Centre for

Positron Emission Tomography

Austin & Repatriation Medical Centre, Melbourne Australia

WORKSHOP 2005

ADVANCES IN PET-SPECT/CT and RTP

9:30-10:00

Principles of Radiotherapy

Treatment Planning

Trevor Ackerly

Peter MacCallum Cancer Centre

Principles of RT Planning

PROCESS

- **<u>CT (IMAGING)</u>**
- TUMOUR LOCALISATION
- TREATMENT PLANNING
- TREATMENT

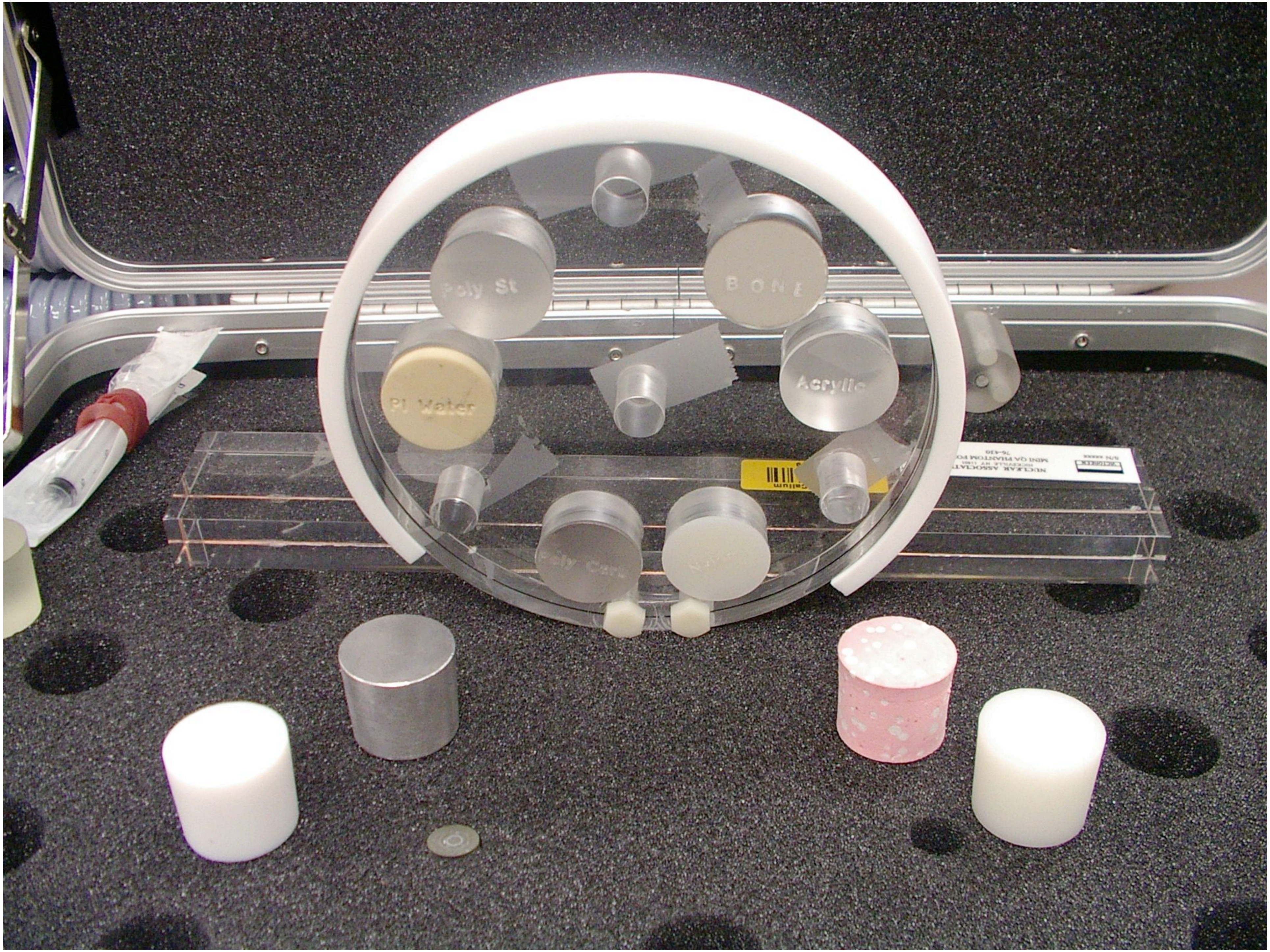
CT scanning Relative Dose Calculation (Isodosing)

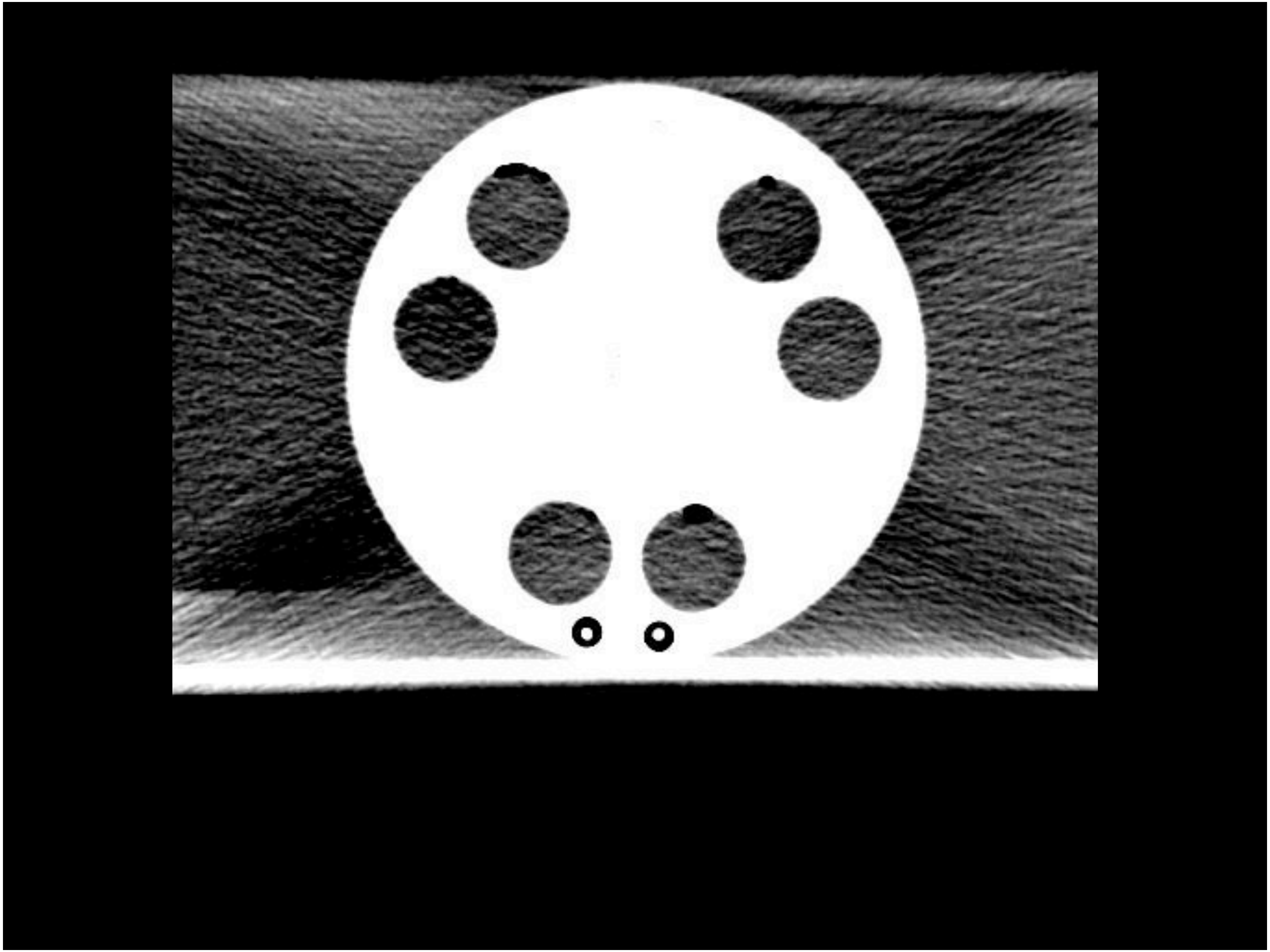
The aim of radiotherapy treatment is to deliver as high a dose as possible to the tumour, while sparing the surrounding normal tissues. To achieve this aim, it is necessary to be able to calculate where the dose from photons of energies from 2 to 18 MeV (megavoltage) will deposit dose within the patient. Generally this requires the three dimensional information of a volumetric CT data set.

Simplistically the predominant interaction of megavoltage beams with the patient is the Compton effect, for which the index of attenuation is approximately the physical density of the medium, or the Relative electron density. For the x-rays produced by the CT scanner, with a maximum energy of about 140 keV, the predominant interaction is the photoelectric effect. So we need to convert from hounsfield units to relative electron density to be able to use a CT scan for radiotherapy isodose calculation. It is not possible to solve the problem of conversion in general for all materials, but as we are only interested in converting things that the human body is made of, we can get away with a piecewise linear inter-relationship.

The hounsfield number for a plug of known relative electron density is assayed over a region to avoid random error.

There are reconstruction artefacts associated with the introduction of these plugs so it is advisable to image the plugs one at a time. It is also advisable to immerse the whole phantom in water. All of this takes time, but it is an initial and then annual procedure.

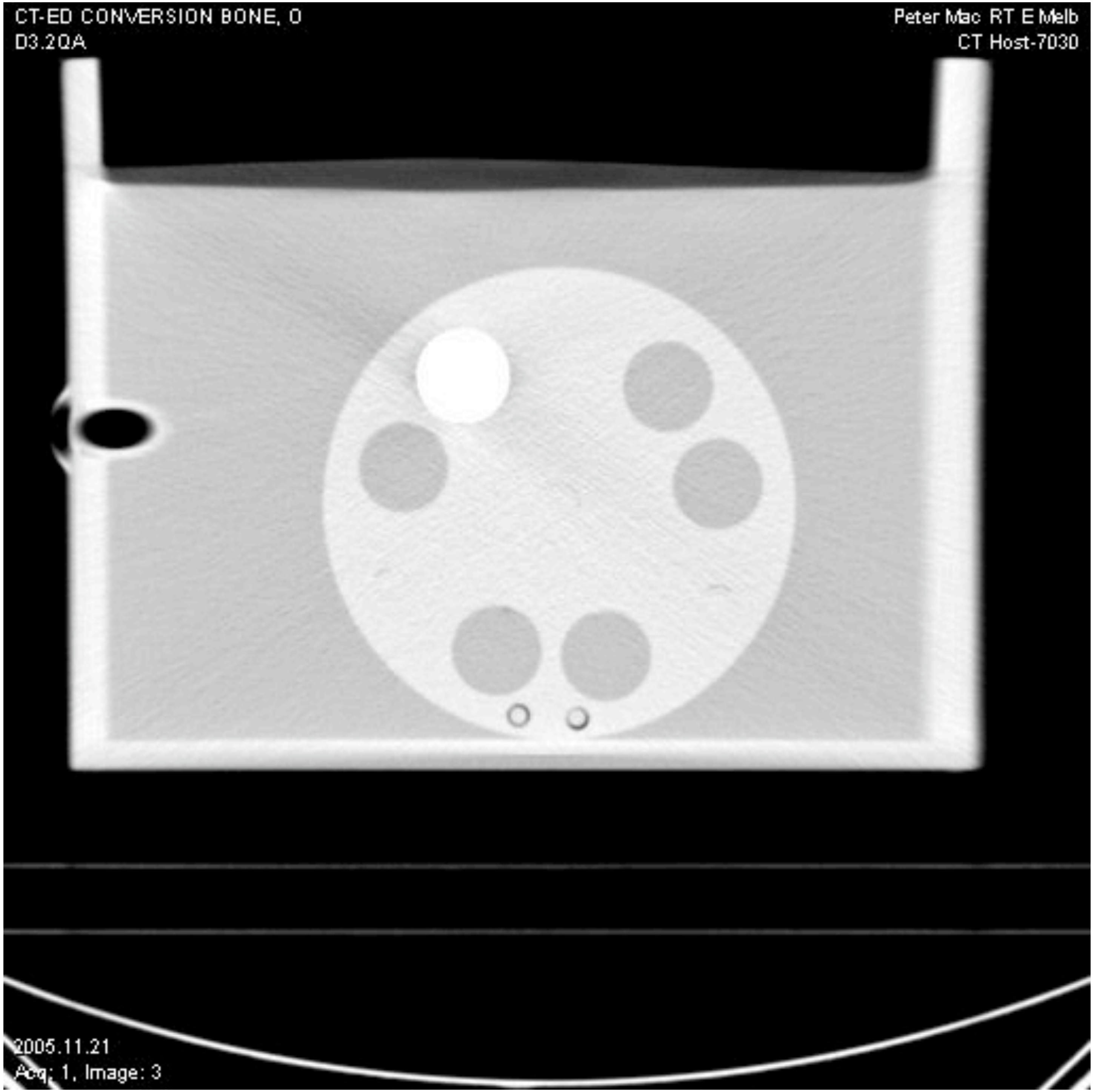

Poly St
BONE
Acrylic
Pl Water

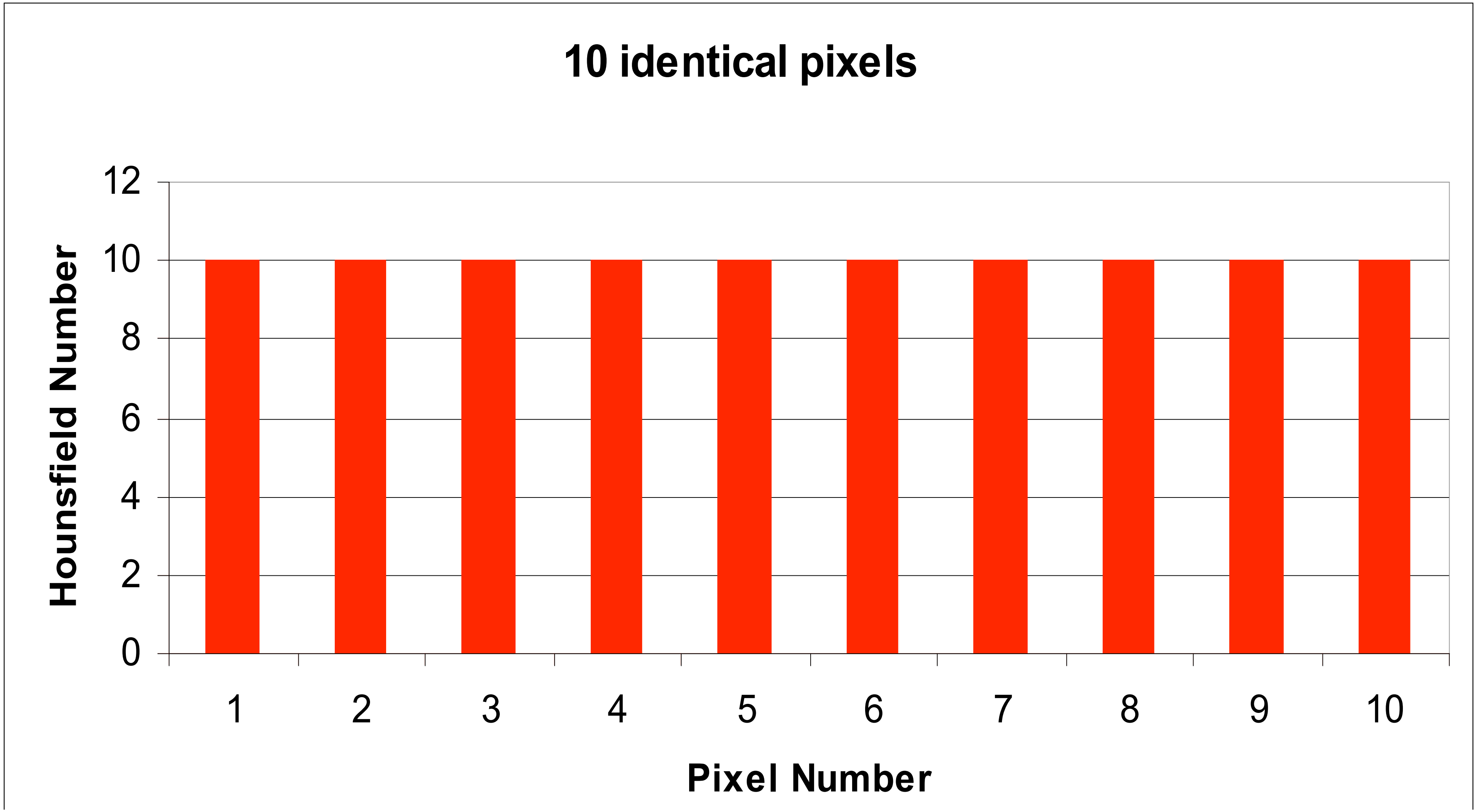


IMMERSION

ARTEFACTS
One insert at a time.

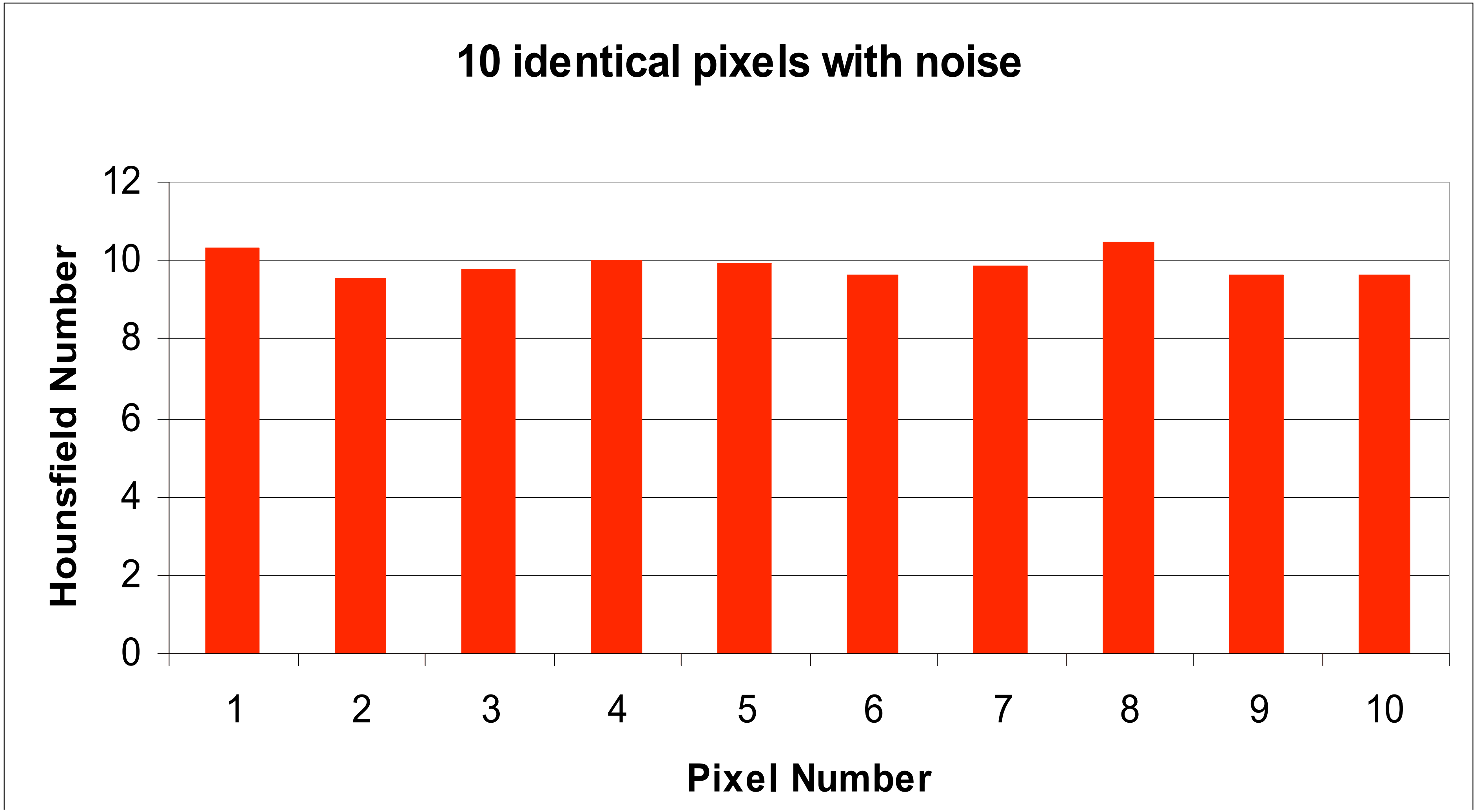
REGION
Take average value,
Measuring a point
Would just measure
Noise.

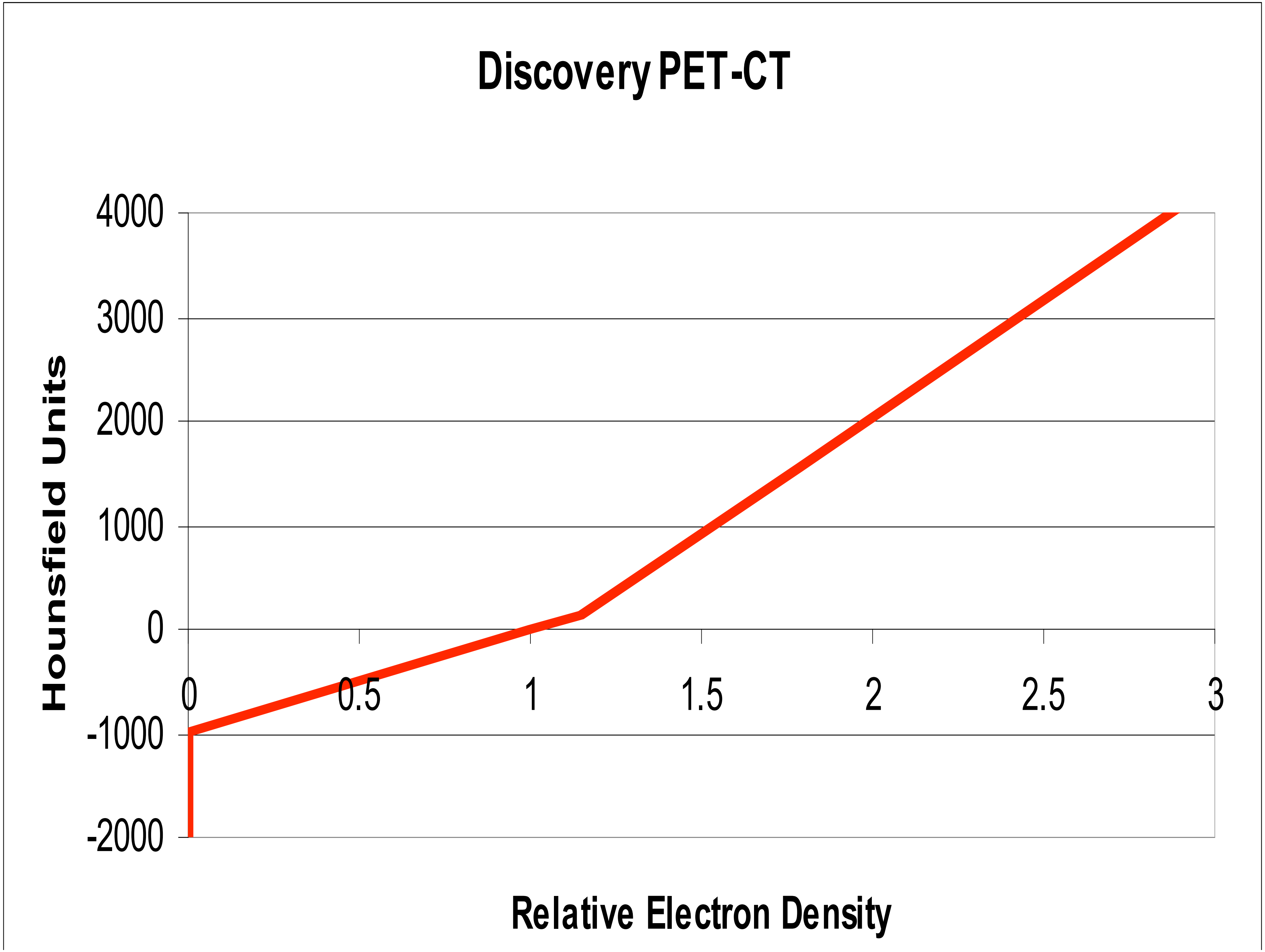



10 identical pixels
Hounsfield Number
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
Pixel Number

Use the mean and record the standard deviation.
Makes no sense to use a single point – random value.
Makes no sense to use the maximum.

Usually hundreds if not thousands of pixels in the region.





Discovery PET-CT
Hounsfield Units
4000
3000
2000
1000
0
-1000
-2000
0
0.5
1
1.5
2
2.5
3
Relative Electron Density

HYBRID IMAGING

GE MEDICAL SYSTEMS
DISCOVERY LS CT PET
BGO CRYSTALS
59 CM BORE

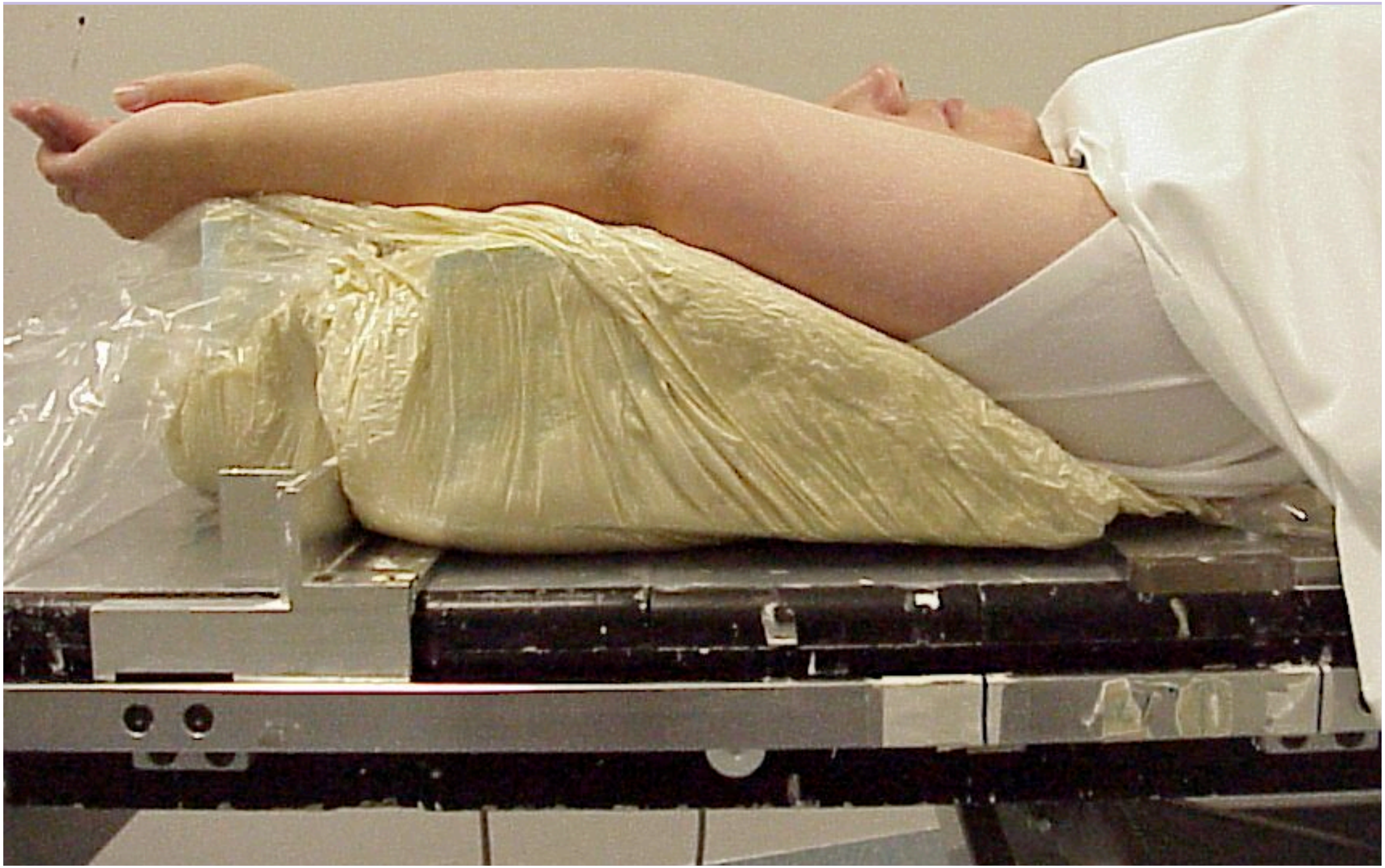
SIEMENS BIOGRAPH CT PET
BGO CRYSTALS
70 CM BORE

PHILIPS MEDICAL SYSTEMS
ALLEGRO CT PET
GSO CRYSTALS
62 CM BORE

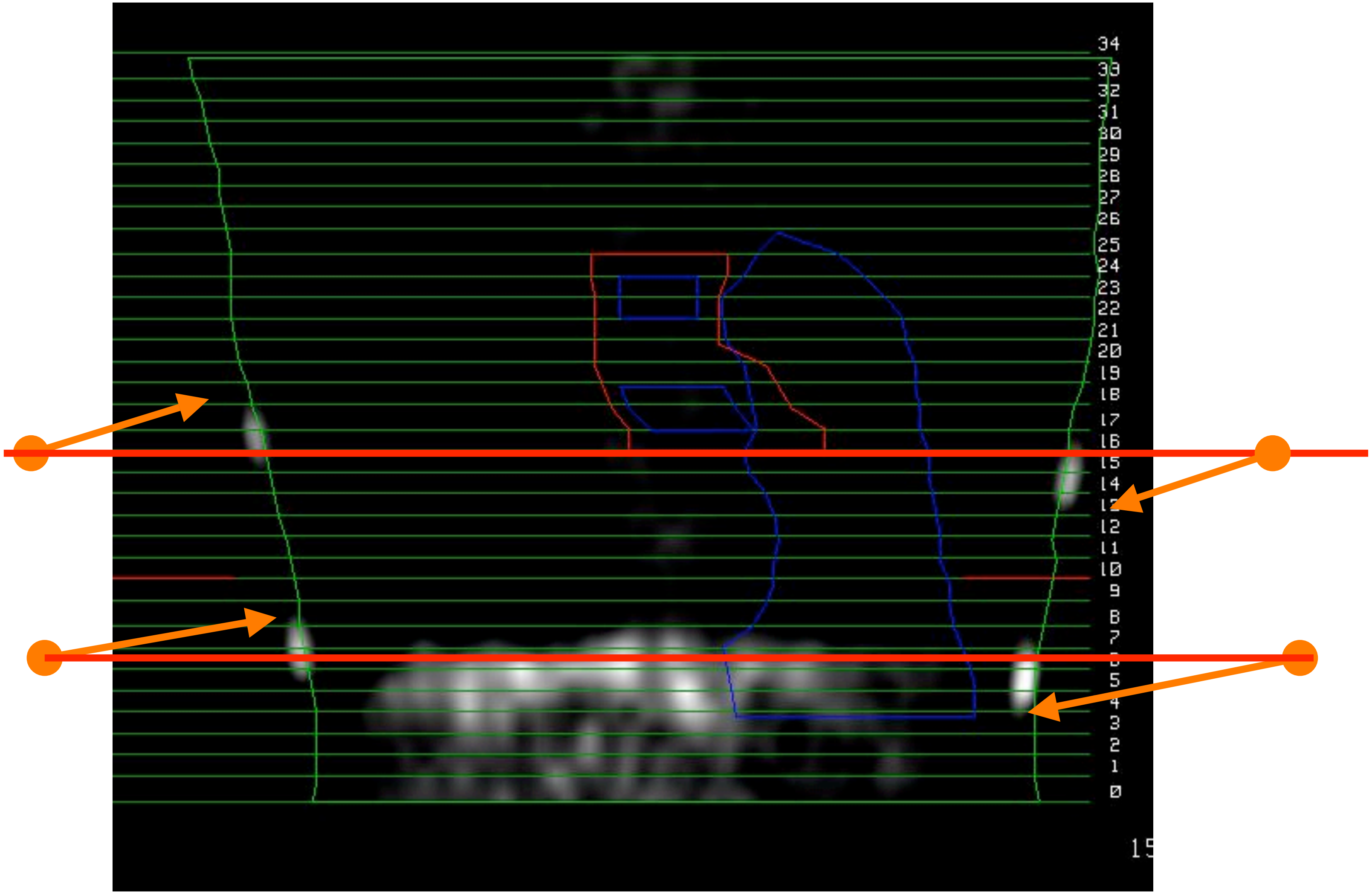
Can we use our PET CT for Radiotherapy planning CTs?
Or do we have to take another CT scan as well as the PET CT.

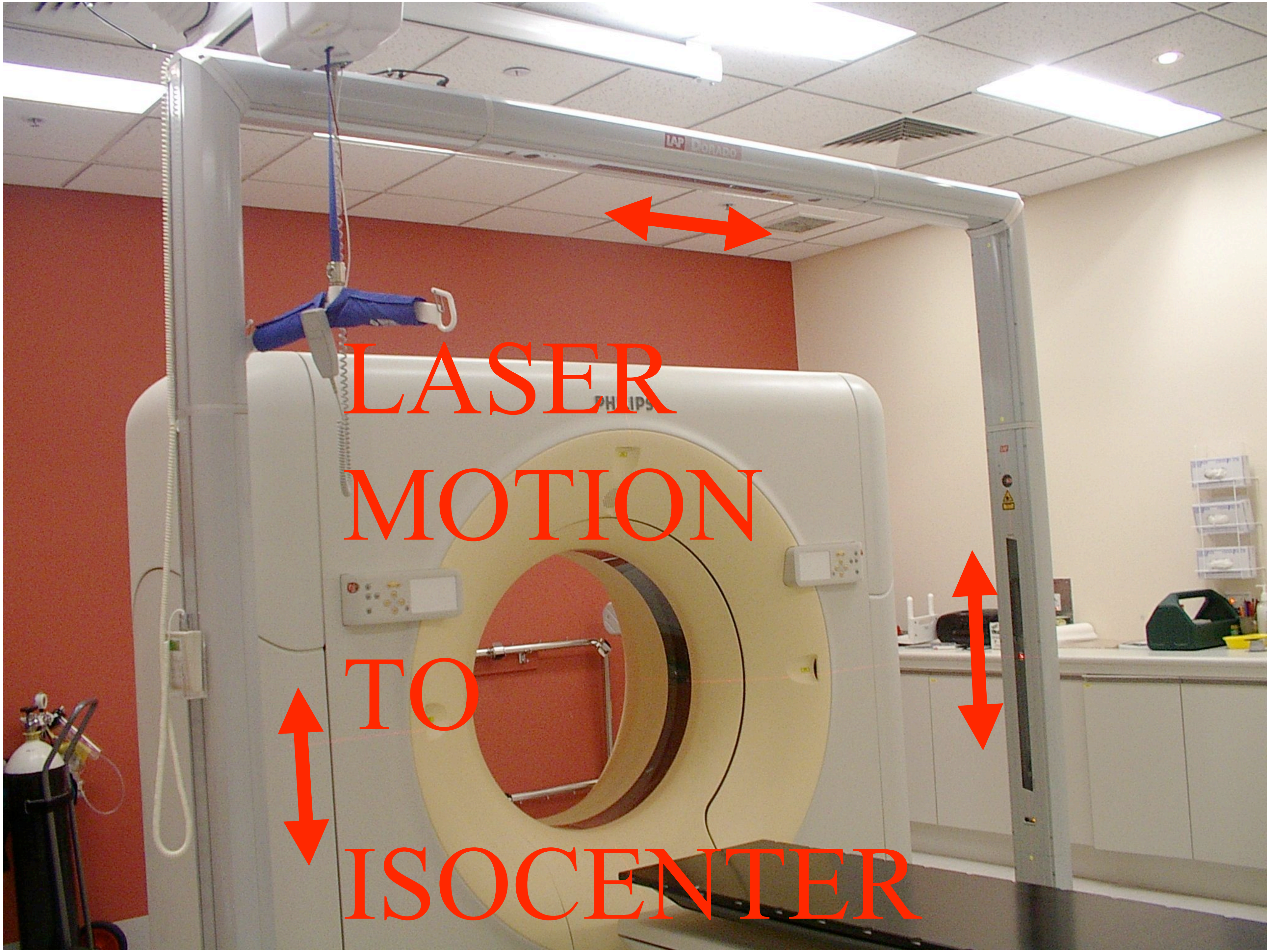
Must image in Treatment position.

Compromise set up for small aperture stand alone PET.



LATERAL FIDUCIALS FOR Y (AP) SHIFT DETERMINATION SHOULD BE SUP-INF COINCIDENT BUT ONLY ONE LATERAL LASER AND ARMS OVER HEAD ADJUSTED (DOES NOT CHANGE AP SHIFT DETERMINATION)




LASER
MOTION
TO
ISOCENTER

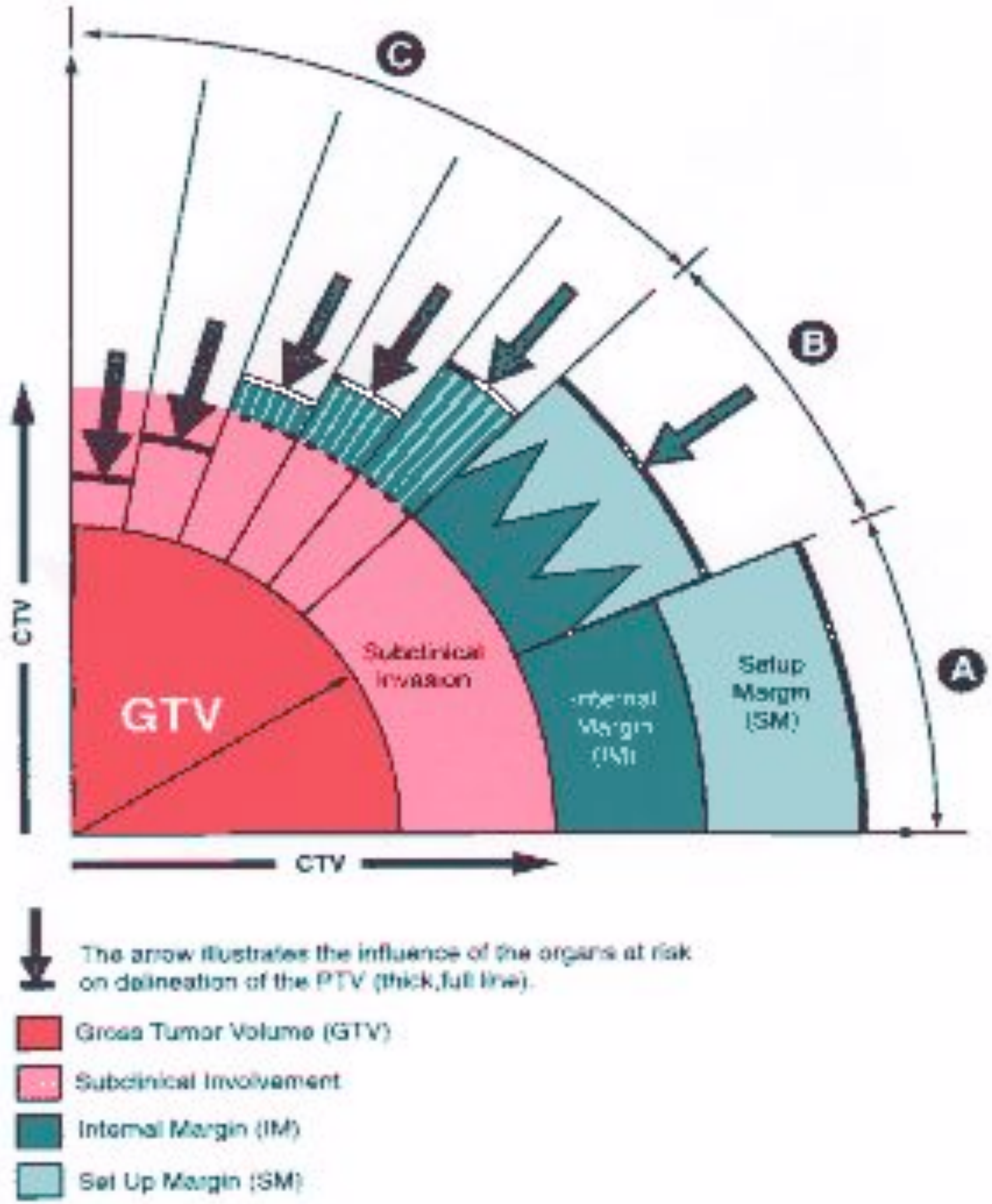

LASER APERTURE

Principles of RT Planning

- PROCESS
- CT (IMAGING)
- **TUMOUR LOCALISATION**
- TREATMENT PLANNING
- TREATMENT

PROCESS
IMAGING
TUMOUR LOCALISATION
TREATMENT PLANNING
TREATMENT

ICRU REPORT



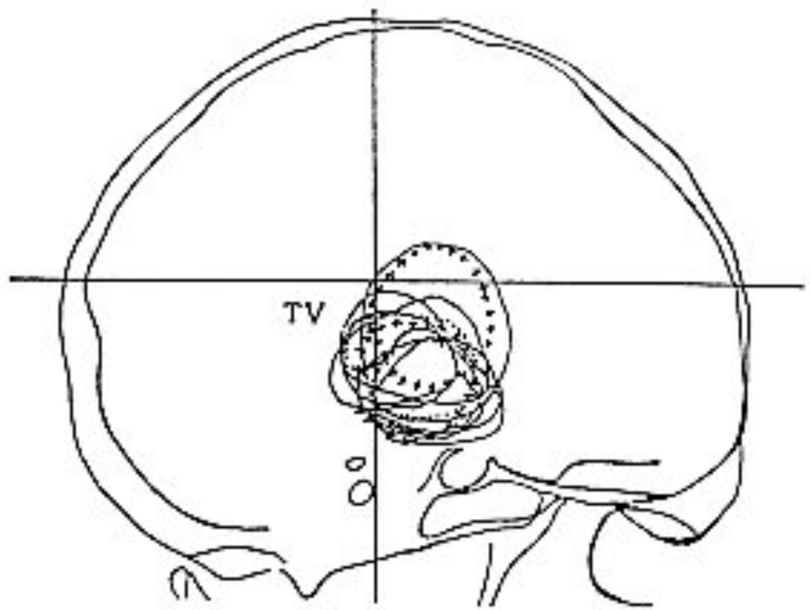
Tumour Localisation

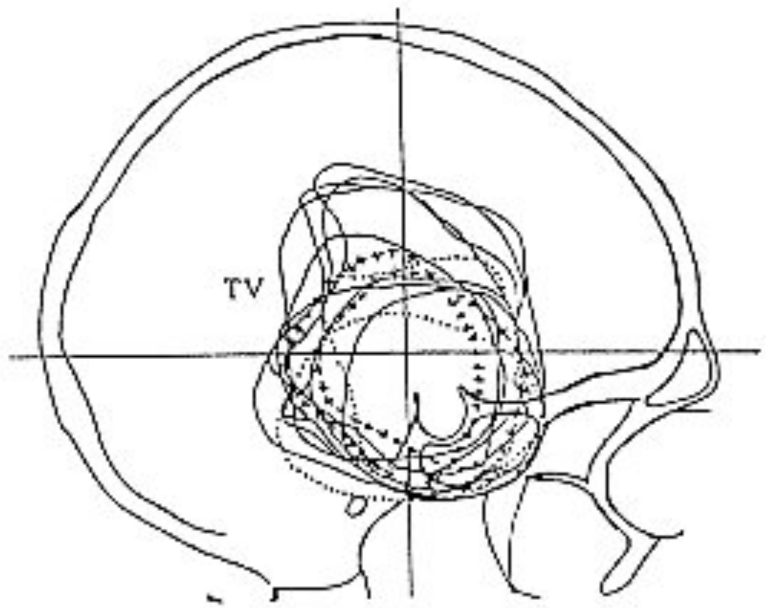
Tumour volume marking from CT scans is the
Weakest link in the radiotherapy treatment
Planning procedure.

ICRU REPORT

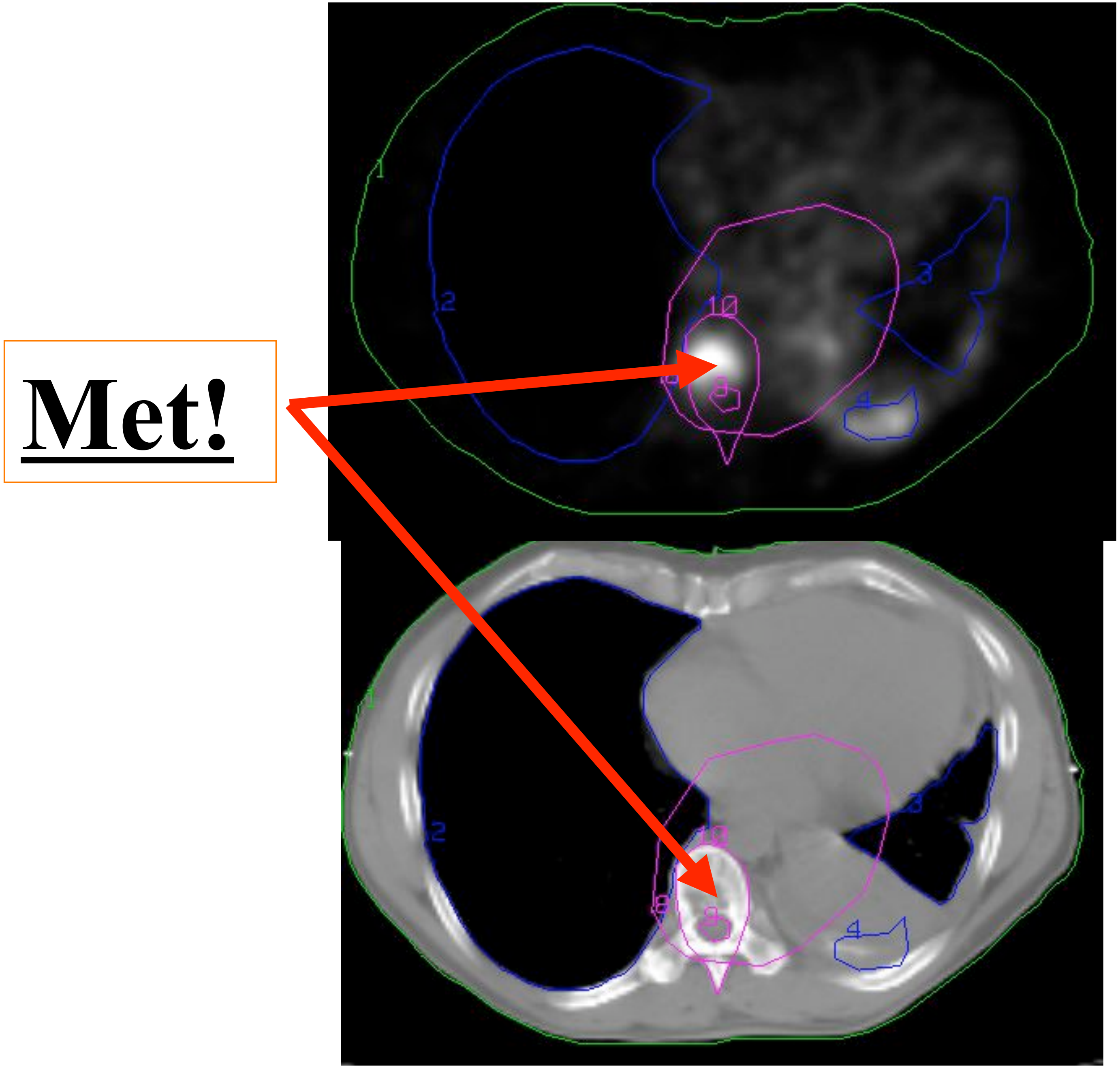
Different marked volumes projected onto
Schematic plane images for comparison.

Use of PET images for tumour volume marking
May improve the whole radiotherapy process.





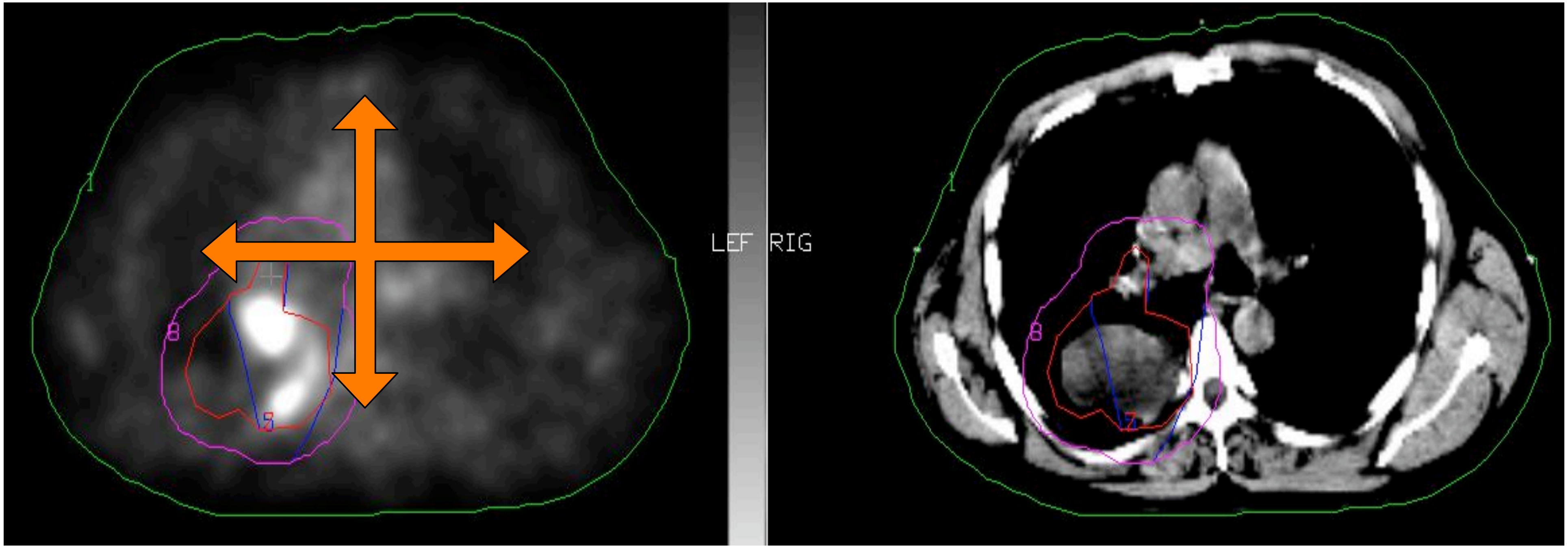
Clinical verification-the first real PET image I ever saw.



PET DATA

CT DATA

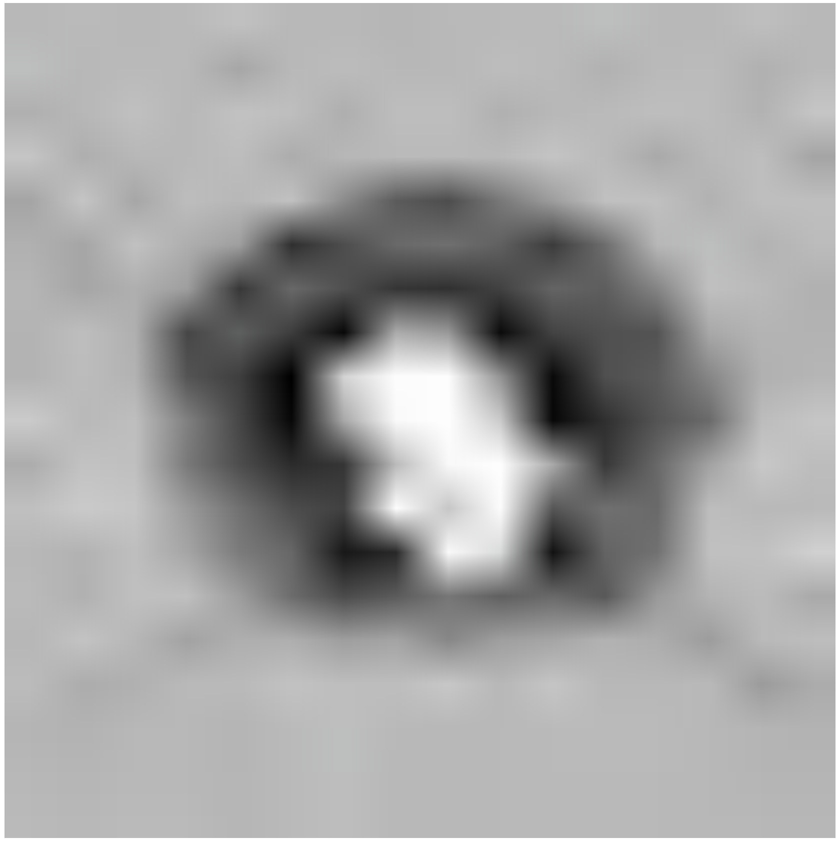
Common Issues with Stand Alone PET.
Are you sure there isn't a co-registration problem?



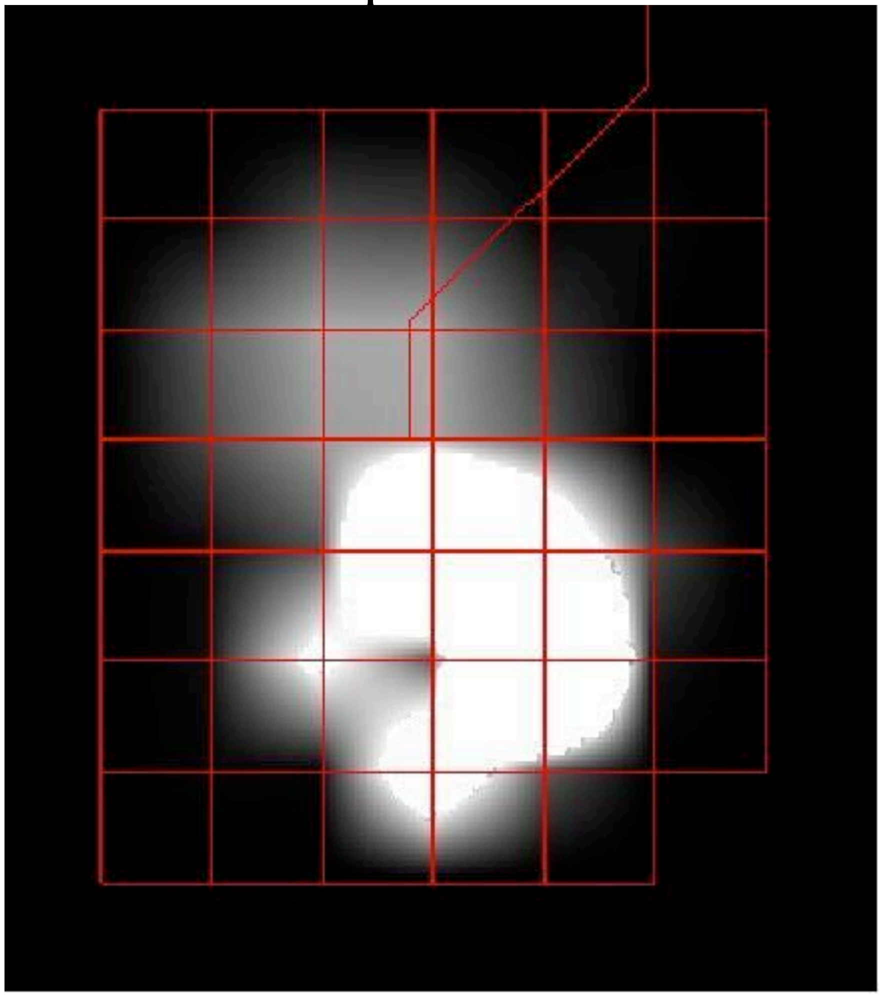
That's why we love PET-CT

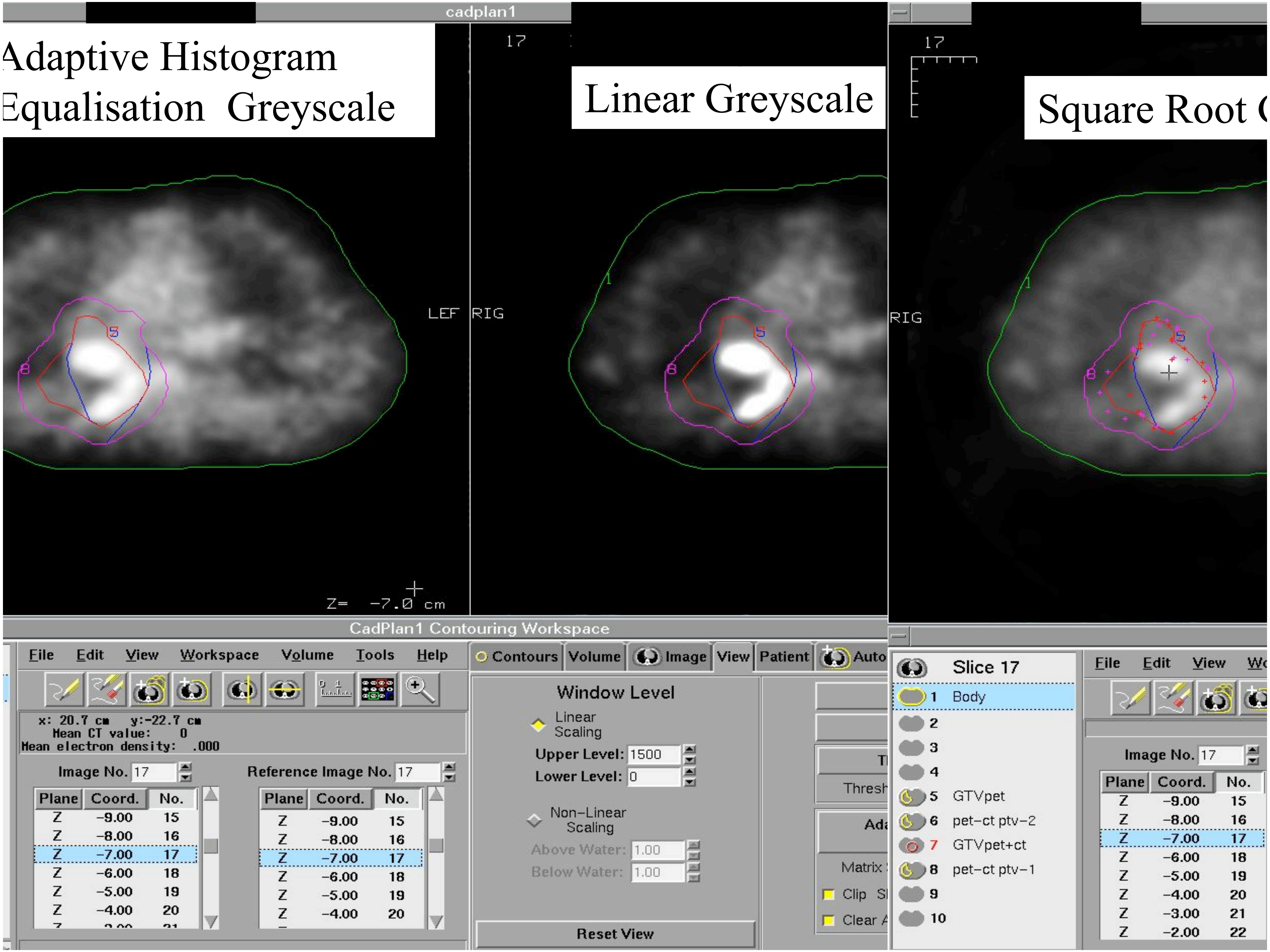
Why doesn't it look the same as on the PET viewstation?

Nearest Neighbour

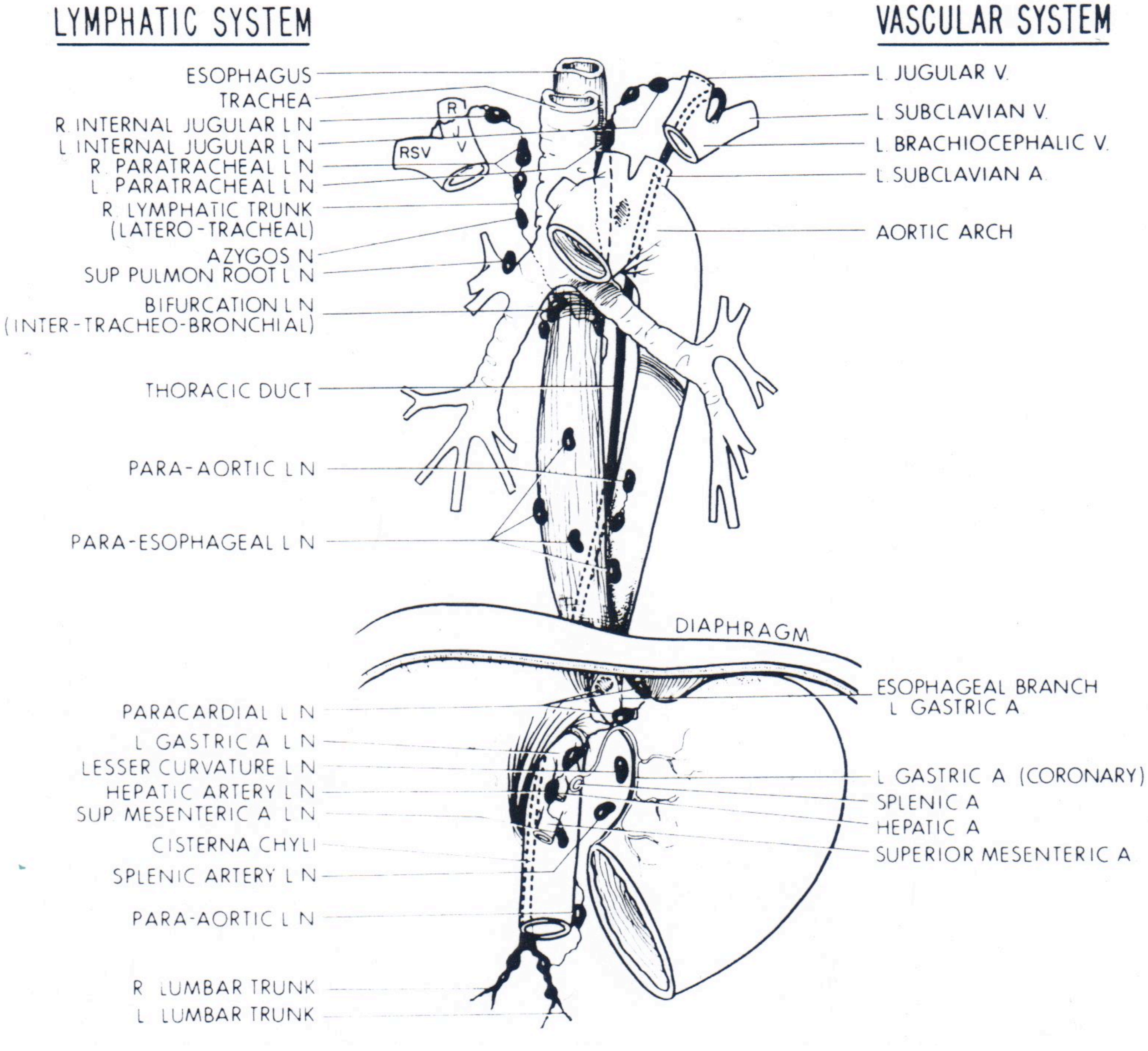


Bilinear Interpolation

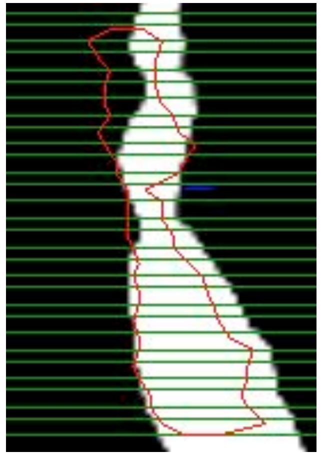


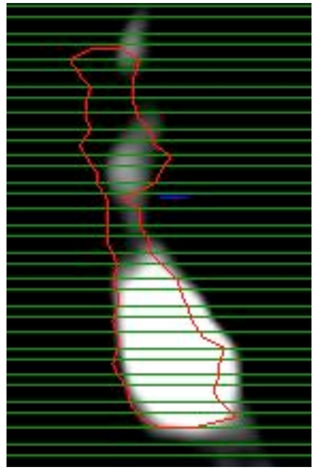

Adaptive Histogram Equalisation Greyscale
Linear Greyscale
Square Root
cadplan1
17
LEF
RIG
Z= -7.0 cm
CadPlan1 Contouring Workspace
File Edit View Workspace Volume Tools Help
Contours Volume Image View Patient Auto
x: 20.7 cm y:-22.7 cm
Mean CT value: 0
Mean electron density: .000
Image No. 17
Reference Image No. 17
Plane Coord. No.
Window Level
Linear Scaling
Upper Level: 1500
Lower Level: 0
Non-Linear Scaling
Above Water: 1.00
Below Water: 1.00
Reset View
Slice 17
1 Body
2
3
4
5 GTVpet
6 pet-ct ptv-2
7 GTVpet+ct
8 pet-ct ptv-1
9
10
Clip
Clear

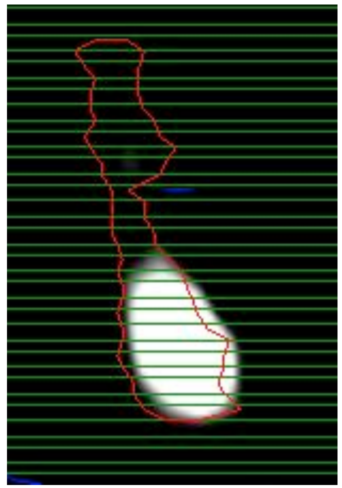
OESOPHAGUS



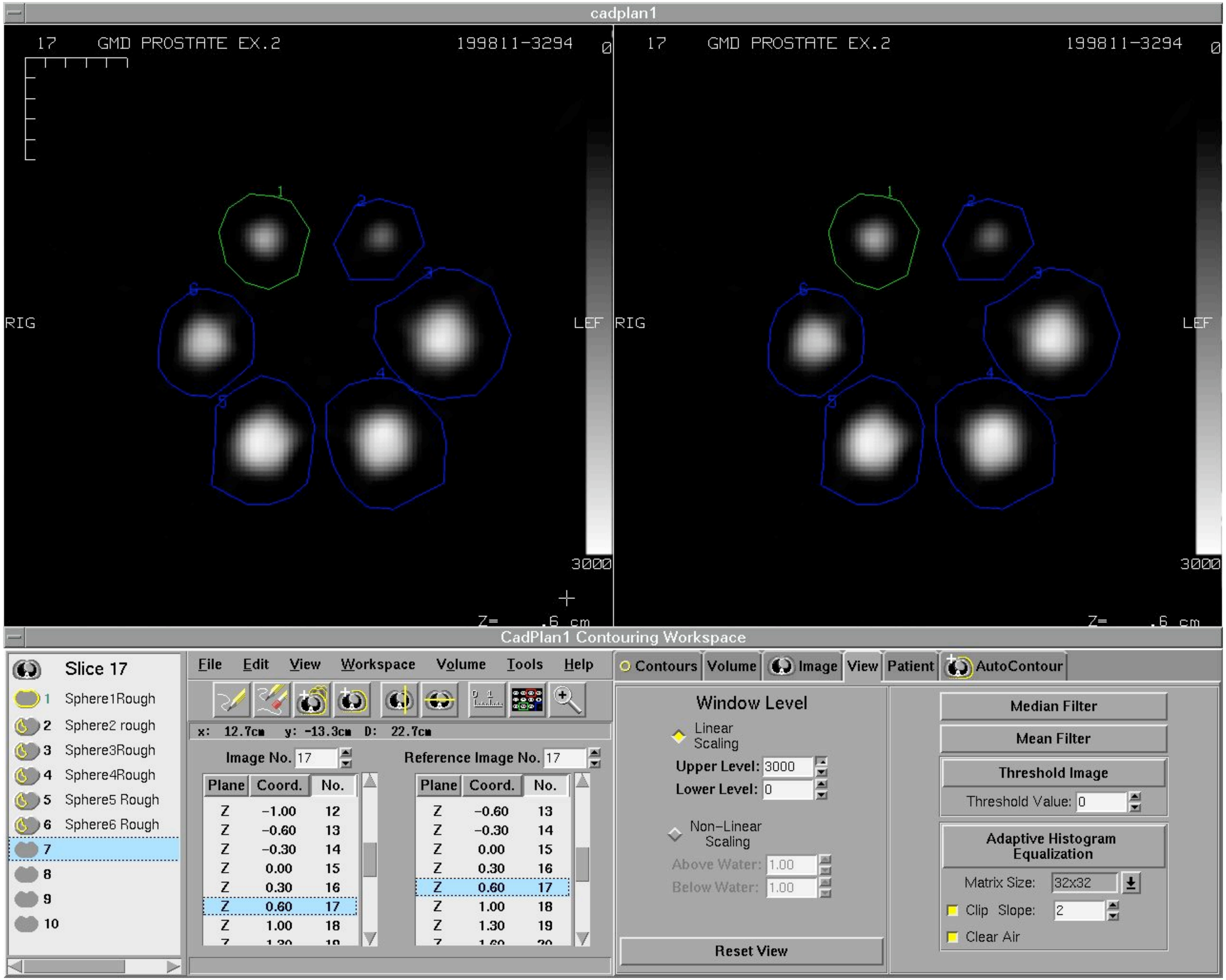
LYMPHATIC SYSTEM
ESOPHAGUS
TRACHEA
R. INTERNAL JUGULAR L N
L INTERNAL JUGULAR L N
R. PARATRACHEAL L N
L. PARATRACHEAL L N
R. LYMPHATIC TRUNK (LATERO-TRACHEAL)
AZYGOS N
SUP PULMON ROOT L N
BIFURCATION L N (INTER-TRACHEO-BRONCHIAL)
THORACIC DUCT
PARA-AORTIC L N
PARA-ESOPHAGEAL L N
PARACARDIAL L N
L GASTRIC A L N
LESSER CURVATURE L N
HEPATIC ARTERY L N
SUP MESENTERIC A L N
CISTERNA CHYLI
SPLENIC ARTERY L N
PARA-AORTIC L N
R LUMBAR TRUNK
L LUMBAR TRUNK
VASCULAR SYSTEM
L JUGULAR V.
L SUBCLAVIAN V.
L BRACHIOCEPHALIC V.
L SUBCLAVIAN A.
AORTIC ARCH
DIAPHRAGM
ESOPHAGEAL BRANCH L GASTRIC A
L GASTRIC A (CORONARY)
SPLENIC A
HEPATIC A
SUPERIOR MESENTERIC A
R
J
V
RSV



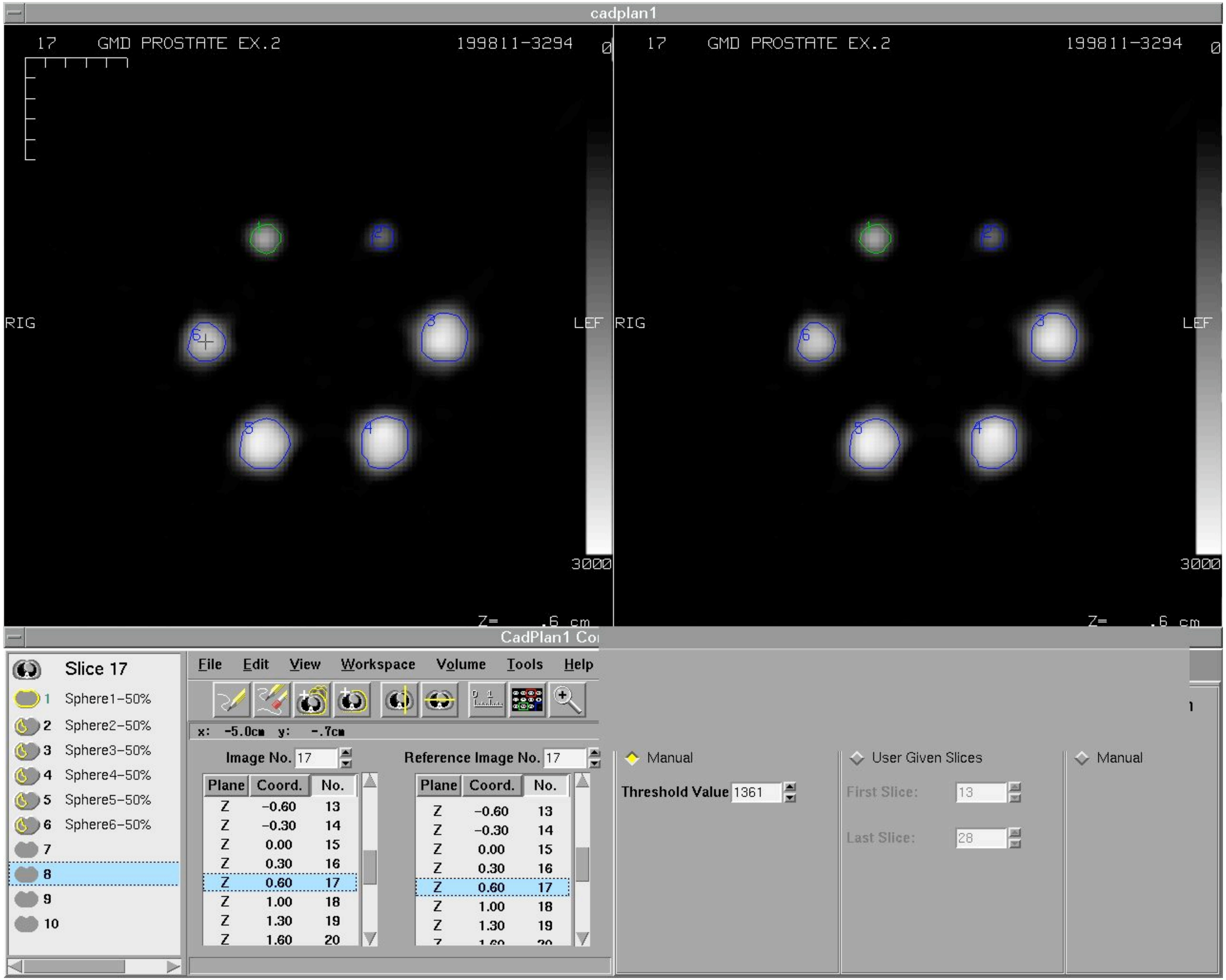




Rough sphere volumes for segmentation



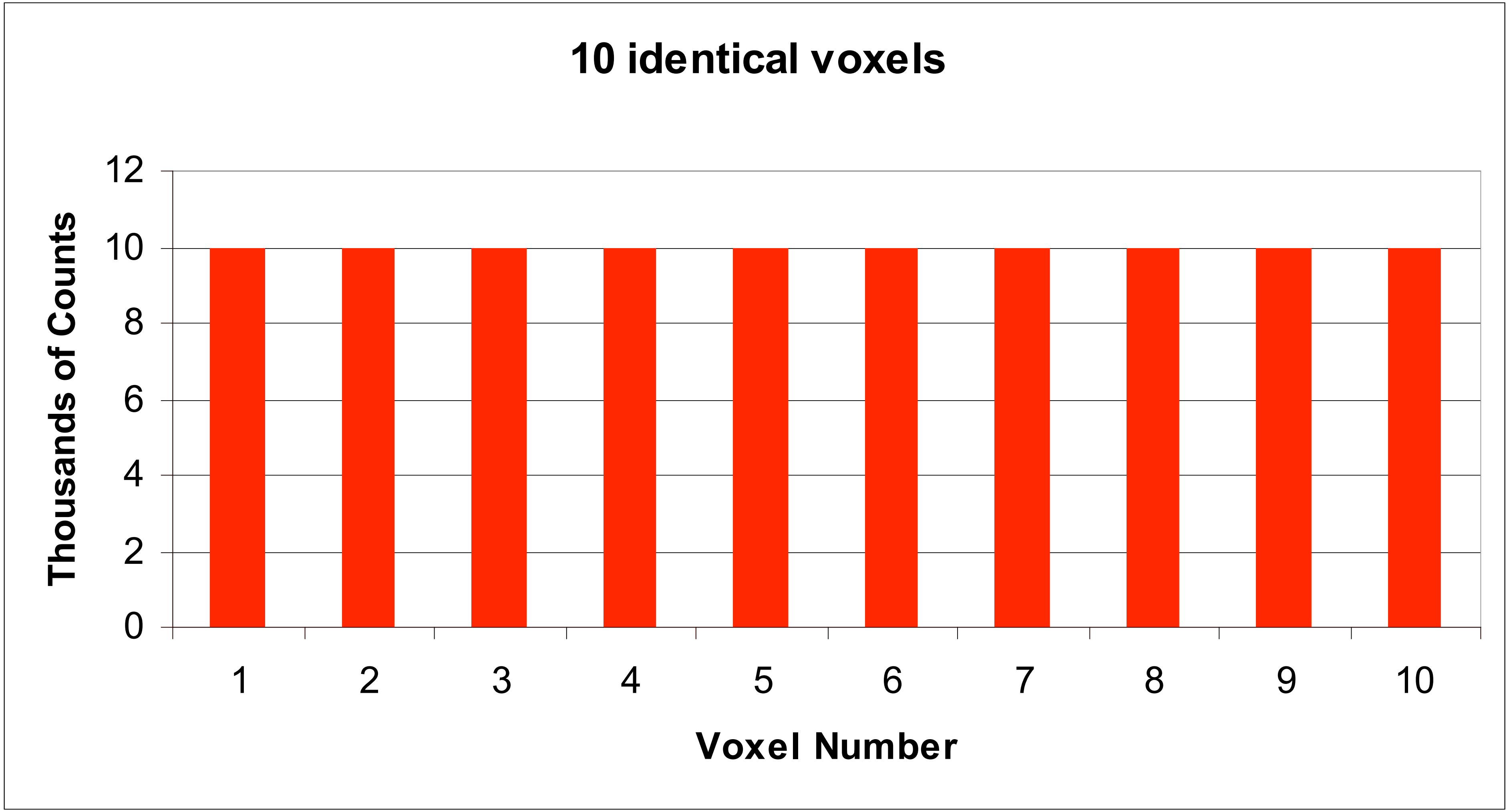
50% INTENSITY SEEMS JUST TOO TIGHT



Segmentation thresholding

Simplest experiment, image a sphere of FDG. Segment the volume with a Threshold that gives the same volume. Plot the volume against the threshold. Repeat for different levels of background. End up with a predictor. Use predictor for segmentation.

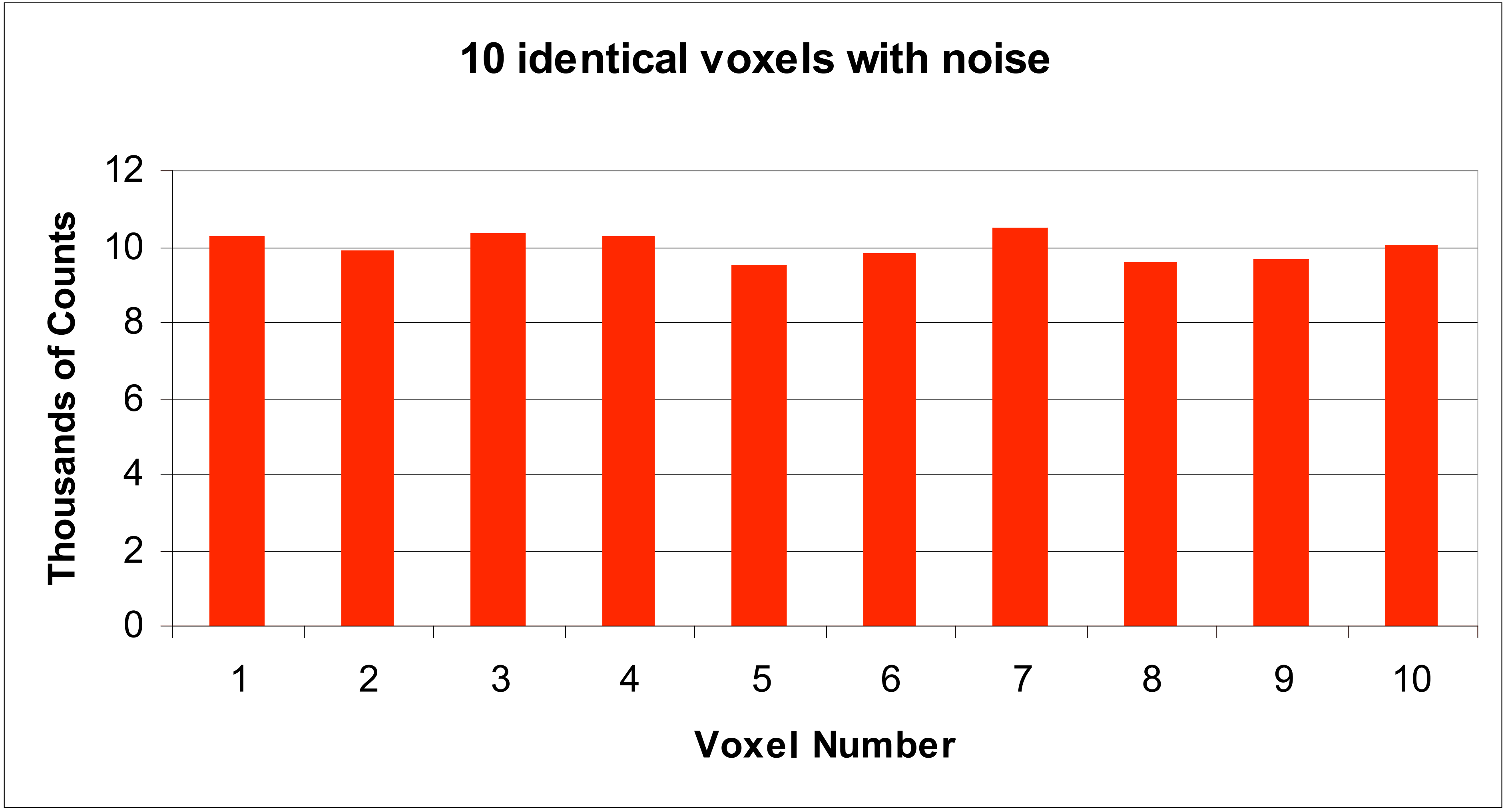
Assumptions
Tumour is spherical.
Tumour does not move during PET scan.
Tumour has uniform uptake.

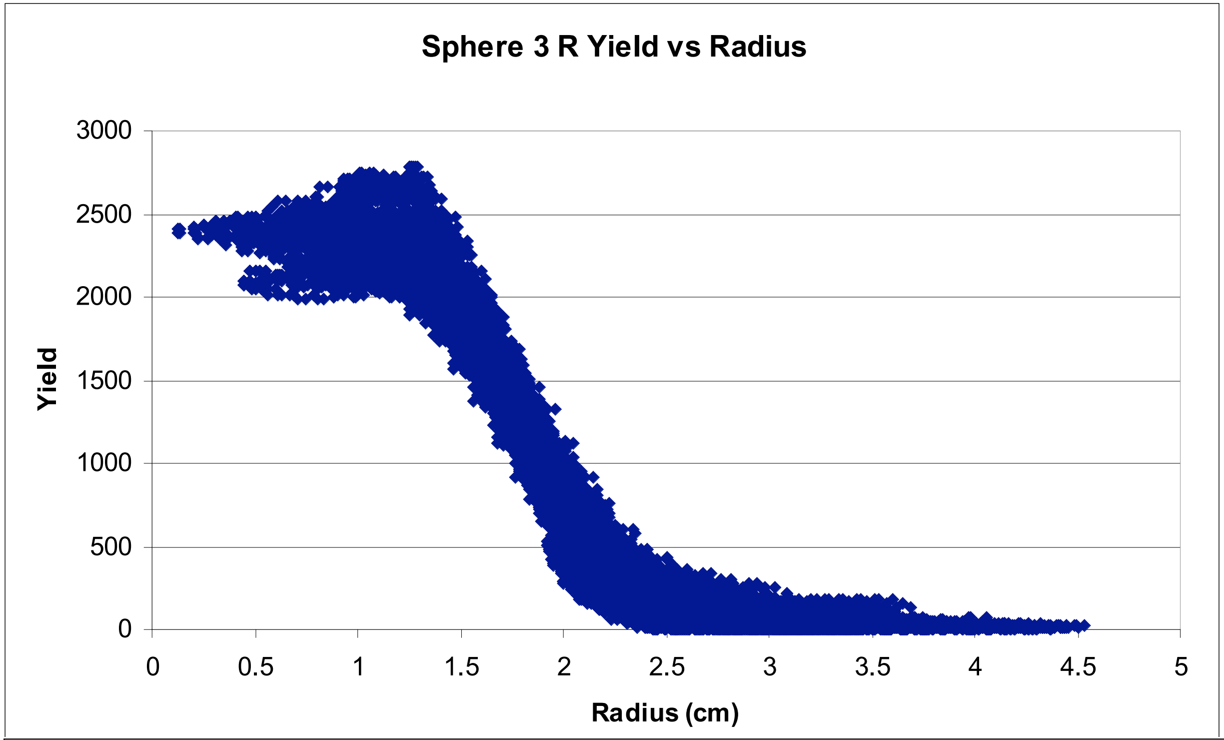


10 identical voxels
Thousands of Counts
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
Voxel Number

Use the mean and record the standard deviation.
Makes no sense to use a single point – random value.
Makes no sense to use the maximum systematically higher.

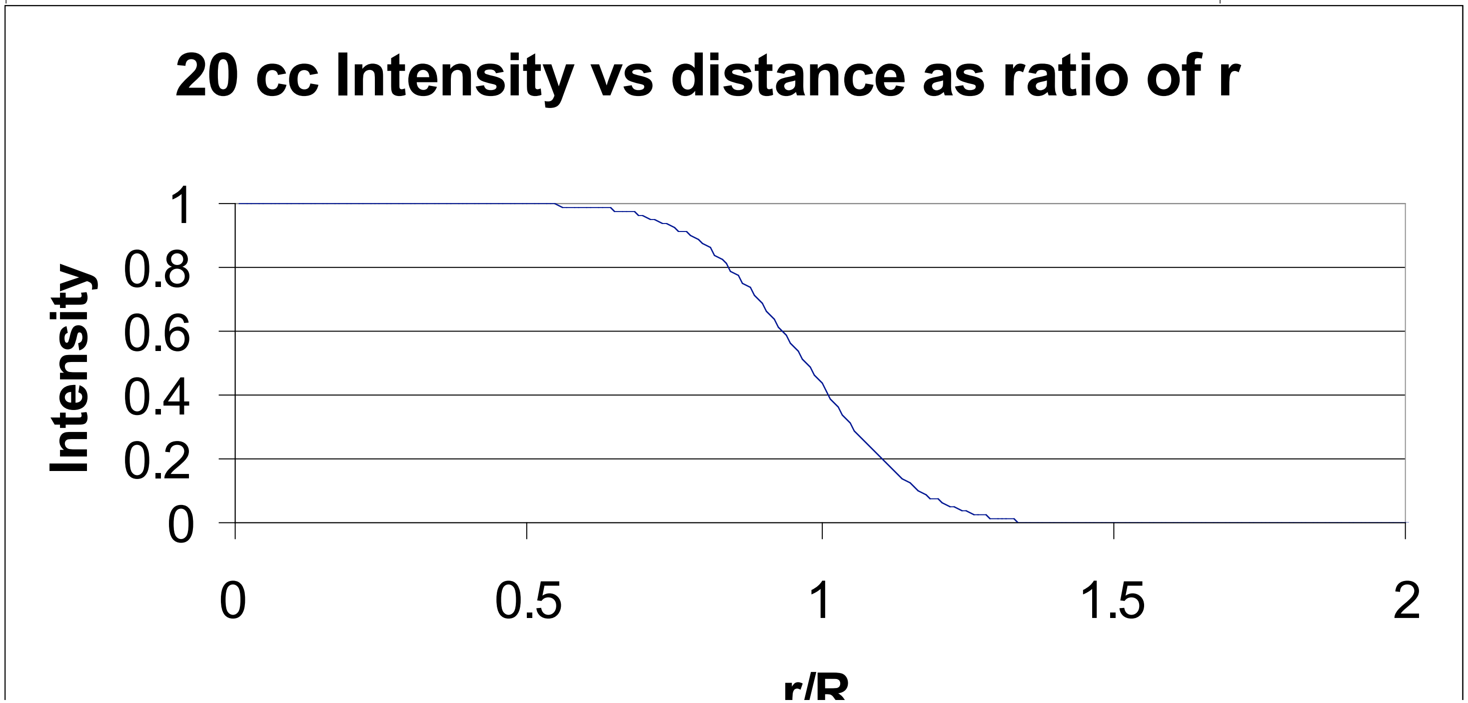
Usually hundreds if not thousands of pixels in the region.





Plot image voxel intensity vs distance from centre of sphere.

In a noisy image the Maximum is increased



Approaches to tumour volume thresholding.

Normalise to average over tumour volume (Not generalizable to arbitrary shape)

Normalise over average of pixels surrounding maximum (Correlated noise.)

Normalise to peak (Neglects effect of noise on maximum)

To generalise to moving tumours requires gating or other motion compensation.

To generalise to non-uniform uptake requires some arbitrary reference level (SUV).

There is no consensus on which method to follow in trials.

Principles of RT Planning

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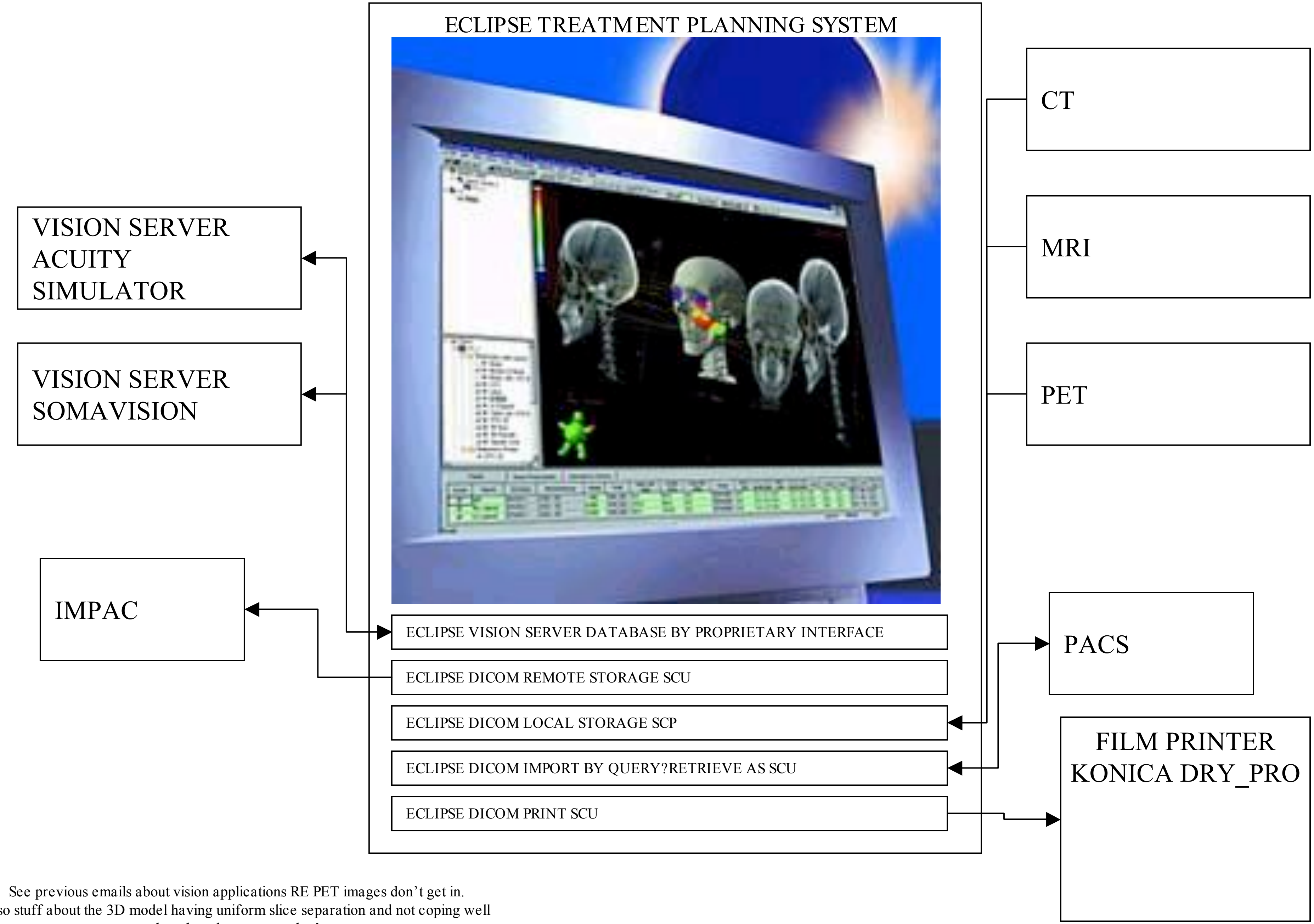
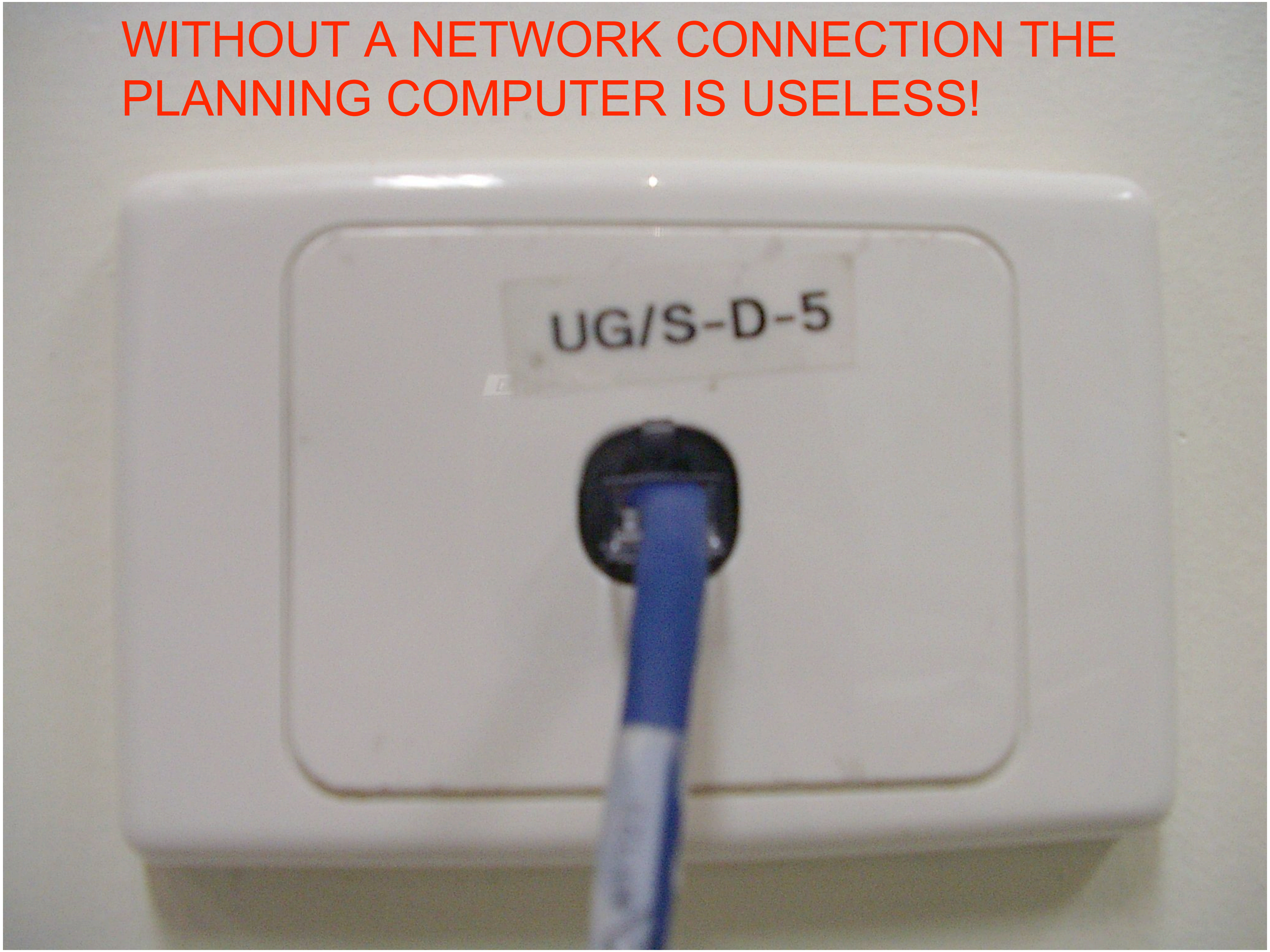
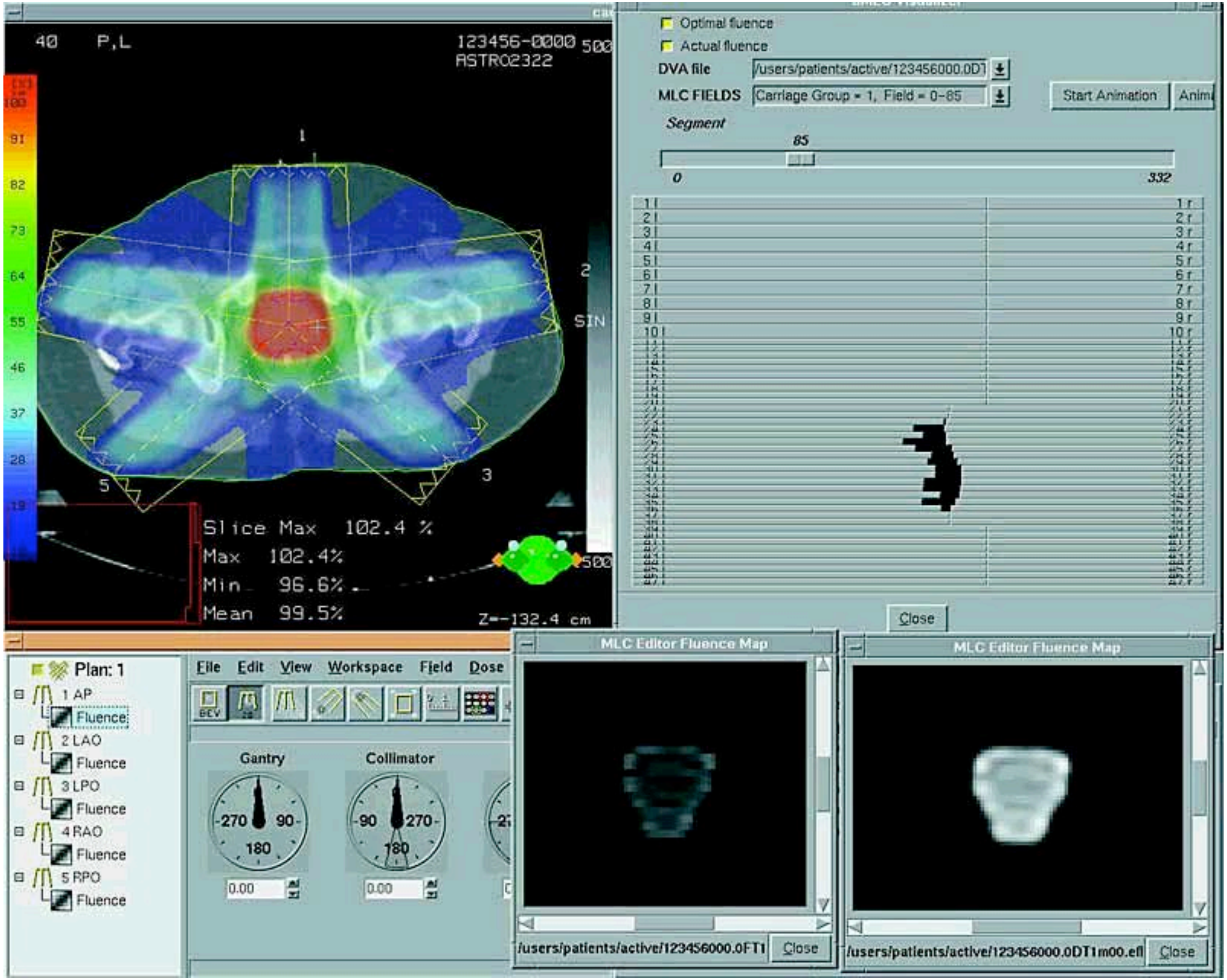
EAST MELBOURNE ECLIPSE DATA FLOW



See previous emails about vision applications RE PET images don't get in.
Also stuff about the 3D model having uniform slice separation and not coping well
when the other systems don't.


WITHOUT A NETWORK CONNECTION THE PLANNING COMPUTER IS USELESS!
UG/S-D-5

Treatment planning aims to produce a plan that gives
The most uniform uniform dose to the tumour.



Dosimetry

Monte carlo planning is required near interface, say at the lung/tissue interface. The Monte Carlo method, will be familiar to those of you from the Nuclear Medicine world through SIMSET and lately the GEANT GATE collaboration.
In radiotherapy we use Monte Carlo to predict the dose near interfaces. Basically, the Monte Carlo method says that if you roll enough dice and interpret the results correctly, you can obtain a statistical prediction of what the dose will be. Now once you have wondered about how many dice you will need to roll and how long it will take, and what will happen if the dice are not fair, you are left with the problem of correctly interpreting the results.
One thing we loose in the radiotherapy scheme is that the maximum dose within the tumour is systematically overestimated.

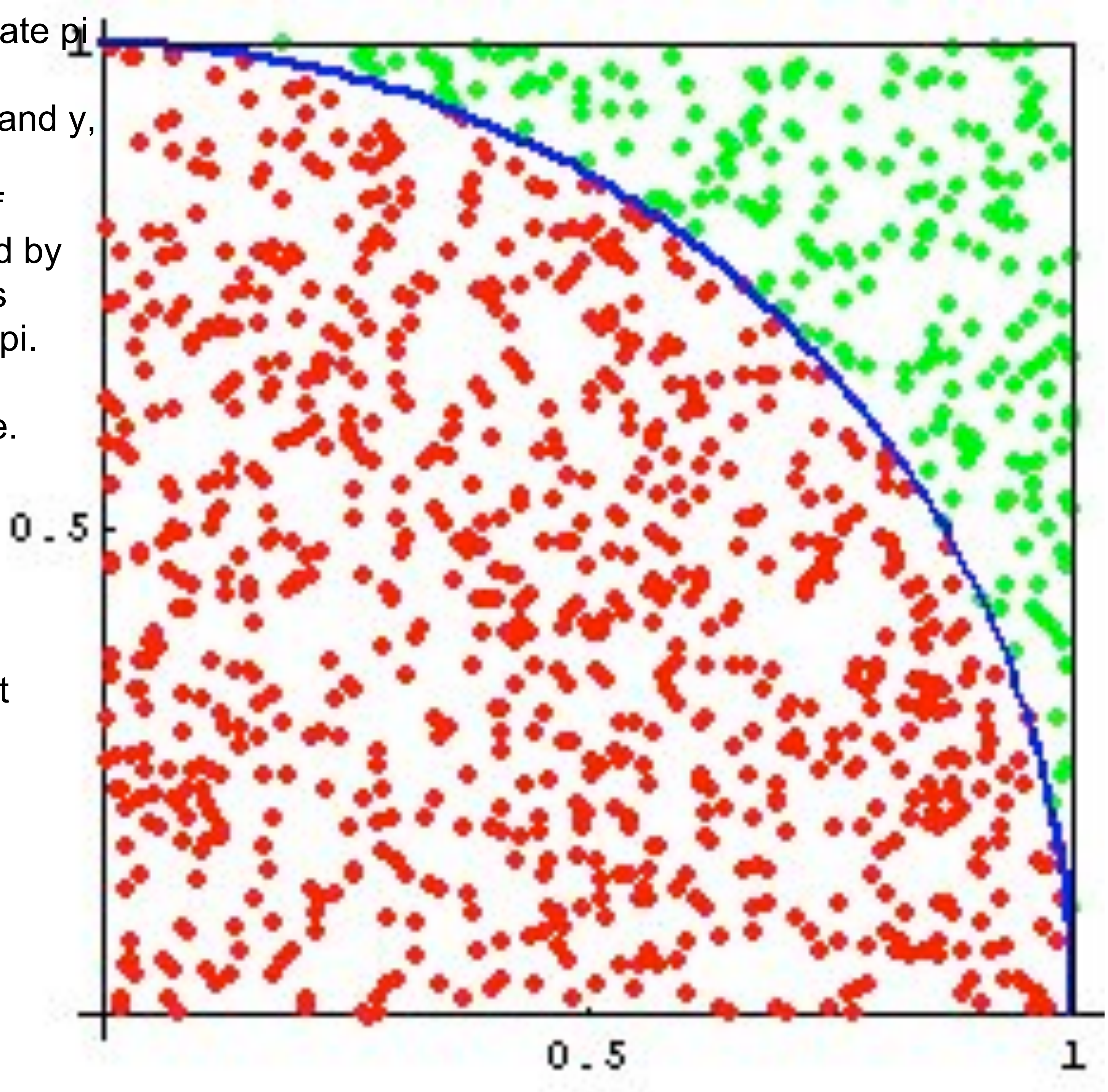
The paradigm of aiming to achieve uniform dose to the tumour is predicated on the assumption of the uniform distribution of clonogens.

PET scans with ligands other than FDG may challenge this assumption by providing information on the spatial distribution of clonogen density, as we will see later today.

Monte Carlo to calculate pi

Determine random x and y,
Test if in circle.
Four times number of
points in circle divided by
total number of points
Gives an estimate of pi.

A **statistical** estimate.



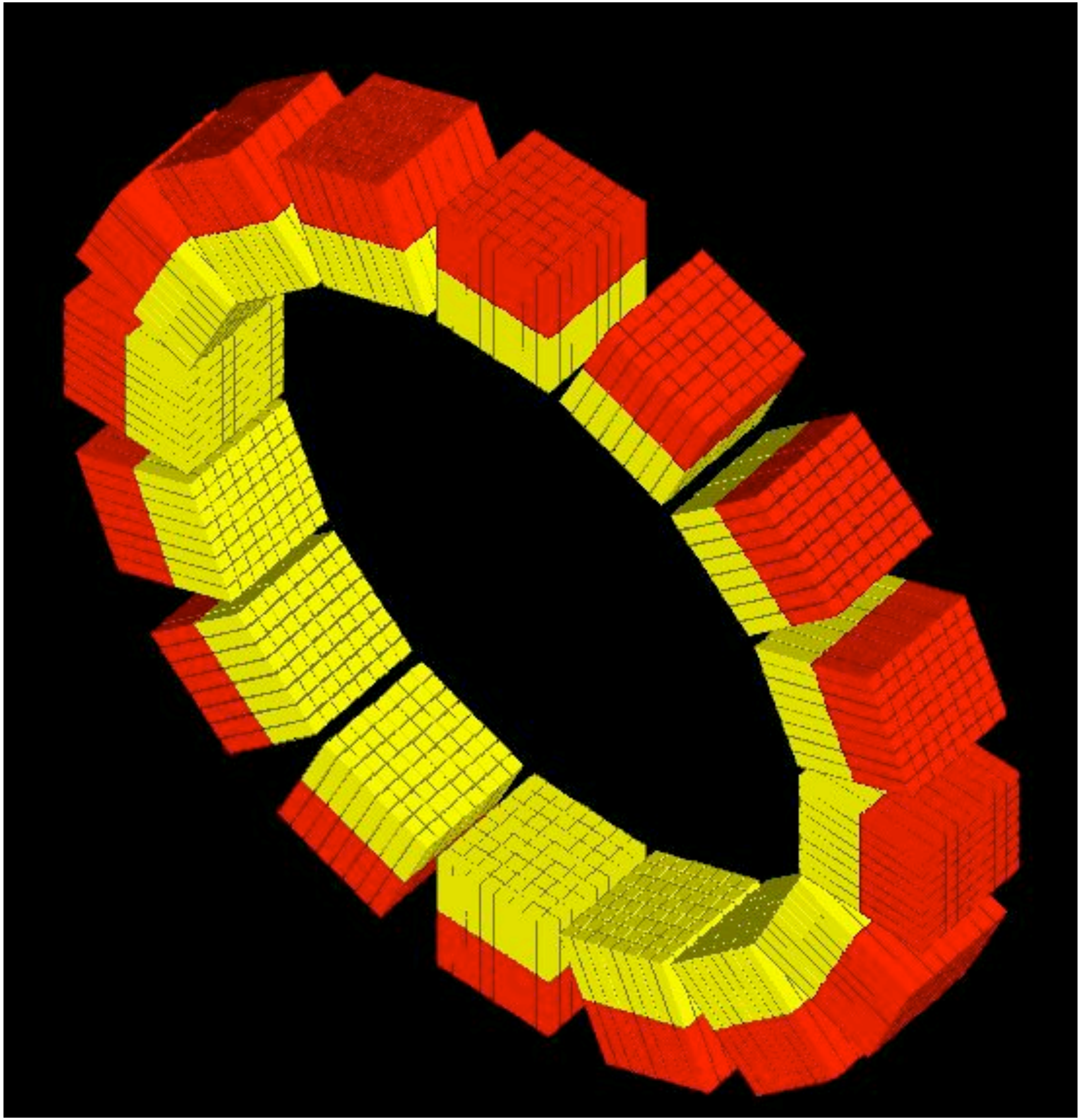
Although a good
Illustration of the
Monte Carlo method
This is not an efficient
Way to estimate pi.
There are faster
Numerical methods.

Monte Carlo is best
For solving problems
With many variables.

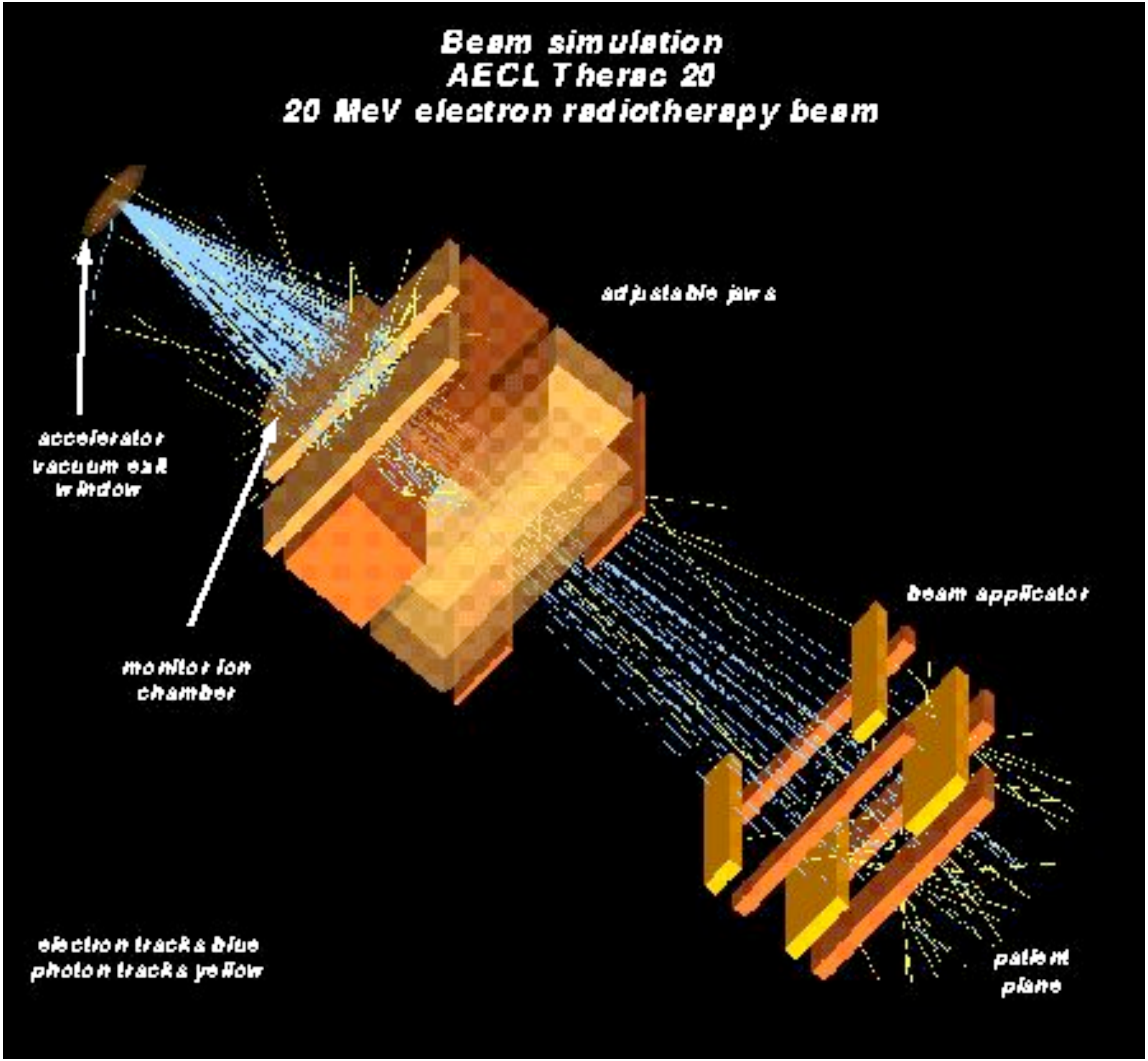
GEANT GATE
COLLABORATION

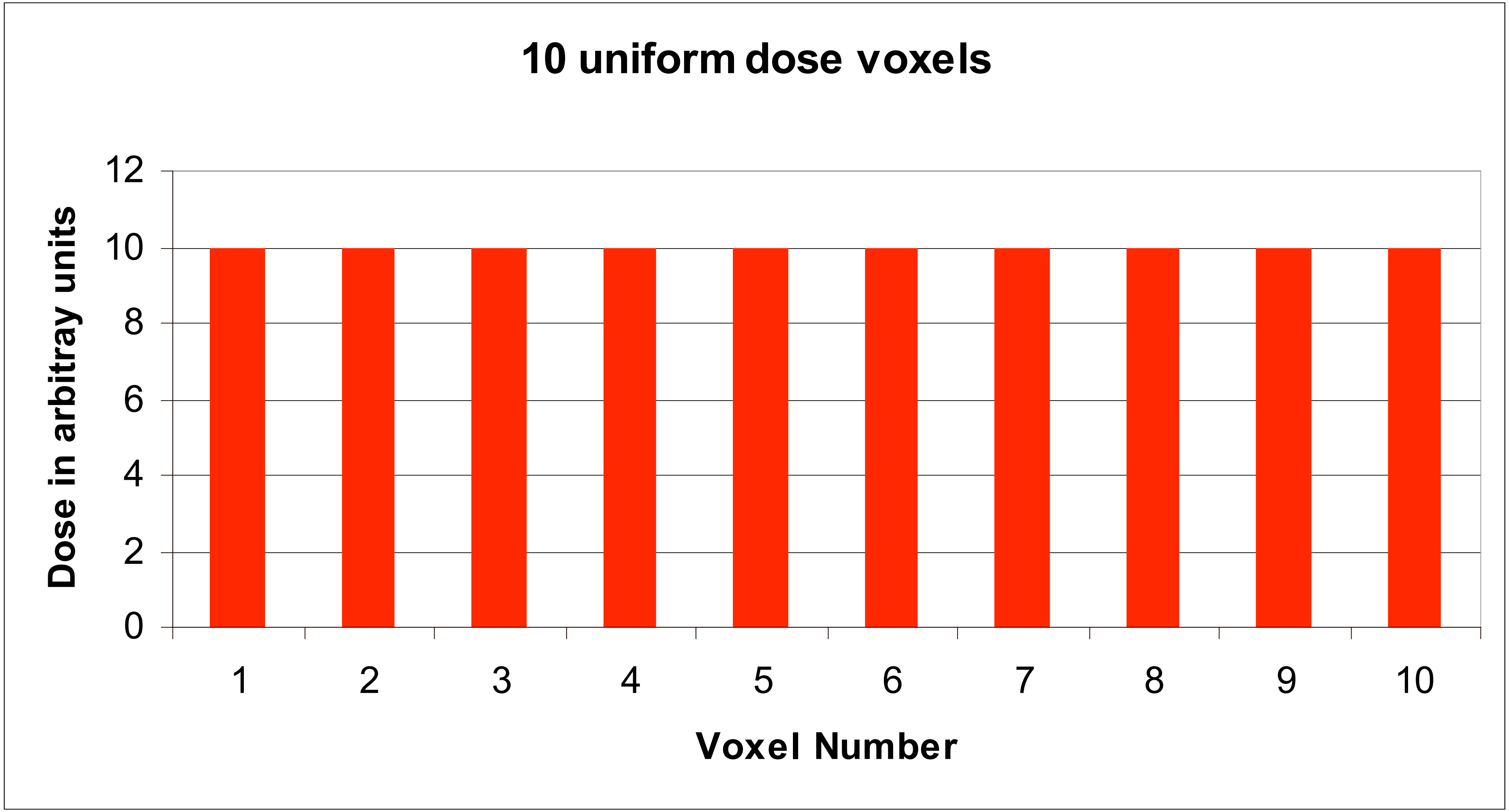
Supports time
varying geometry,
But slow to calculate.

SIMSET is faster
But will not
Support time
Varying geometry
Explicitly.

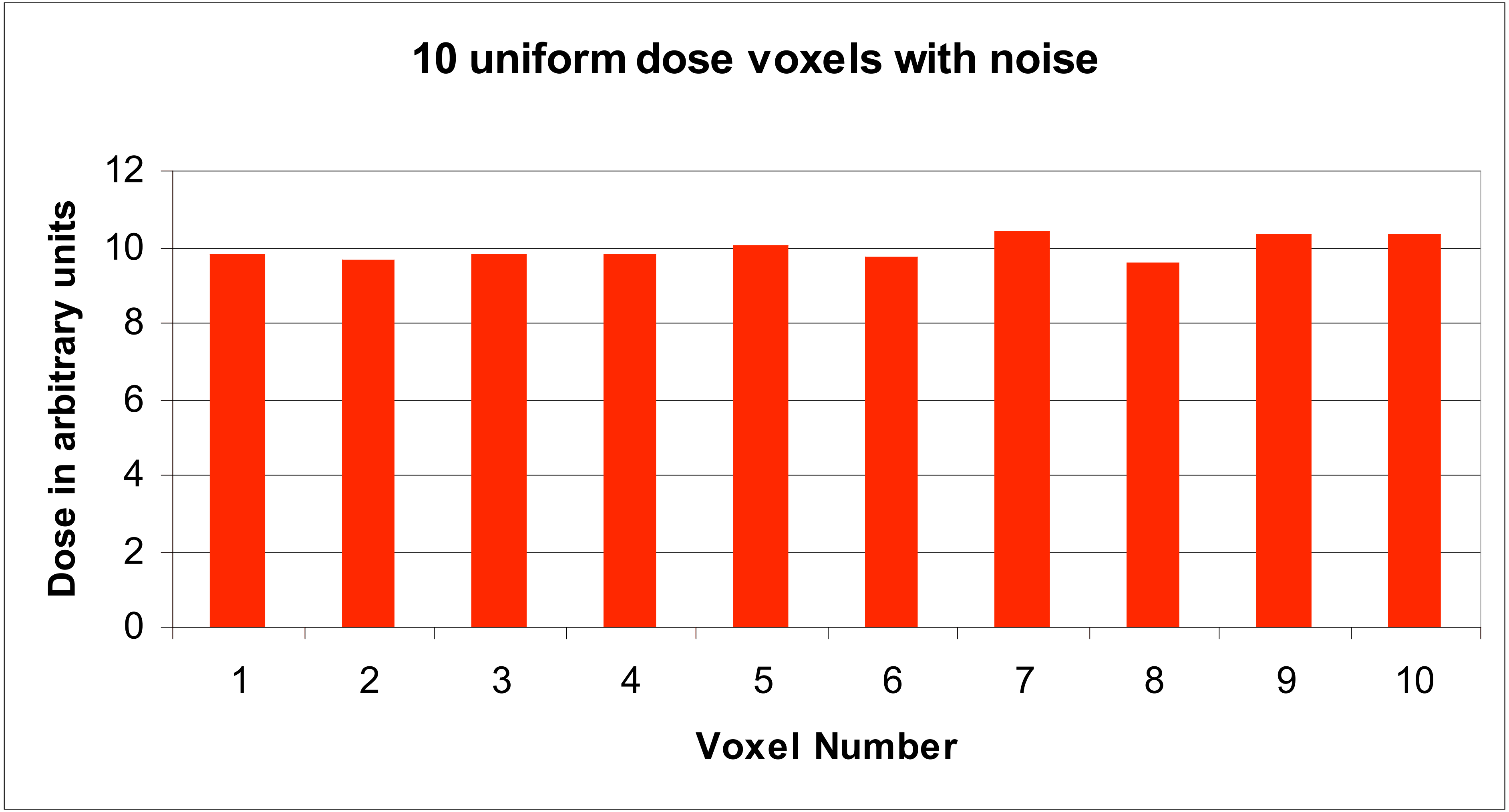


EGS4 BEAM


Beam simulation
AECL Therac 20
20 MeV electron radiotherapy beam
adjustable jaws
accelerator vacuum exit window
monitor ion chamber
beam applicator
patient plane
electron tracks blue
photon tracks yellow


10 uniform dose voxels
Dose in arbitray units
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
Voxel Number

Use the mean and record the standard deviation through dose volume histogram.
Makes no sense to use a single dose point – random value.
Makes no sense to use the maximum dose in the tumour, it will be systematically higher.
Usually hundreds if not thousands of voxels in the tumour volume



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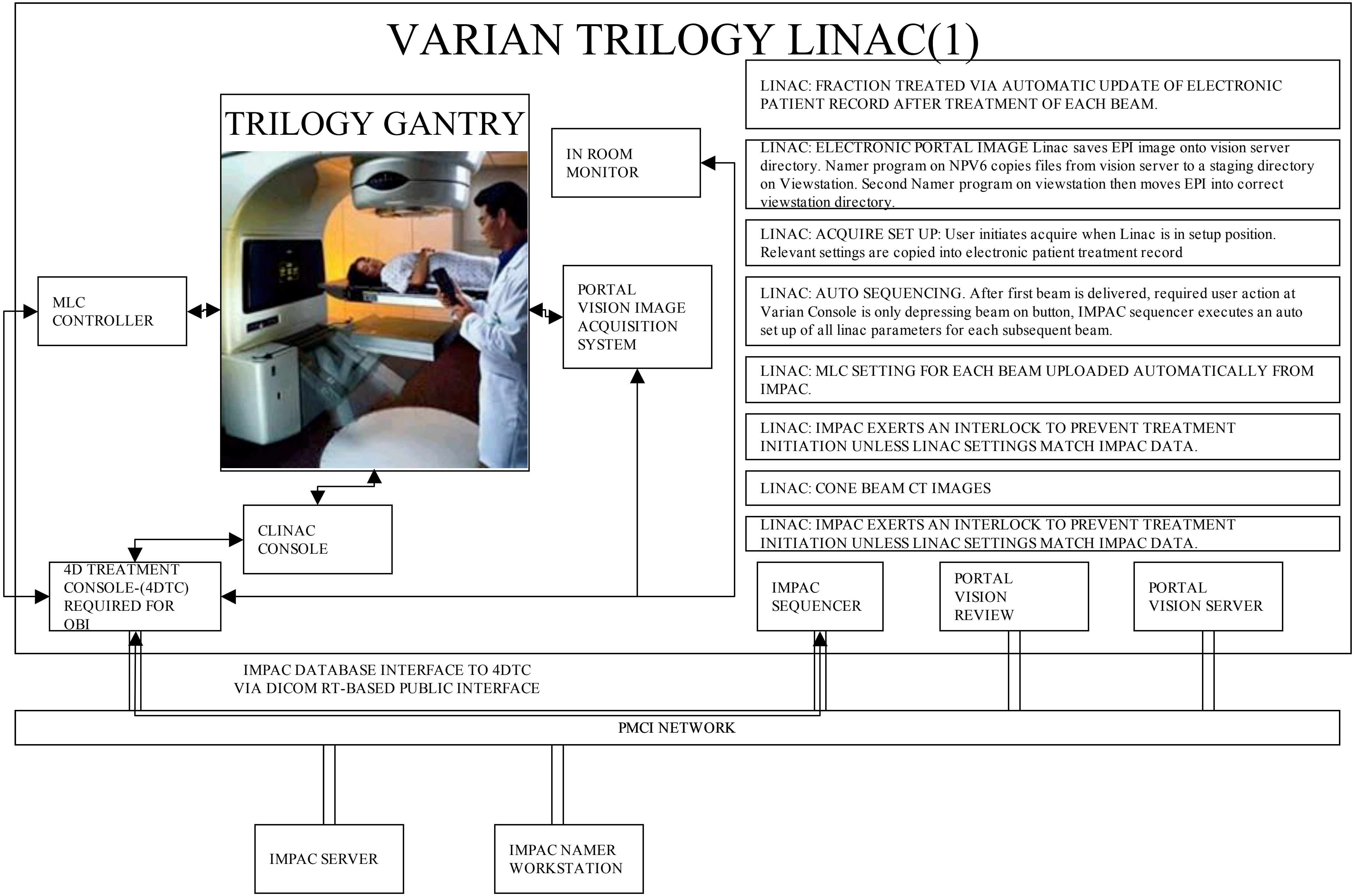
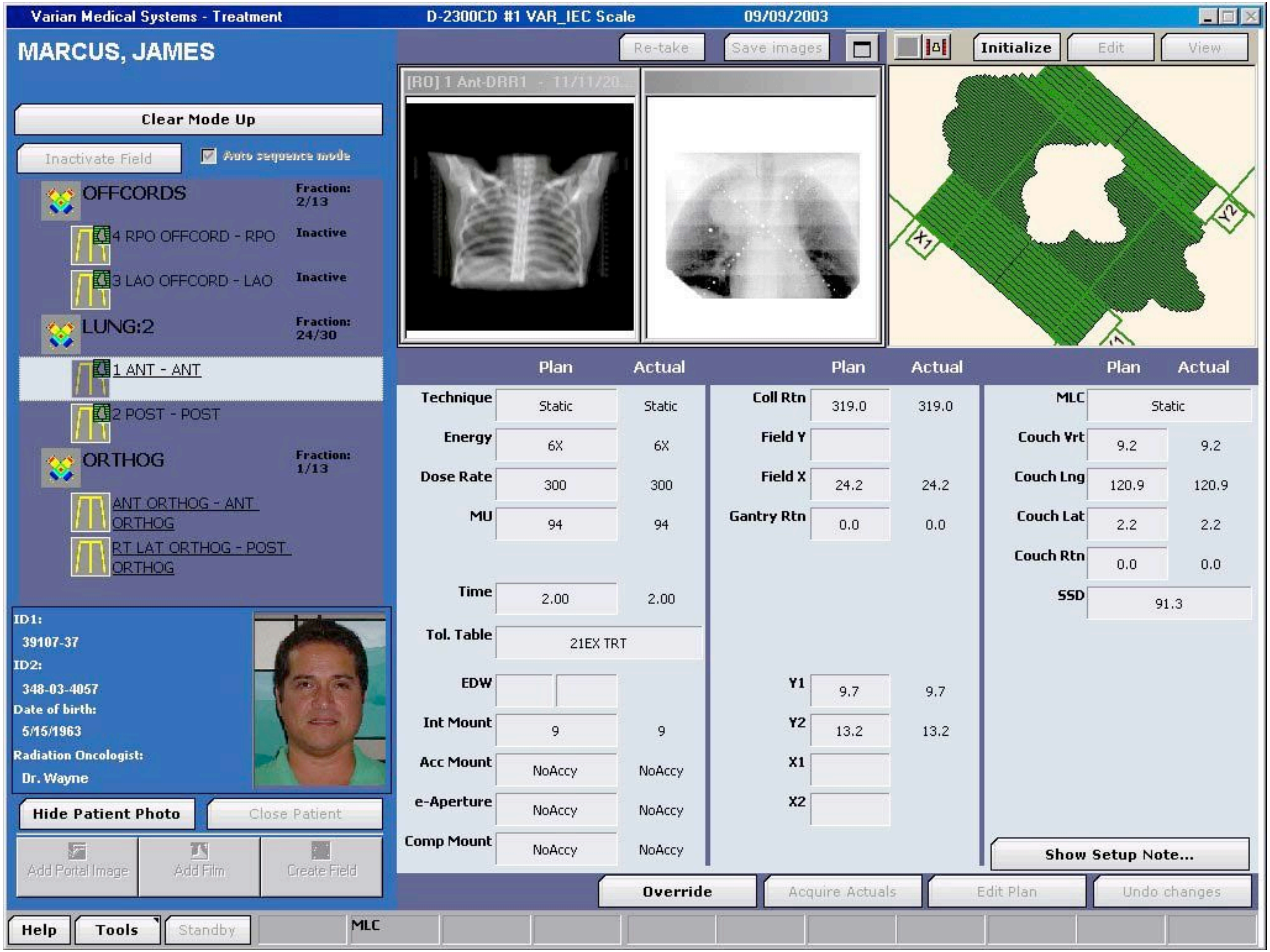
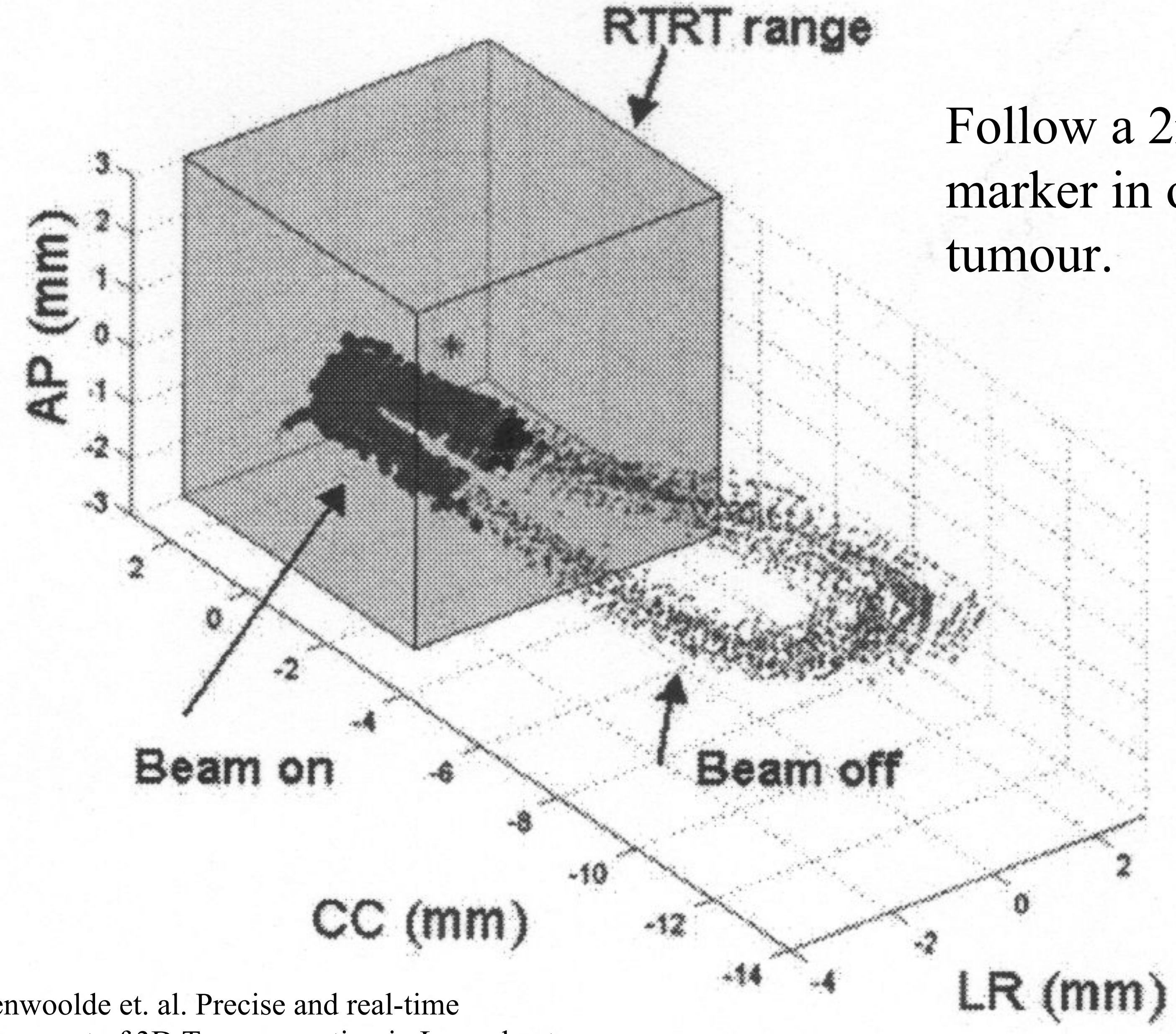
WITHOUT A NETWORK CONNECTION THE PLANNING COMPUTER IS USELESS!

EAST MELBOURNE TRILOGY LINAC (1) DATAFLOW




Varian Medical Systems - Treatment
D-2300CD #1 VAR_IEC Scale
09/09/2003
MARCUS, JAMES
Re-take
Save images
Initialize
Edit
View
Clear Mode Up
Inactivate Field
Auto sequence mode
OFFCORDS
Fraction: 2/13
4 RPO OFFCORD - RPO
Inactive
3 LAO OFFCORD - LAO
Inactive
LUNG:2
Fraction: 24/30
1 ANT - ANT
2 POST - POST
ORTHOG
Fraction: 1/13
ANT ORTHOG - ANT ORTHOG
RT LAT ORTHOG - POST ORTHOG
[RO] 1 Ant-DRR1 - 11/11/20...
X1
Y2
ID1:
39107-37
ID2:
348-03-4057
Date of birth:
5/15/1963
Radiation Oncologist:
Dr. Wayne
Hide Patient Photo
Close Patient
Add Portal Image
Add Film
Create Field
Plan
Actual
Technique
Static
Static
Energy
6X
6X
Dose Rate
300
300
MU
94
94
Time
2.00
2.00
Tol. Table
21EX TRT
EDW
Int Mount
9
9
Acc Mount
NoAccy
NoAccy
e-Aperture
NoAccy
NoAccy
Comp Mount
NoAccy
NoAccy
Plan
Actual
Coll Rtn
319.0
319.0
Field Y
Field X
24.2
24.2
Gantry Rtn
0.0
0.0
Y1
9.7
9.7
Y2
13.2
13.2
X1
X2
Plan
Actual
MLC
Static
Couch Vrt
9.2
9.2
Couch Lng
120.9
120.9
Couch Lat
2.2
2.2
Couch Rtn
0.0
0.0
SSD
91.3
Show Setup Note...
Override
Acquire Actuals
Edit Plan
Undo changes
Help
Tools
Standby
MLC



Follow a 2mm gold marker in or near tumour.

Seppenwoolde et. al. Precise and real-time measurement of 3D Tumour motion in Lung due to breathing and Heartbeat, measured during radiotherapy *IJROBP 2002 53(4) 822-834*.

HYBRID IMAGING

GE MEDICAL SYSTEMS
DISCOVERY LS CT PET
BGO CRYSTALS
59 CM BORE

SIEMENS BIOGRAPH CT PET
BGO CRYSTALS
70 CM BORE

PHILIPS MEDICAL SYSTEMS
ALLEGRO CT PET
GSO CRYSTALS
62 CM BORE

WITHOUT A NETWORK CONNECTION
THE PET CT IS USELESS FOR RADIOTHERAPY

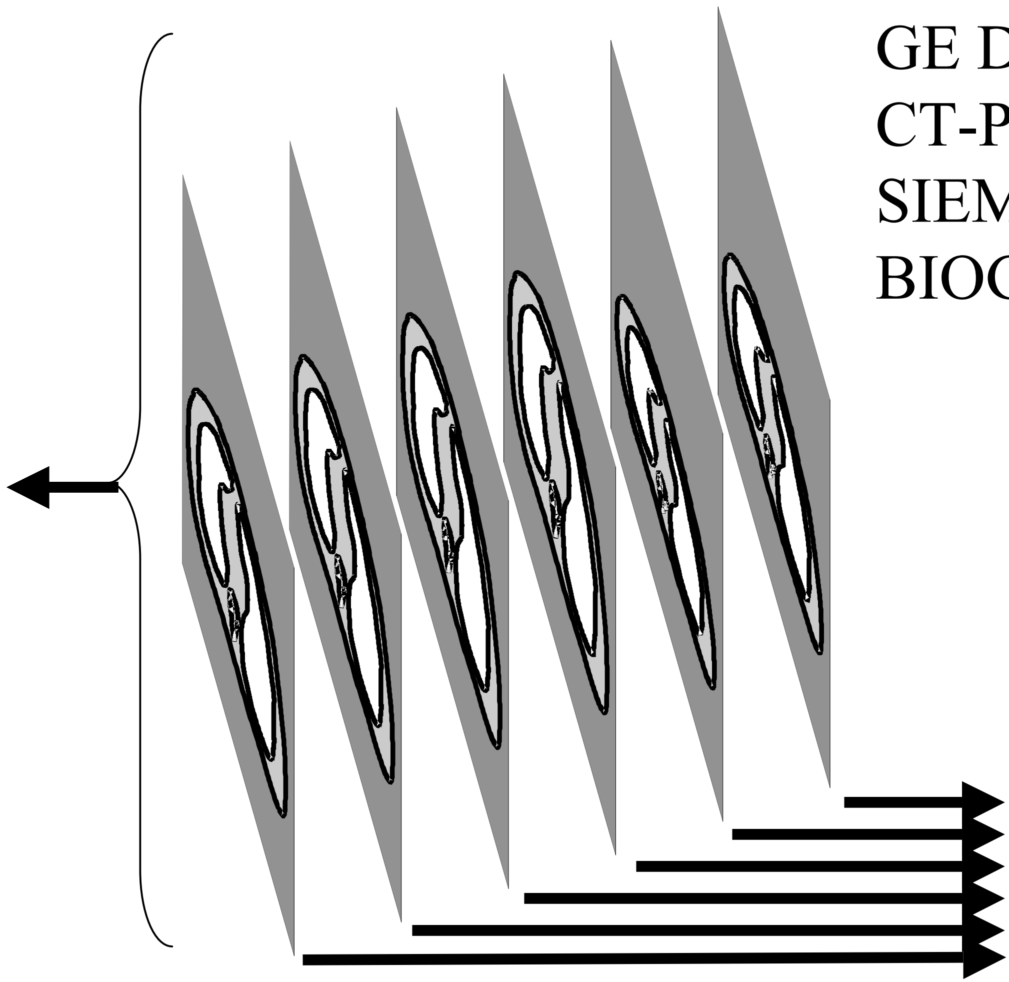
READ THE DICOM CONFORMANCE STATEMENT CAREFULLY!

PHILIPS ALLEGRO PET CT CAN STORE IN EITHER FORMAT

UID 1.2.840.10008.5.1.4.1.1.20	UID 1.2.840.10008.5.1.4..1.1.128
Nuclear Medicine Image Storage	Positron Emission Tomography Image Storage

GE QUEST

GE DISCOVERY LS CT-PET
SIEMENS BIOGRAPH



One File

MULTIPLE FILES

Conclusion

- PET CT is of proven worth for staging.
- Tumour marking is the weak link in RTP.
- PET CT is expected to improve tumour marking.
- PET CT may impact on the RTP process in many other ways, clonogen non-uniformity, treatment monitoring for example.
- All of the talks that follow today deal with aspects of PET-CT that are, or have the potential in the future to be, important to radiotherapy.
- There is a convergence between Nuclear Medicine and Radiotherapy.

Many Thanks

Austin PET Centre

- Dr. Graeme O'Keefe

RMIT

- Dr. Moshi Geso

Radiotherapy Treatment Unit PMCC

- Judy Andrews
- Sarah Everitt

Physical Sciences PMCC

- Michael Kenny
- Guang Li Song
- Jim Cramb

Radiation Oncology PMCC

- Dr. David Ball
- Dr. Michael MacManus
- Dr. Ieta D'Costa

- PET Centre PMCC
- Dr. Rod Hicks
- Dr. Eddie Lau
- David Binns