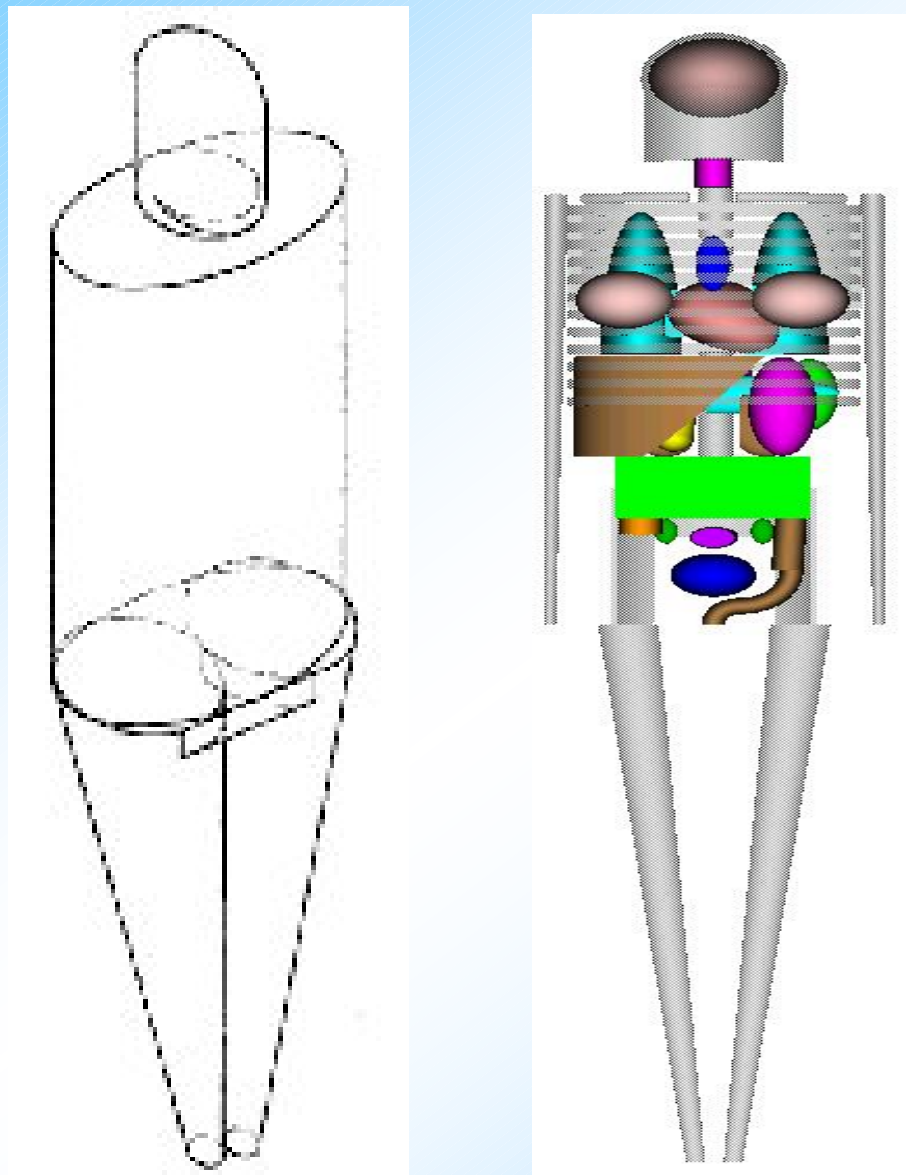
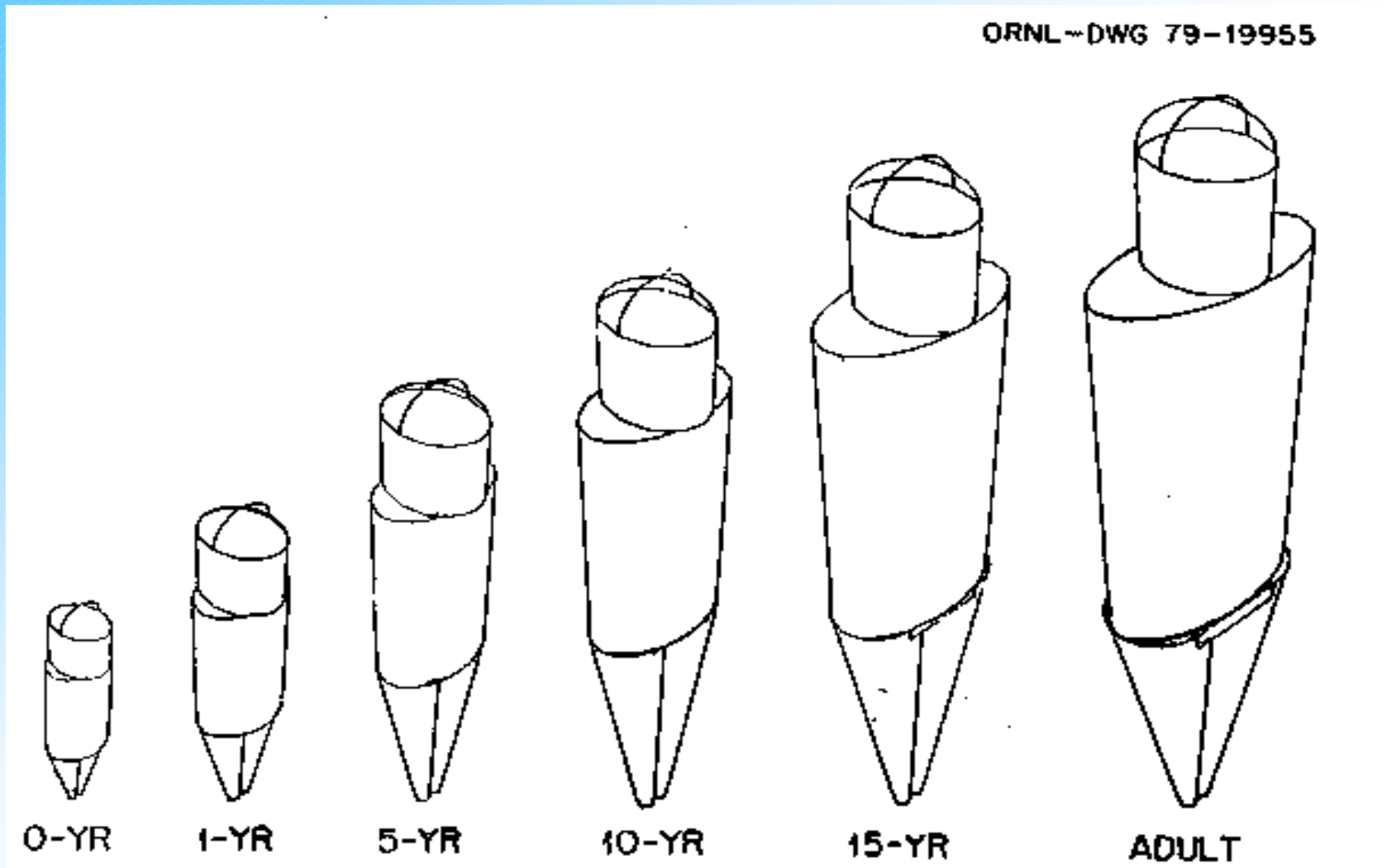
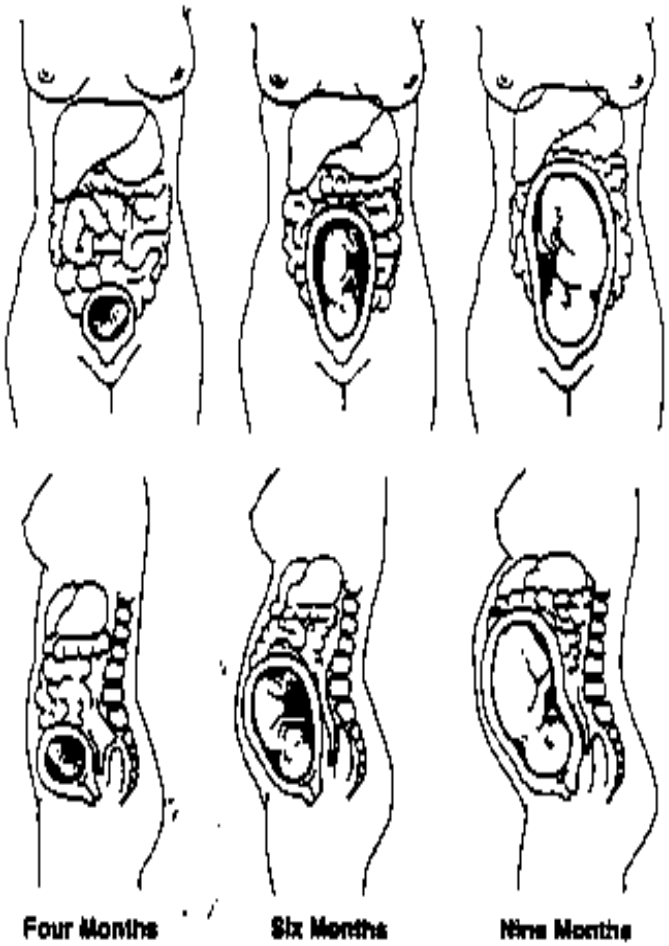


Stylized adult male Fisher-Snyder model showing (a) exterior view, and (b) the skeleton and internal organs.

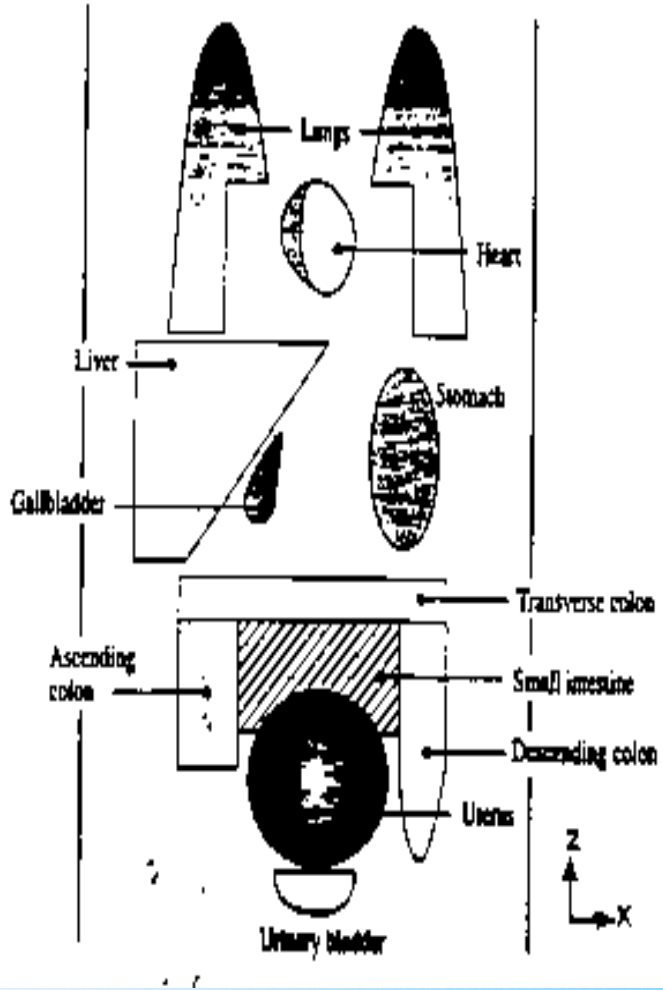


Equation-based models of children and adults (Cristy/Eckerman, 1987)

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



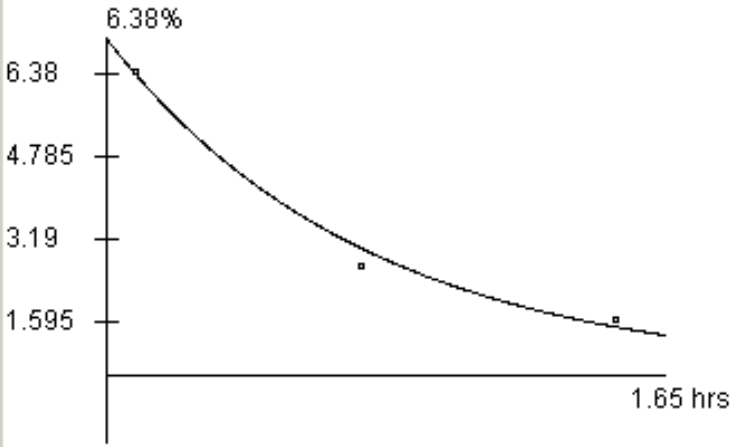
Sketches of the woman at various stages of gestation



Geometrical model for the 3 month pregnant woman

Disintegrations Calculator null

Activity(t)=A*exp(-at)+B*exp(-bt)+C*exp(-ct)



Title : Liver

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

Squared Error = 1.37E-1

R Squared = 1.00E+0

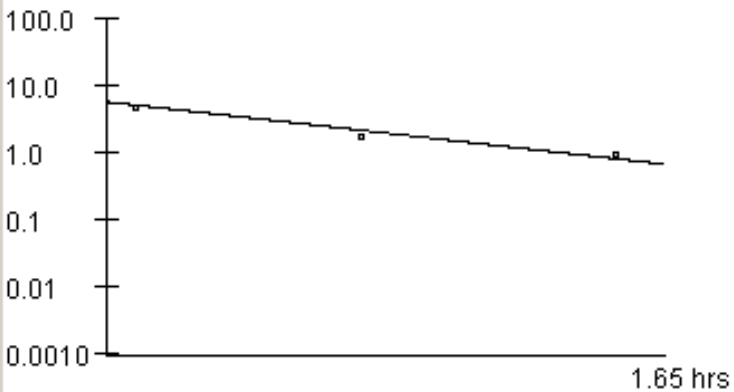
Iteration = 0 of 100

Phys Half Life (Hrs) = 3.40E-1

Num Disintegrations = 1.92E-2

Integral Start Time = 0

Integral End Time = 438300



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

Data are decay corrected ☑

☑ A 6.40E+0

☐ B

☐ C

☑ a 1.30E+0

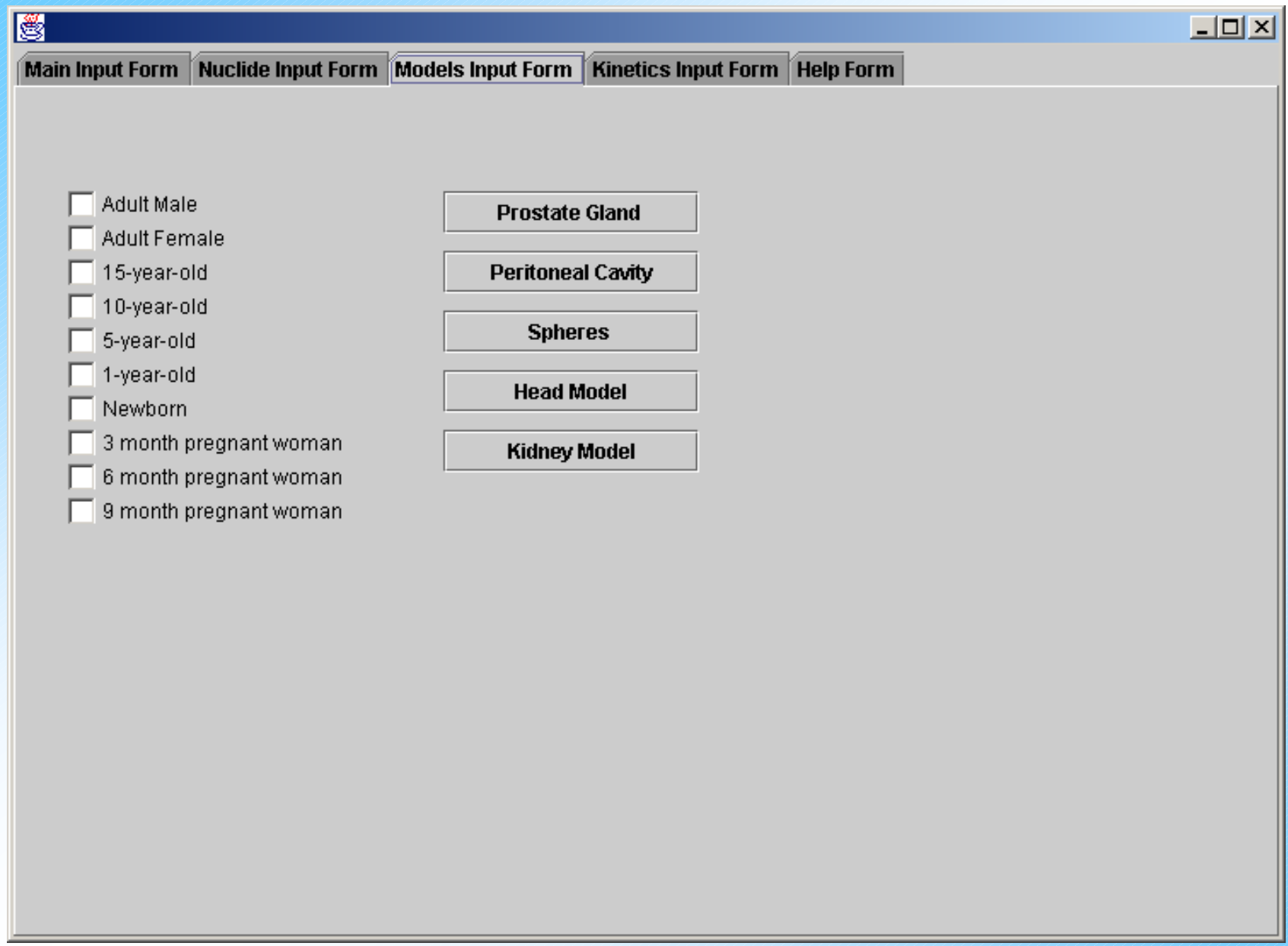
☐ b

☐ c

Refresh | Open Data | Clear Screen

Fit | Save Data | Clear Organs

Done | Show Help


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

Organ Doses:

File View

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

Reliable absorbed dose calculations in systemic radiation therapy are essential for assessing tumor response to absorbed doses, for evaluating normal tissue toxicity, and for treatment planning. Physicians treating cancer need to know the radiation absorbed dose to the tissues of interest.

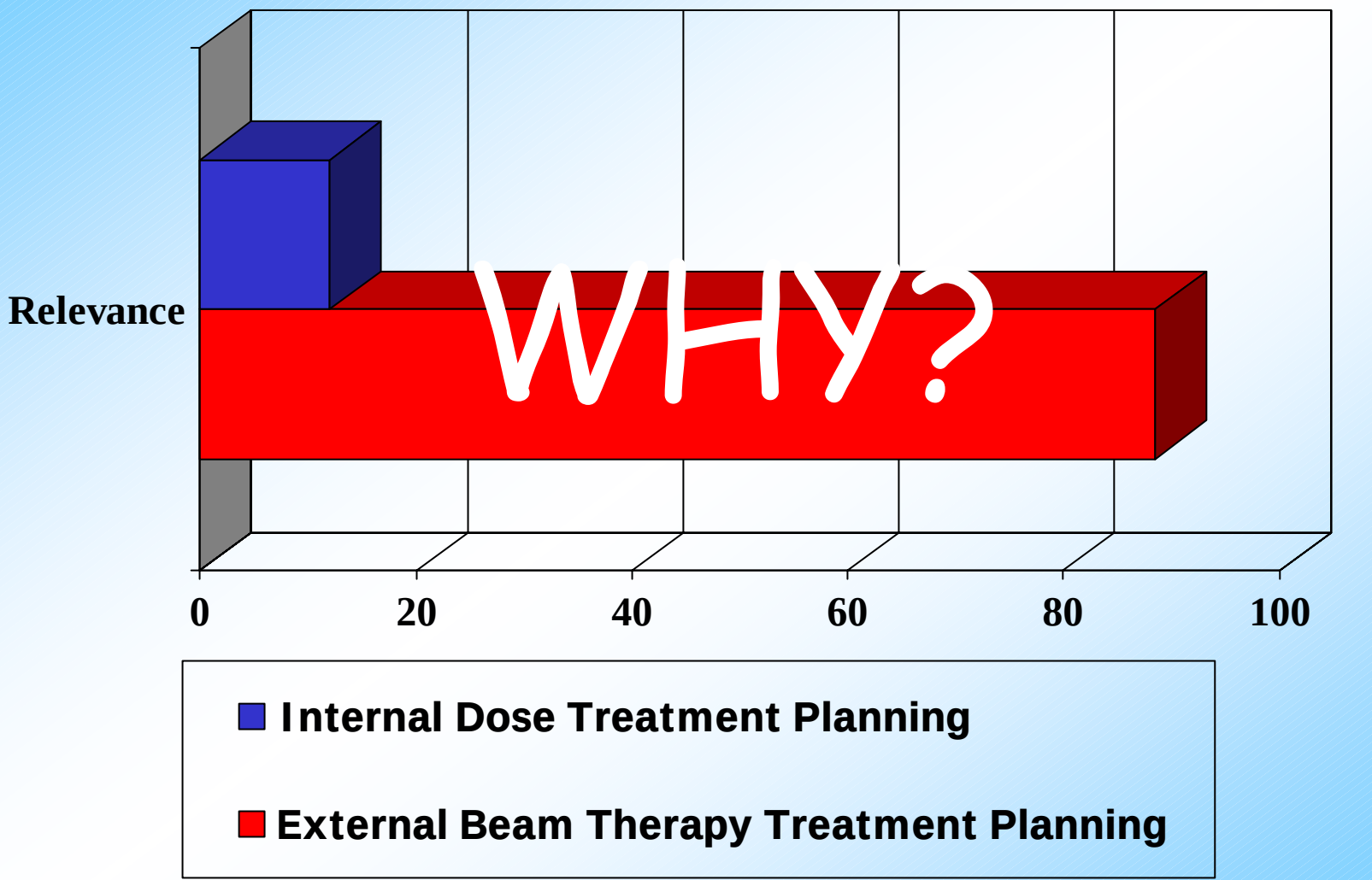
Darrell Fisher,
1995

Dosimetrists are parasites who hinder the progress of radioimmunotherapy. We should rather just look empirically which antibody has promising clinical results instead of wasting our time with useless dosimetric speculations.

Jeff Schlom, 1995

“Parasite Behavior”

“Rocket Science”



Dose Calculations for Nuclear Medicine Therapy Applications

- Internal dose estimates:
  - Average organ dose (not dose distributions)
  - Doses to standard individuals
  - Weak correlations of dose with effect
- Questions:
  - What models are good enough for use in therapy?
  - What models will produce clinically meaningful results?

Dose Calculations for Nuclear Medicine Therapy Applications

- Patient-specific dose calculations are not always performed for nuclear medicine patients
  - "One dose fits all"
  - Patients have different tumor and normal organ uptake
  - Patients have different clearance half-times
  - Patients have different organ sizes and geometries

Dose Calculations for Nuclear Medicine Therapy Applications

- This would be equivalent to using identical beam geometries and exposure times for all patients in external therapy!
- Optimization of therapy –
  - Maximize dose to tumor
  - Minimize dose to normal tissues

Dose Calculations for Nuclear Medicine Therapy Applications

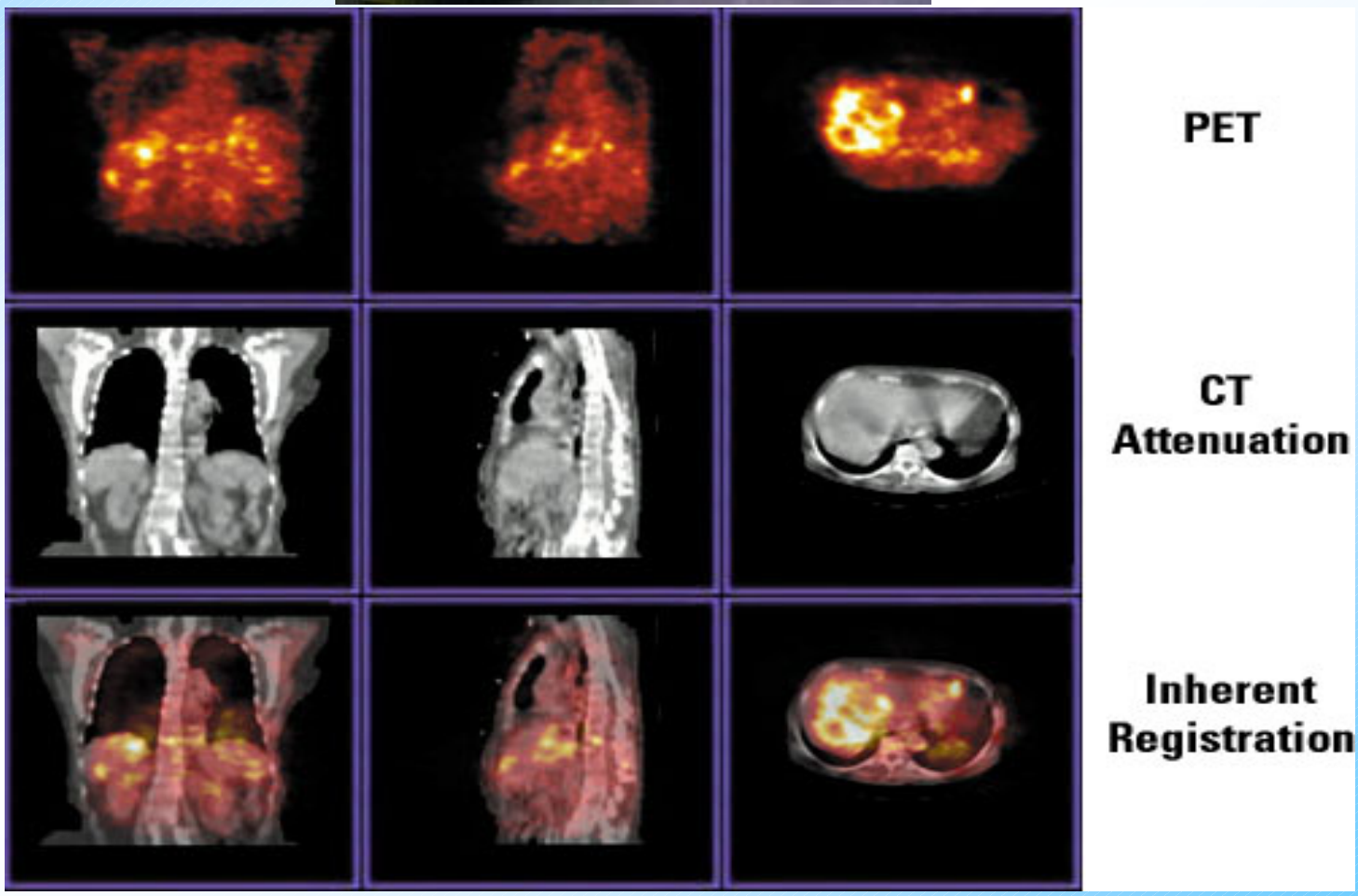
- In thyroid cancer therapy, we are working with a very wide “therapeutic window”
- In many other cases (radiolabeled antibodies, bone agents against osseous metastases, etc.) the therapeutic window is more narrow, and principles of optimization are more important.

Use of MCNP 4B to Calculate Dose Distributions in a Voxel Based Phantom

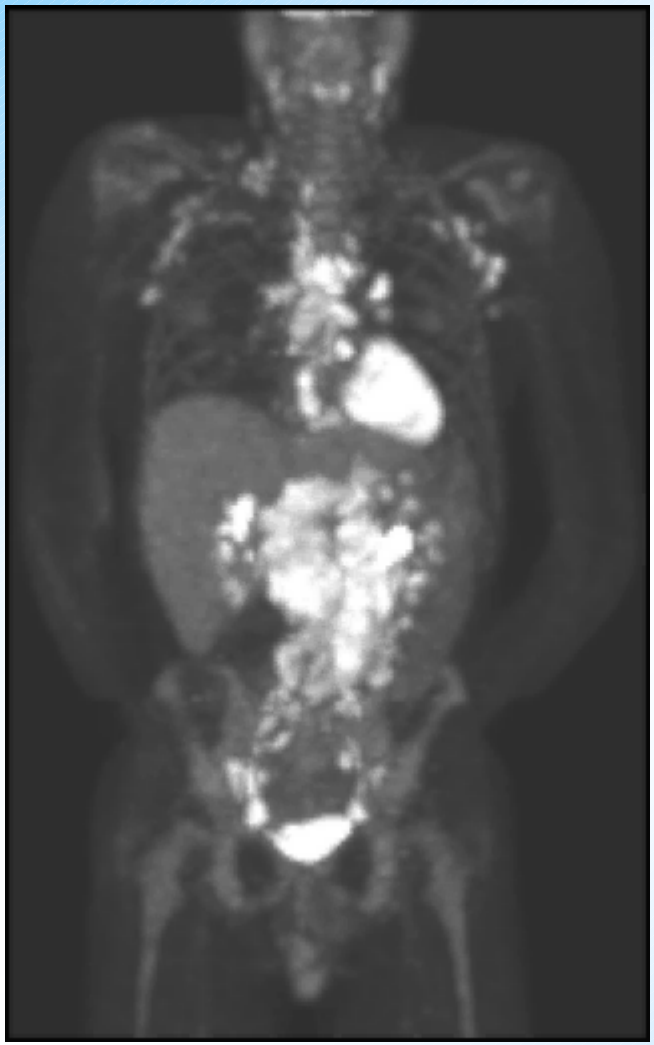
- Current needs in radioimmunotherapy (RIT) are increasing the trend towards more patient-specific, as opposed to model-based, dosimetry.
- Accurate absorbed dose estimates for subjects are needed; an automated calculational system that performs in a reasonable time would be desirable.

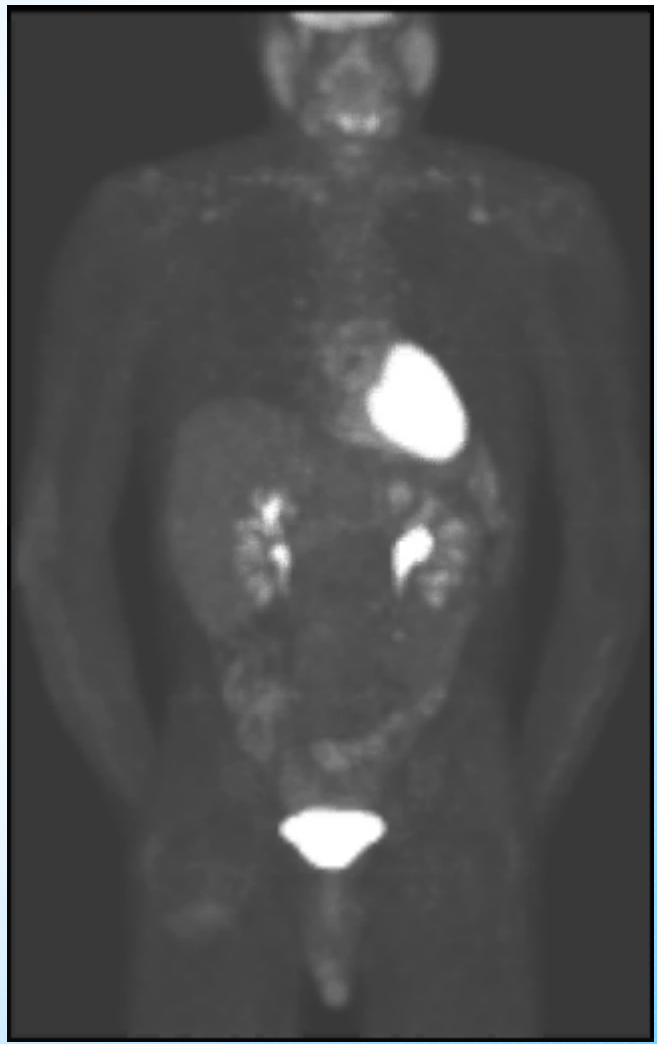
New Phantoms for Dose Assessment

- We investigated whether dose distributions could be determined performing the radiation transport with the code MCNP-4B.
- Two applications for this technology are envisioned:
  - Dose distributions for therapy patients receiving radiopharmaceuticals (using specific voxel images of each patient), and
  - Calculation of dose conversion factors (DCFs) for a new generation of more realistic phantoms.


PET
CT
Attenuation
Inherent
Registration

Tumor Response with Zevalin





Slide courtesy of Dr. Greg Wiseman, Mayo Clinic, Rochester, MN

Applications

- Existing codes:
  - 3D-ID (MSKCC)
  - RTDS (COHMS)
  - SIMIND (Univ of Lund)
  - RMDP (Royal Marsden Hospital, UK)
  - “Mr. Voxel” (St. George Hospital, Sydney, Australia)
  - Vanderbilt – voxel images + MCNP radiation transport

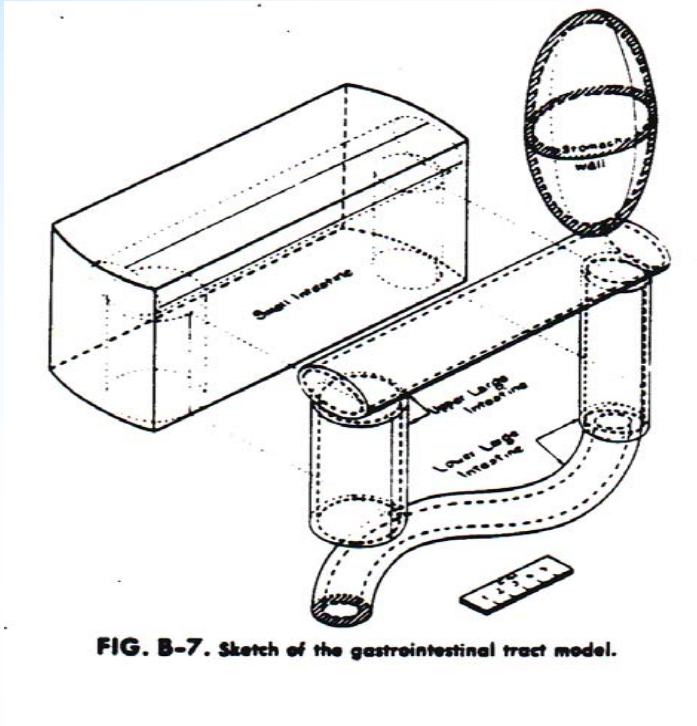
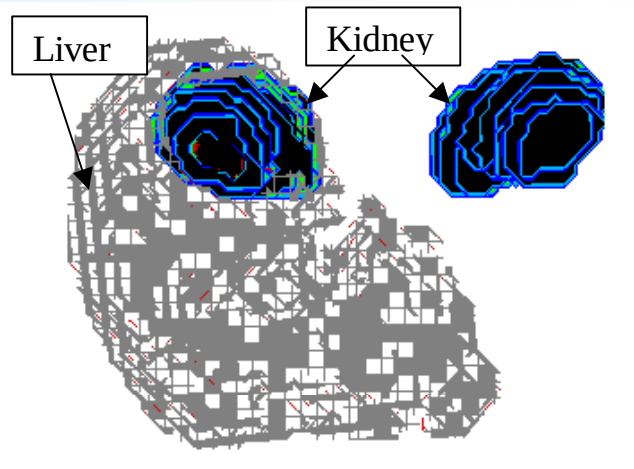
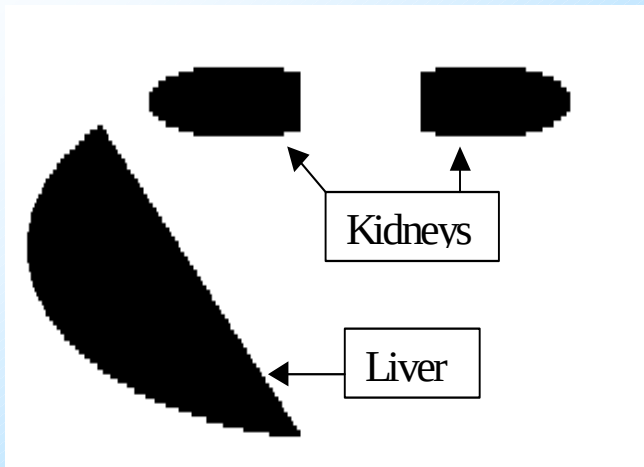
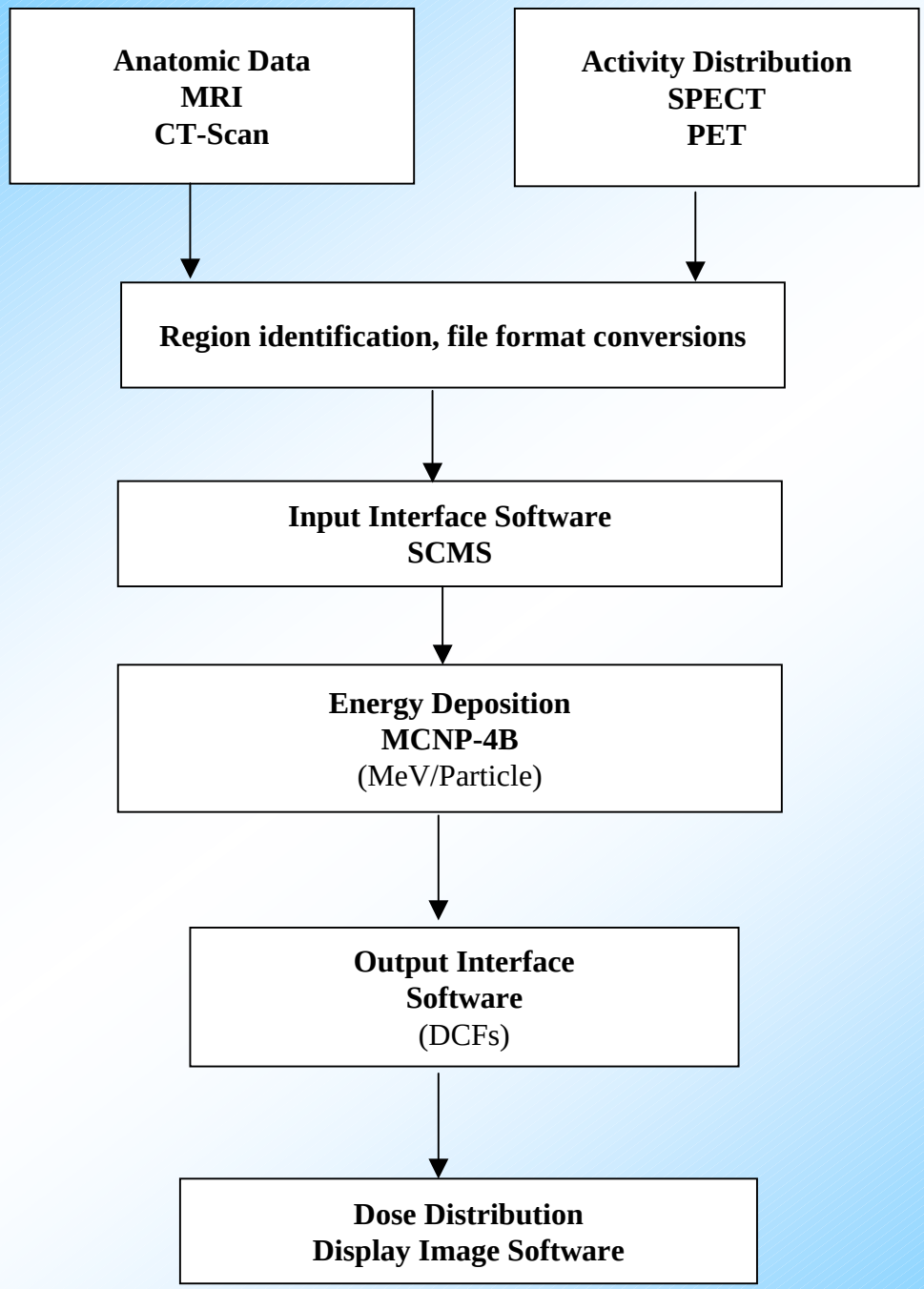


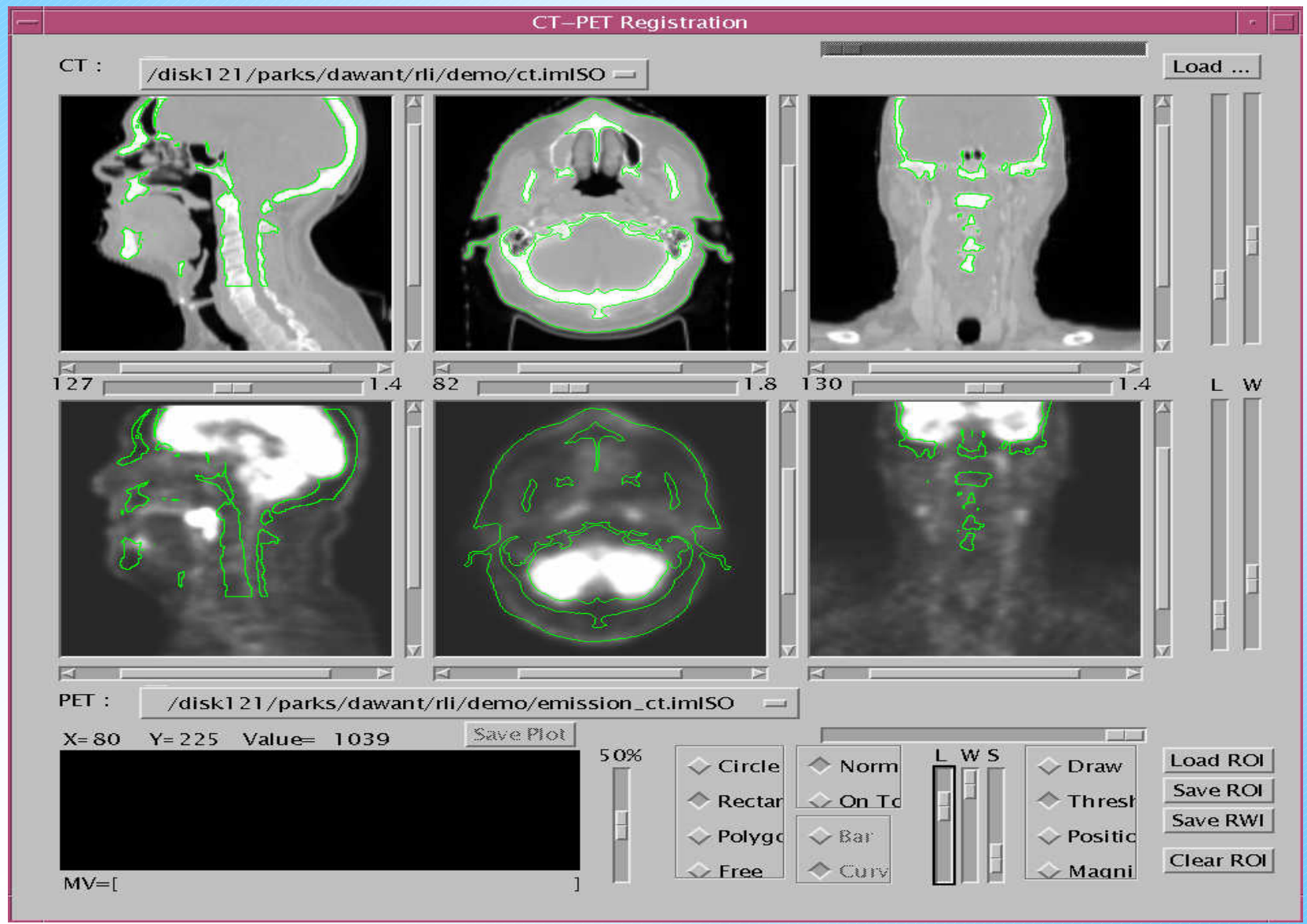
FIG. B-7. Sketch of the gastrointestinal tract model.

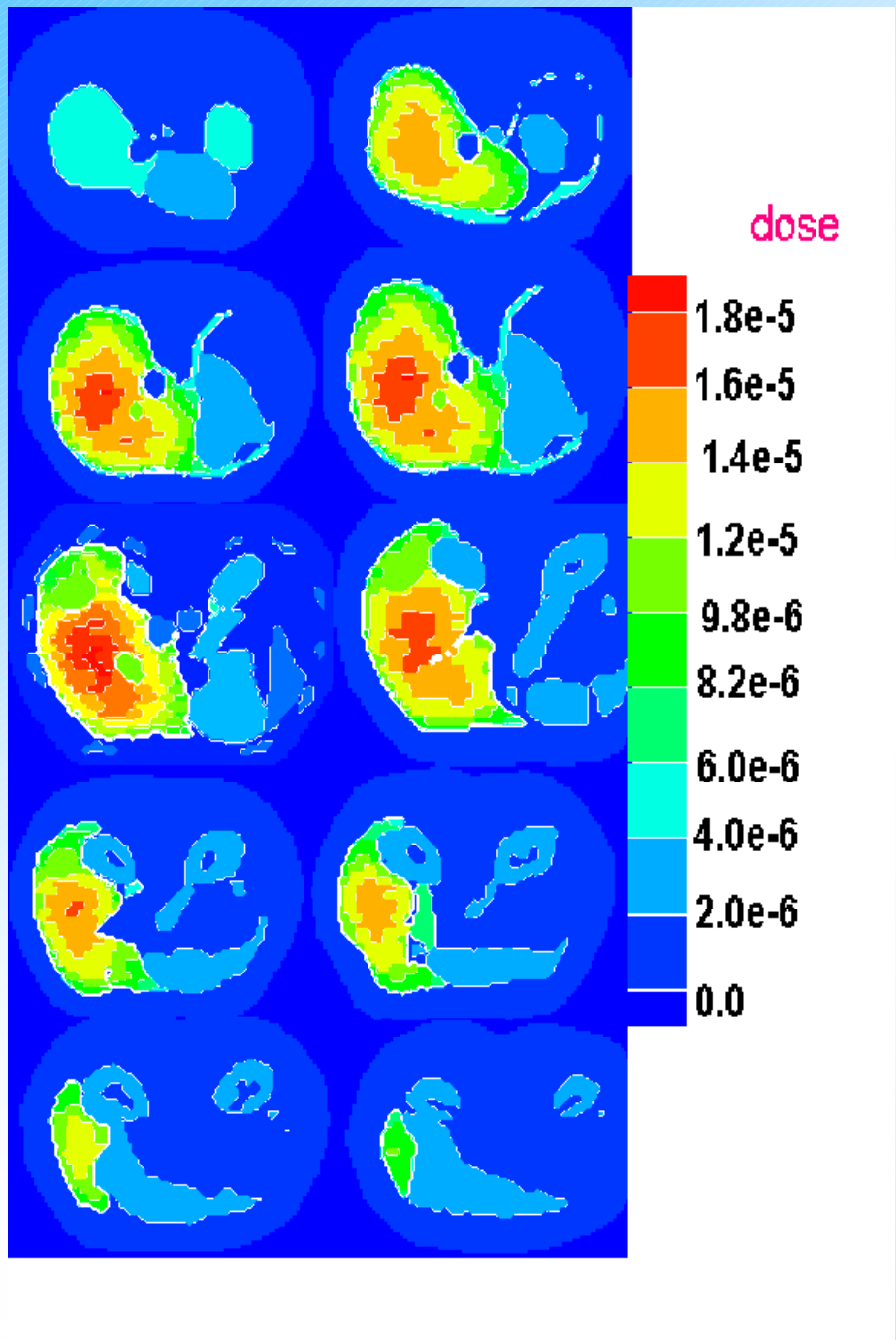





Anatomic Data
MRI
CT-Scan
Activity Distribution
SPECT
PET
Region identification, file format conversions
Input Interface Software
SCMS
Energy Deposition
MCNP-4B
(MeV/Particle)
Output Interface
Software
(DCFs)
Dose Distribution
Display Image Software

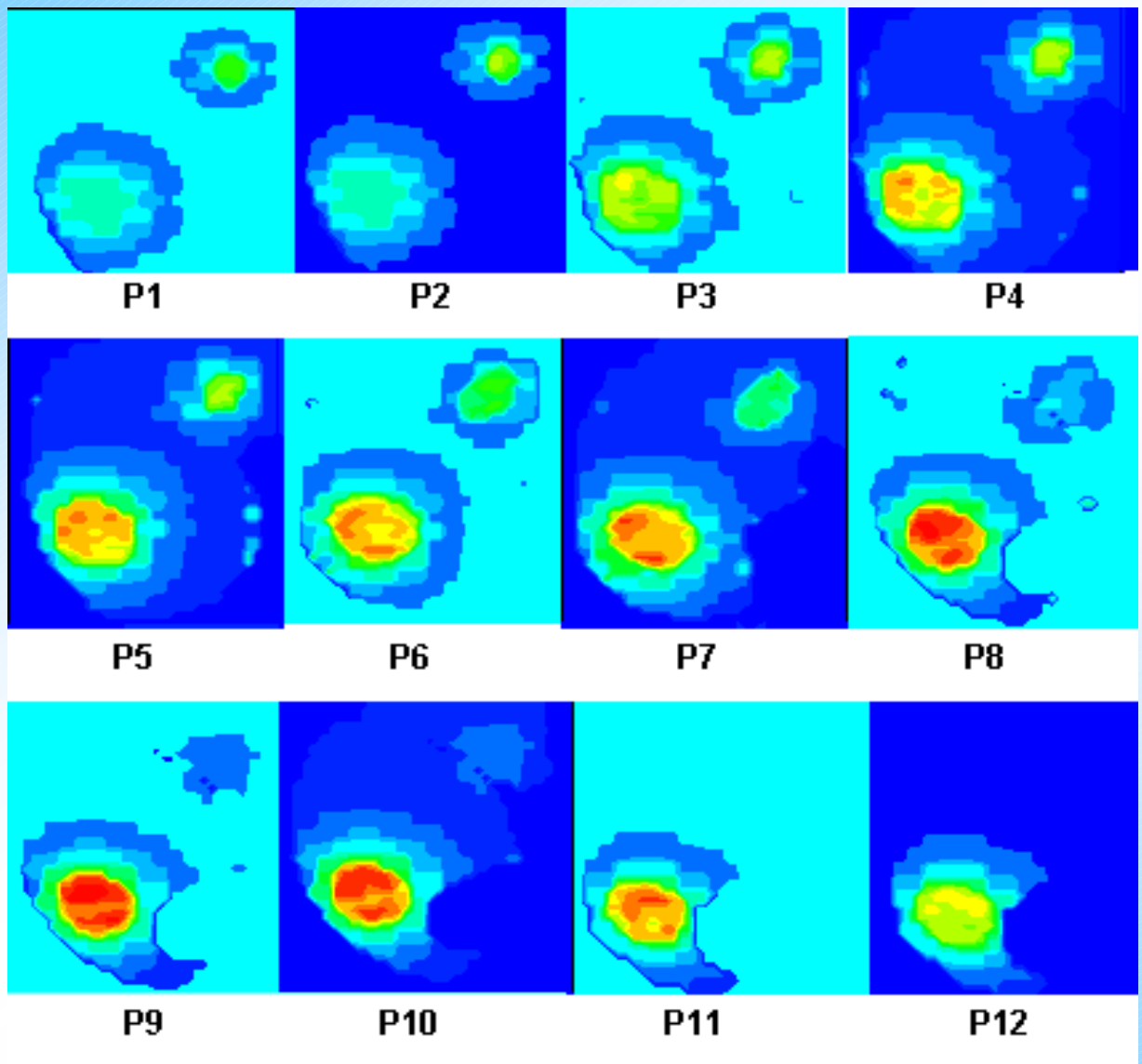
Region identification and organ number assignment (coregistered images)

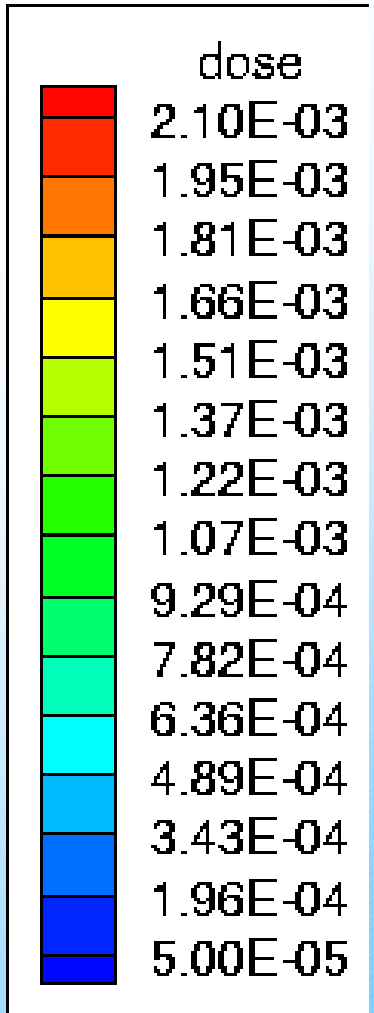


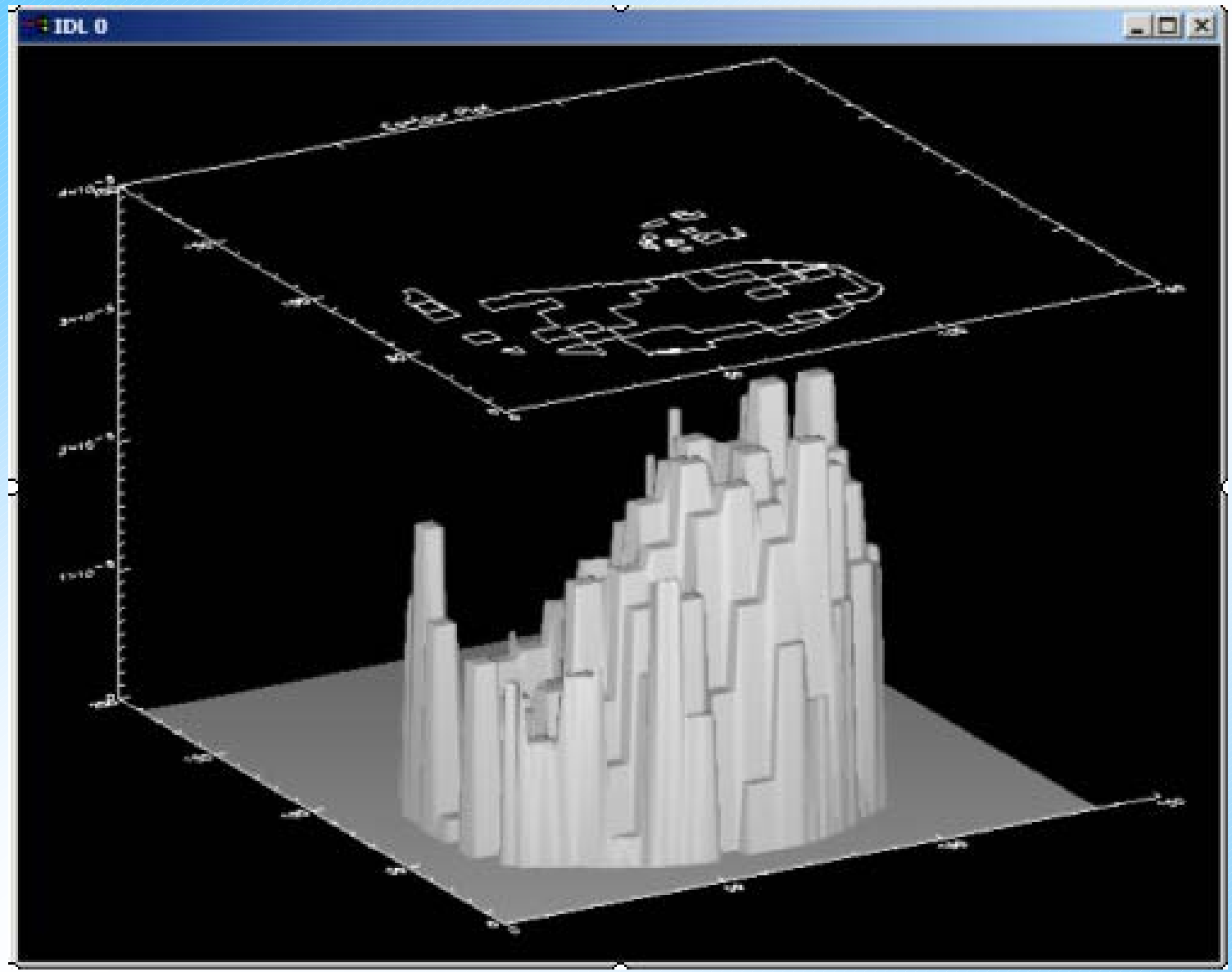


Dose distribution in the liver, uniform source distribution, 1.0 MeV photons. Dose units are (mGy/MBq.s).

Regional dose distribution in the lesion region and surrounding tissues due to a hypothetical non-uniform activity distribution. Dose units are mGy/MBq.s.







3D representation of dose to a section of liver for a patient receiving In-111 Zevalin.

CPU Time Versus Number of Tallies

(100,000 photon histories)

Number of Tallies	CPU Time (*) Relative Units
1	1
27	1.11
125	4.63
1000	22.46

(*) DEC-ALPHA 3000

Individual target voxel tally errors

Source Organ - Kidneys, Target Organ - Liver

Number of Photon Histories	MCNP Individual target voxel relative errors	CPU time (hours)
1,000,000	0.51	25
2,000,000	0.32	46
3,000,000	0.29	66

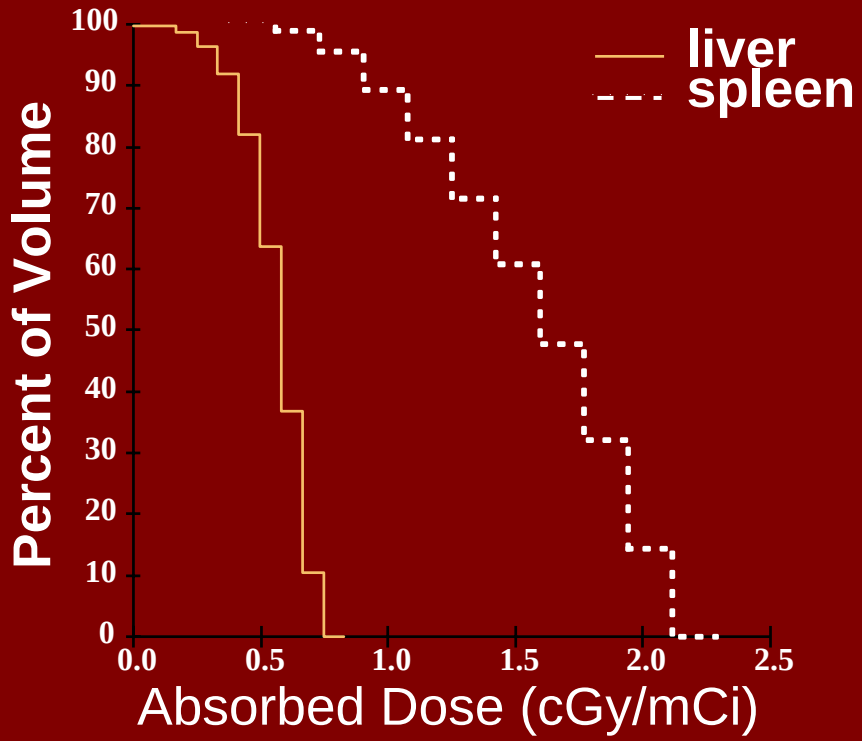
Dose Distribution
Tallying individual voxels

- CPU time is strongly dependent on the number of tallies
- It is nearly impossible to tally each voxel cell in the phantom (4 million cells)
- The relative errors tend to be large in individual voxels because of poor statistics

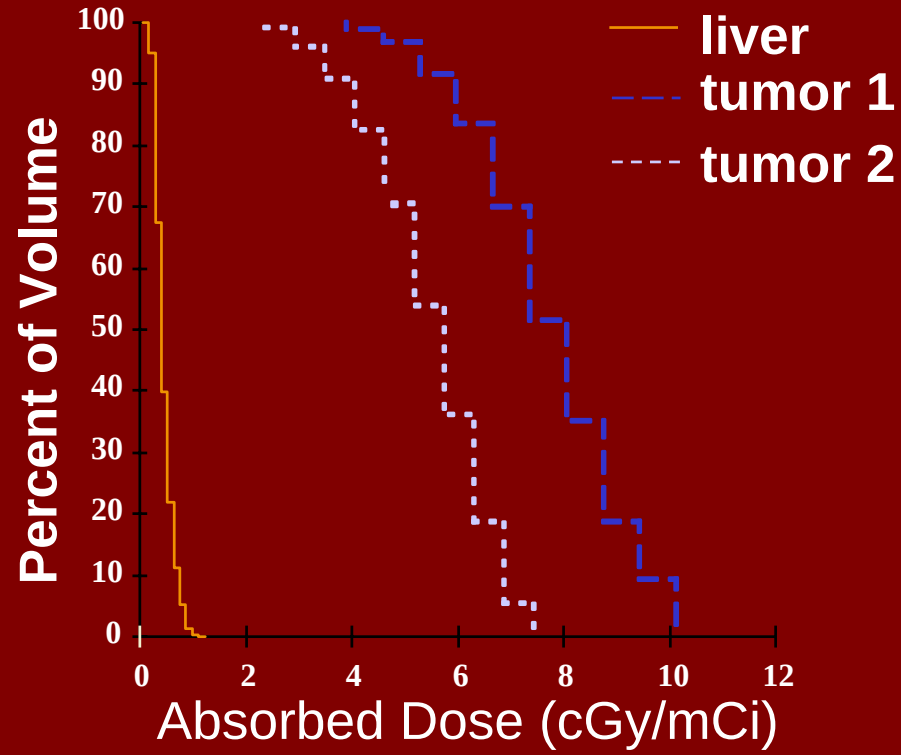
Input Interface Software for Regional Dose Distribution in the Organ

- Each organ is divided in a certain number of regions, with each region consisting of a certain number of voxels (definable by the user).
- Average dose can be determined for each region instead of in individual voxels.
- Each organ may have different number of regions, so that some organs may have more detailed dose distribution than others.
- As a result, regional dose distributions can be determined within a reasonable time.

Histogram representation

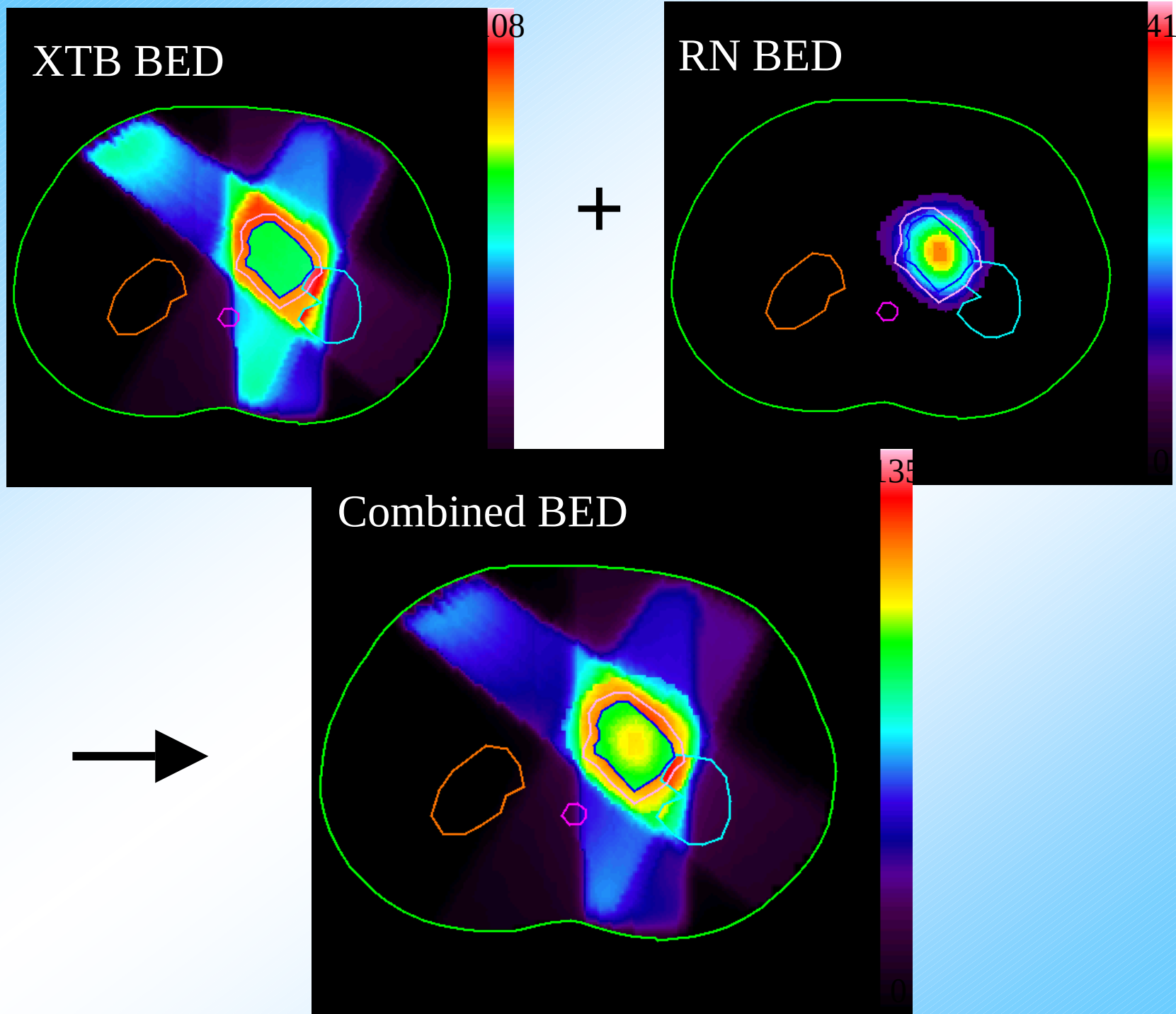


Patient 1



Patient 2

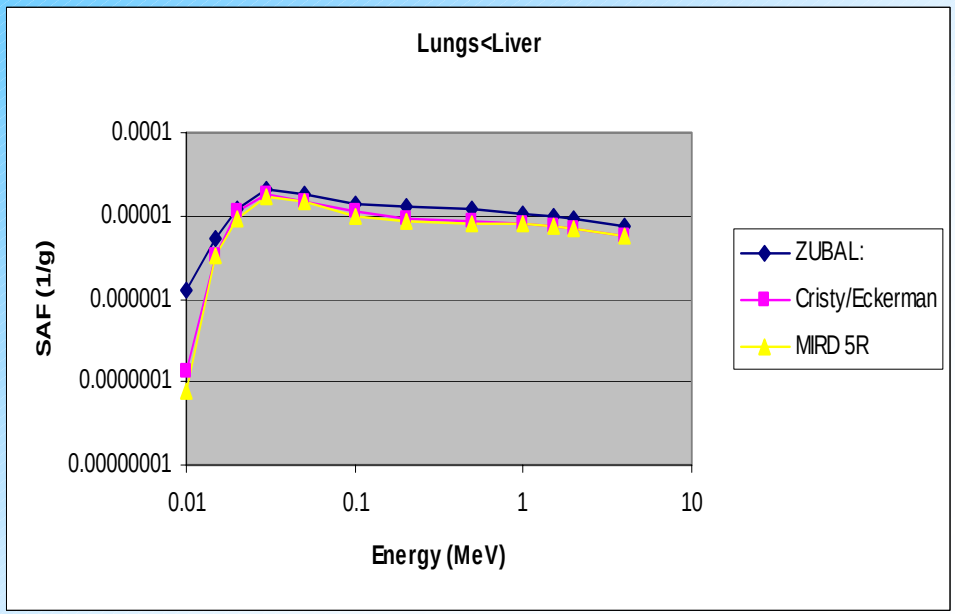
Dr. G. Sgouros, Memorial Sloan-Kettering Cancer Center, 2001

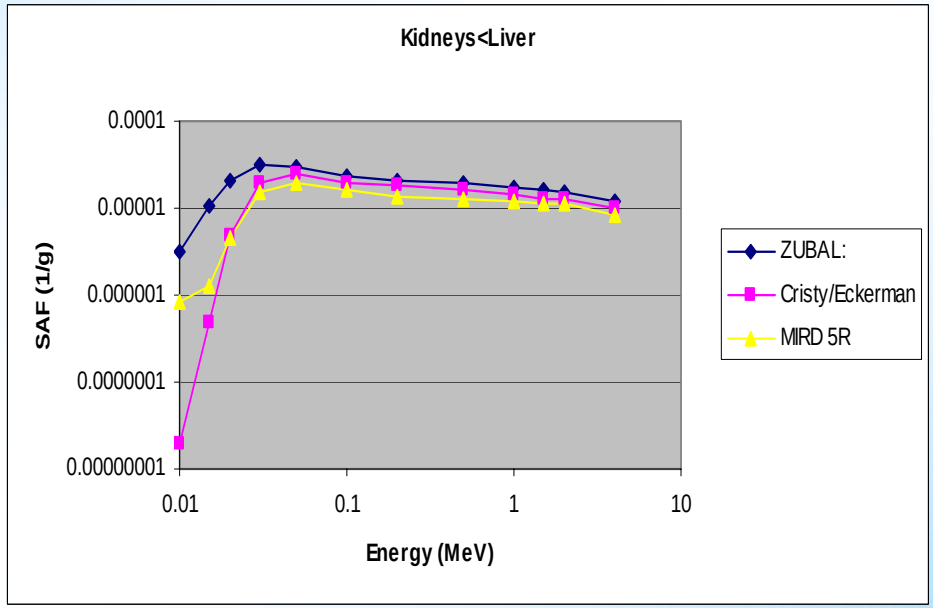

XTB BED
108
RN BED
41
0
Combined BED
135
0

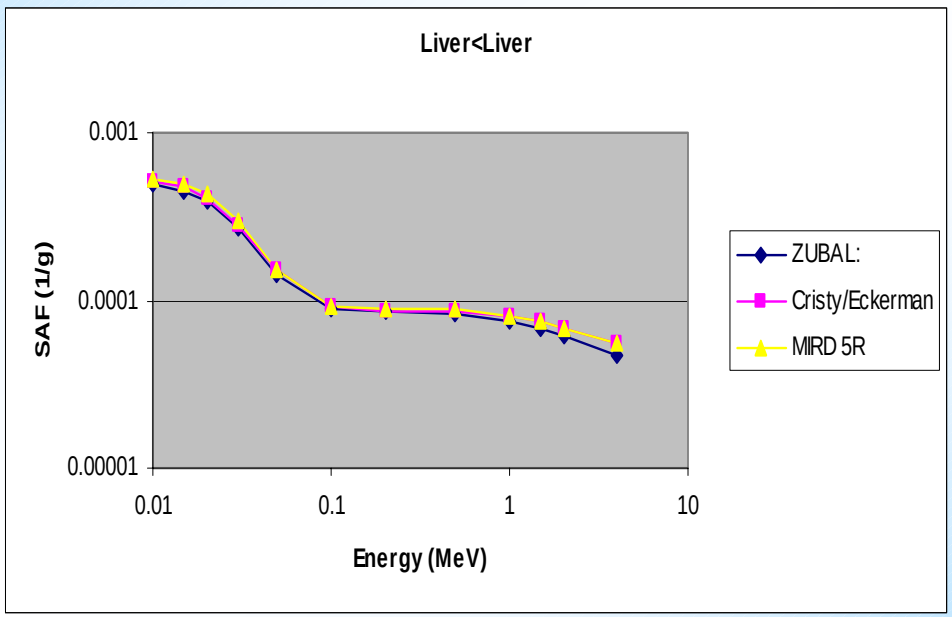
New Phantoms for Dose Assessment

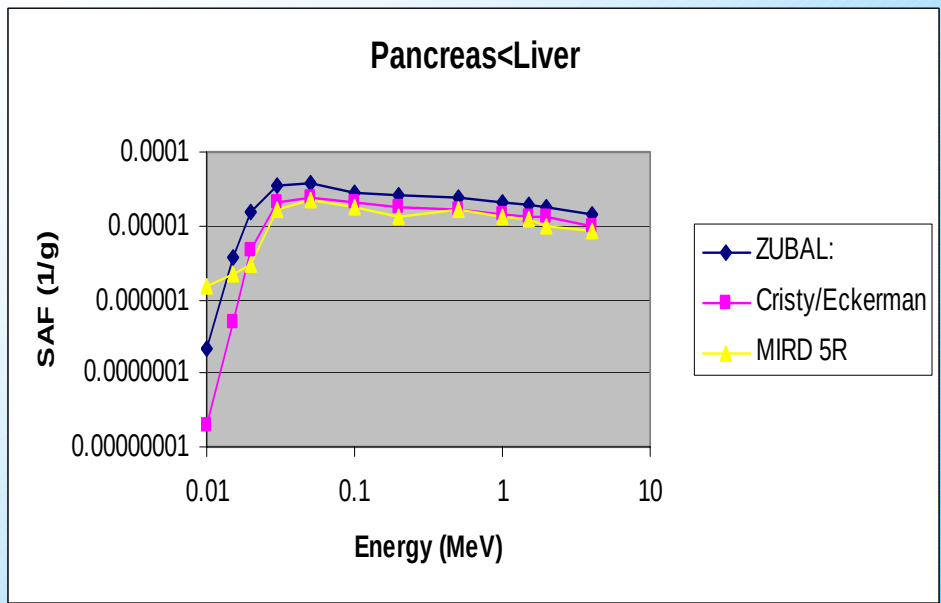
- We have also generated a fairly complete set of DCFs for the Zubal et al. (Yale) voxel phantom.
- We have calculated DCFs for whole organs as sources and targets using this technique, for the 12 standard discrete energy values employed by others (Snyder et al. 1975, Cristy and Eckerman 1987).

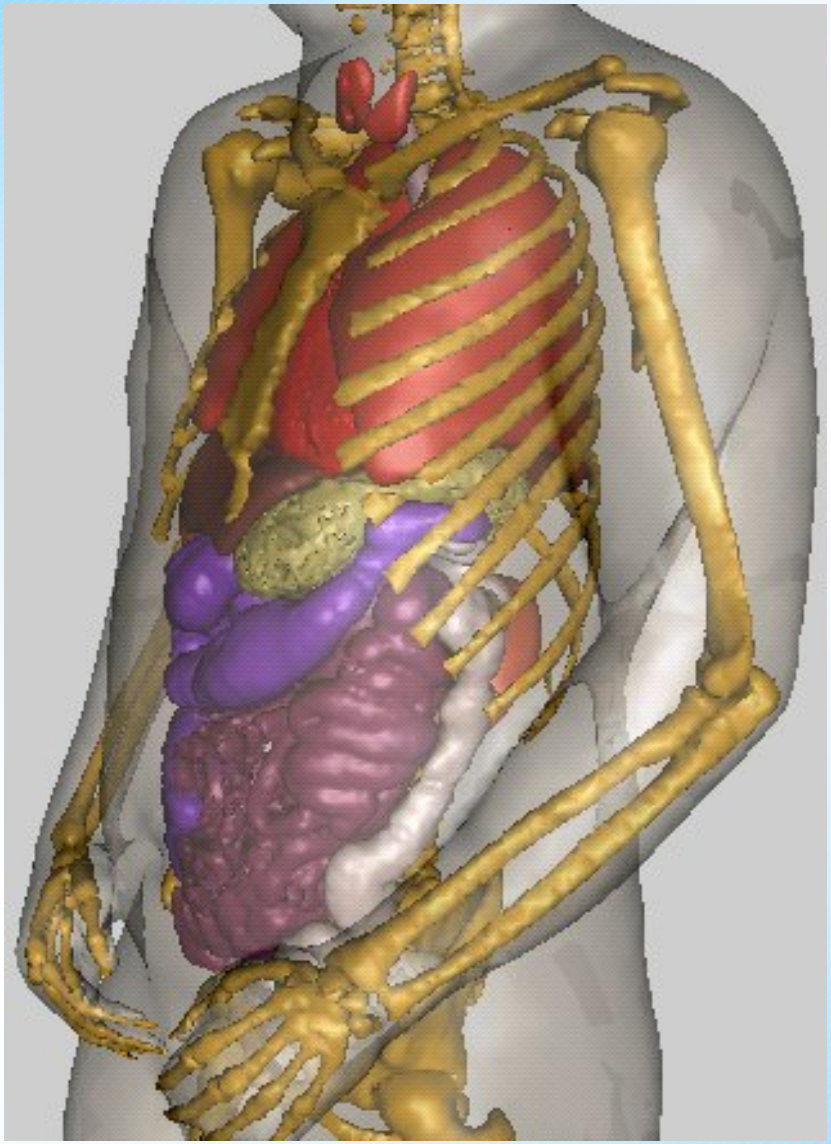
Selected Results - Source = Liver, Photons











Exterior view of the VIP-Man phantom showing internal organs.

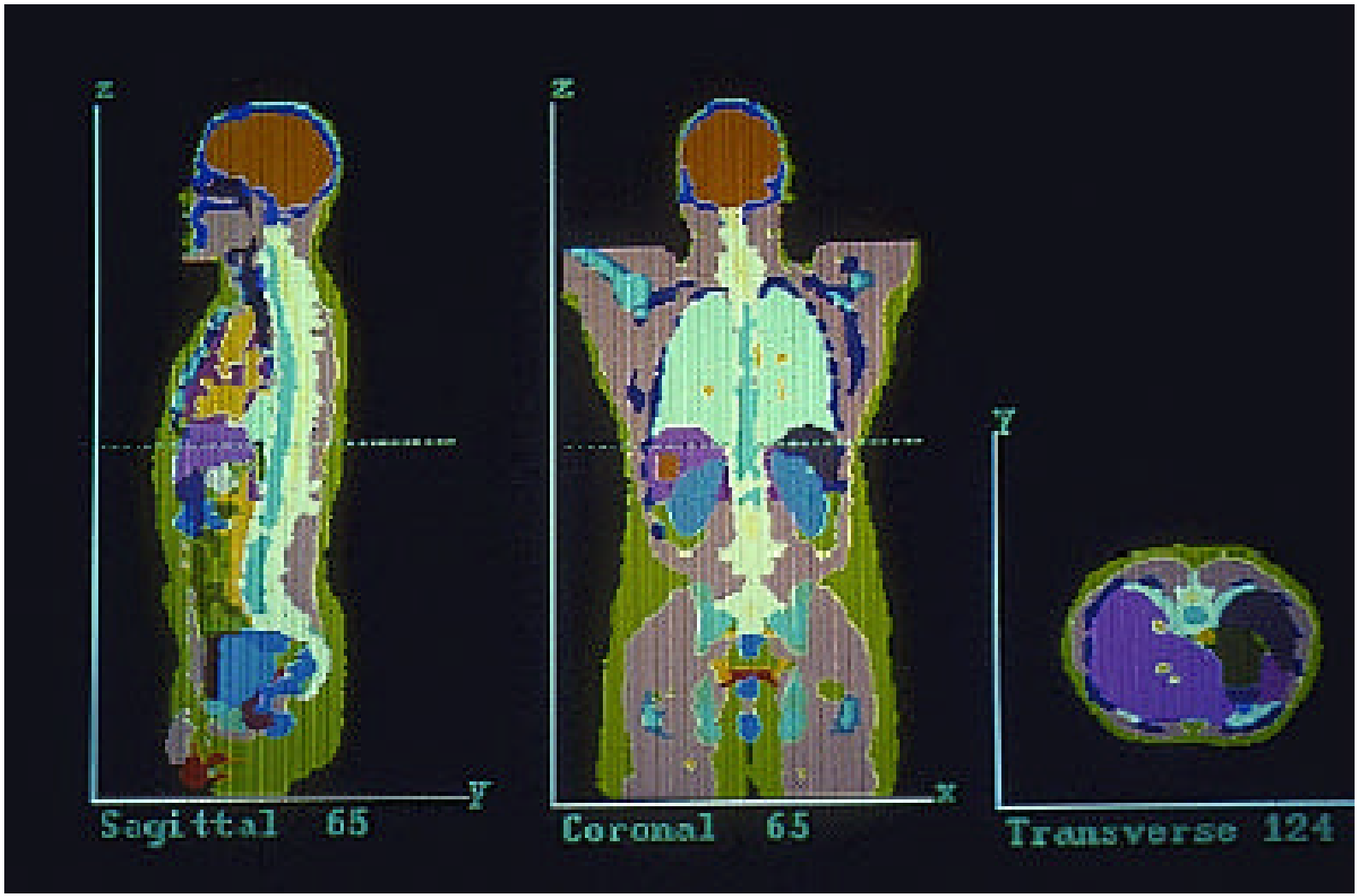
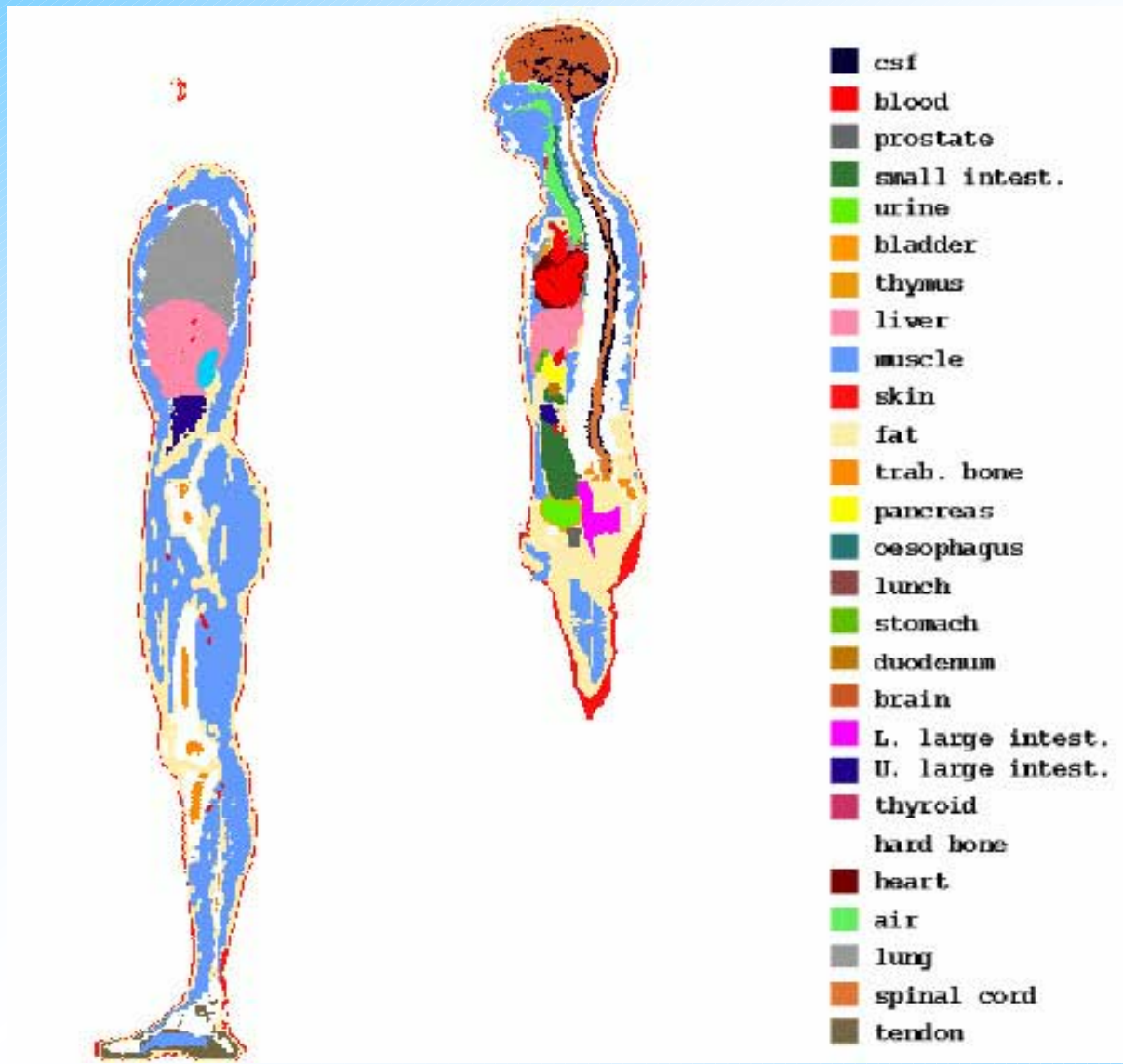
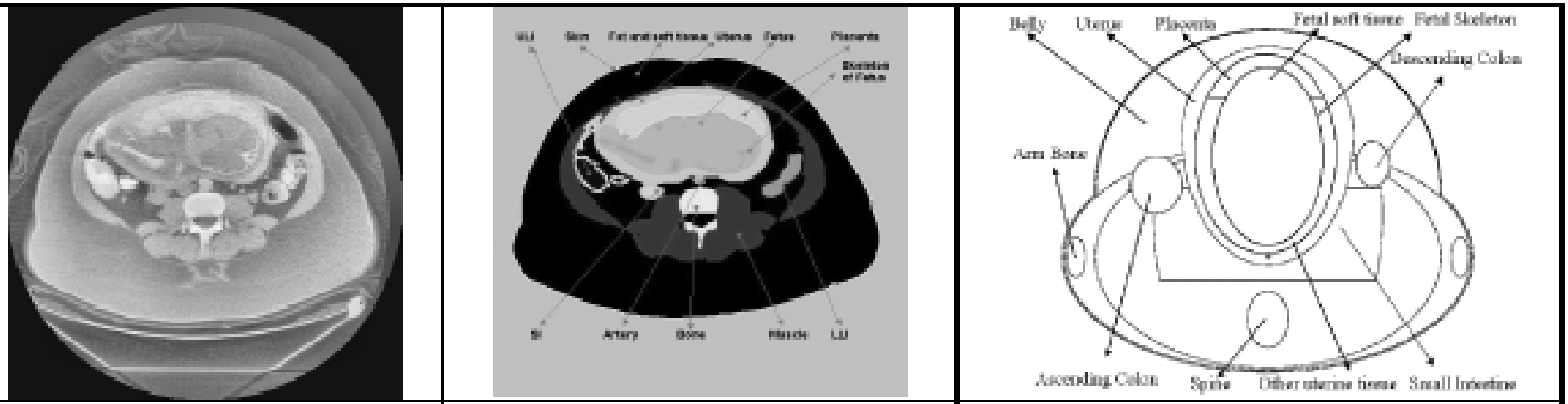


Figure 1: Saggital, coronal, and transverse slice through the voxel-based phantom of Zubal et al.



Using NORMAN to define the effects of high frequency electromagnetic radiation (including microwaves)



A B C

Fig. 1. A) A CT slice of the original images, B) The same slice after segmentation and labeling, C) Cross section of the stylized pregnant woman model [20].

Discussion - Phantom SAFs

- Yoriyaz H, Stabin MG, and dos Santos A. Monte Carlo MCNP-4B-based absorbed dose distribution estimates for patient-specific dosimetry. J Nucl Med 42(4):662-669, 2001.
- Stabin MG and Yoriyaz H. Photon specific absorbed fractions calculated in the trunk of an adult male voxel-based phantom. Health Phys. 82(1):21-44, 2002.

- Bozkurt A, Chao TC and Xu XG. Fluence-to-dose conversion coefficients from monoenergetic neutrons below 20 MeV based on the VIP-Man anatomical model. Phys. Med. Biol. 45:3059-3079, 2000.
- Chao TC and Xu XG. Specific absorbed fractions from the image-based VIP-Man body model and EGS4-VLSI Monte Carlo code: internal electron emitters. Phys. Med. Biol. 46: 901-927, 2001.
- Chao TC, Bozkurt A, and Xu XG. Conversion coefficients based on the VIP-man anatomical model and EGS4-VLSI code for external monoenergetic photons from 10 keV TO 10 MeV. Health Physics. 81(2):163-183, 2001.
- Bozkurt A, Chao TC, and Xu XG. Fluence-to-dose conversion coefficients based on the VIP-man anatomical model and MCPNX code for monoenergetic neutrons above 20 MeV. Health Physics.81(2):184-202, 2001.
- Chao TC, Bozkurt A, and Xu XG. Organ dose conversion coefficients for 0.1-10 MeV electrons calculated for the VIP-man tomographic model. Health Physics. 81(2):203-214, 2001.


graphy AcclaimImages.com Photogr

Conclusions

- MCNP can be used to determine photon and electron dose distributions in voxelized phantoms.
- With patient data, it may not be possible to determine the dose for each individual voxel in a reasonable CPU time in this application, however, organs can be divided into a number of regions containing different numbers of voxels, with the average dose in those regions obtained in a reasonable CPU time (24-48 hr).

Conclusions

- The present input interface program is written to read specific CT-scan data provided for this phantom, but will be modified to read more general data formats.
- Organ/region identification must be done in each case until an automated method is developed. Ultimately, the goal is to develop an automated code for distribution.
- The use of more realistic phantoms for standardized dosimetry should replace the older, stylized models, as new voxel phantoms are added to the existing library.