INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/638-20

College on Medical Physics: Imaging and Radiation Protection

31 August - 18 September 1992

CT Quality Assurance

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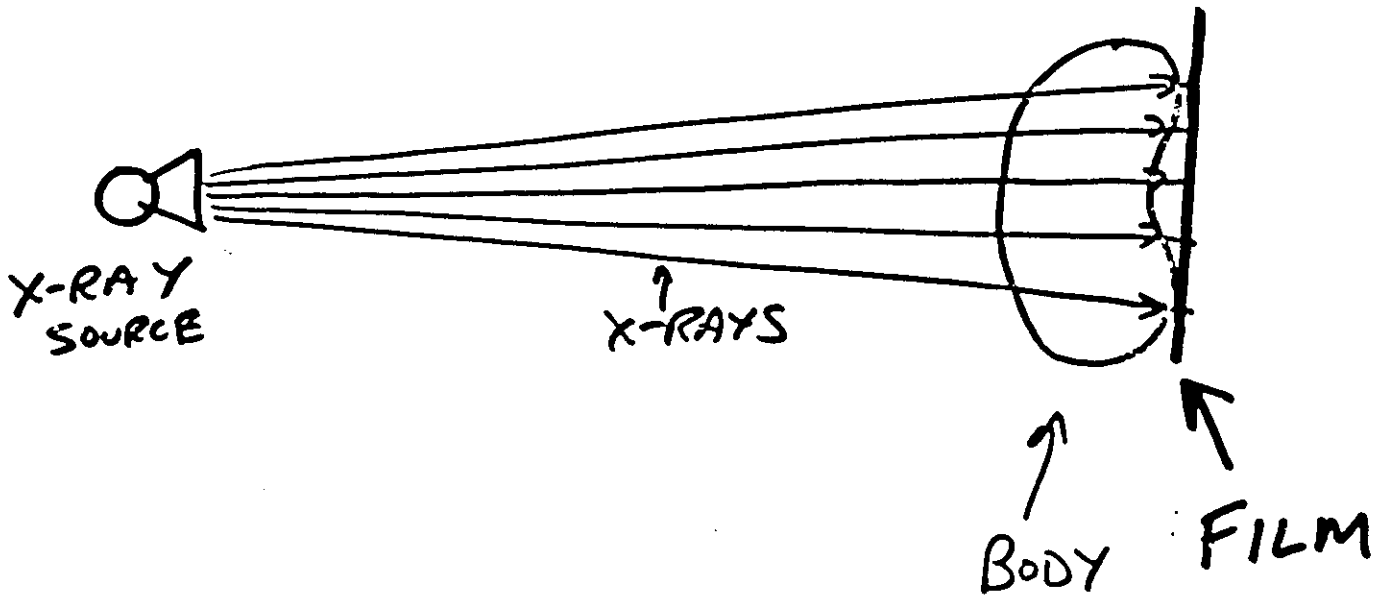
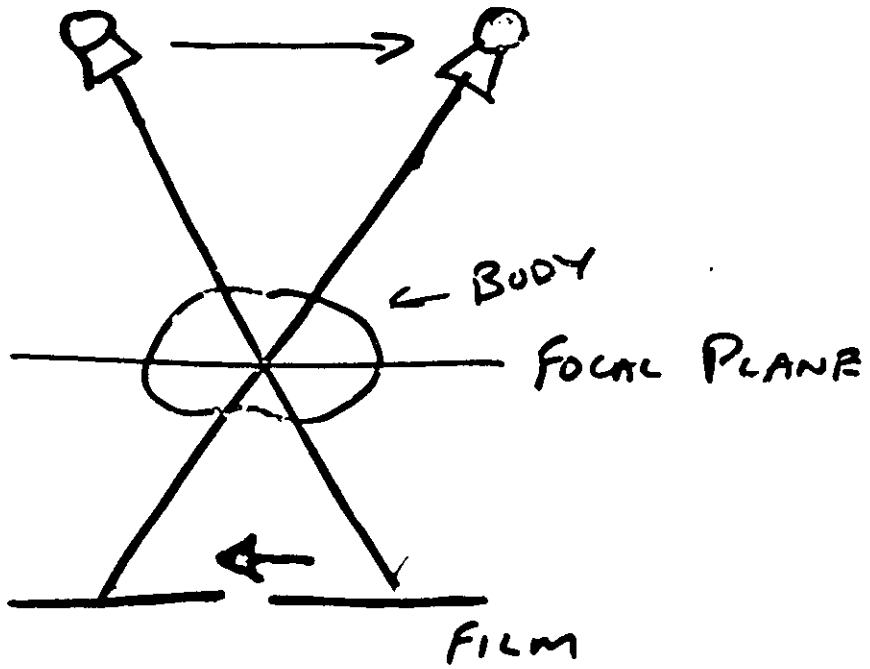
University of Wisconsin-Madison
Dept. of Medical Physics
Medical Sciences Center
Madison, U.S.A.

COMPUTED TOMOGRAPHY

CONVENTIONAL RADIOGRAPHY (ROENTGEN 1895)

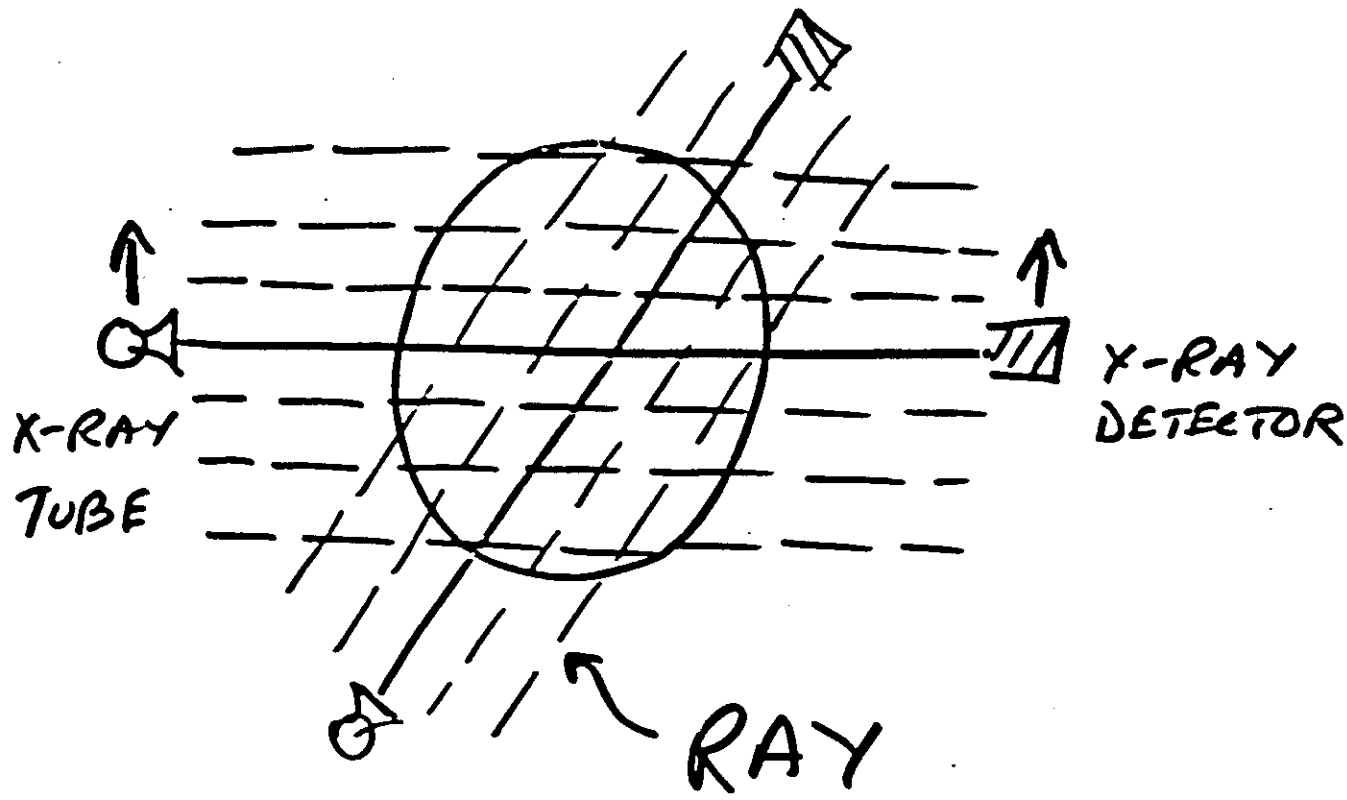


CONVENTIAL TOMOGRAPHY (1922)



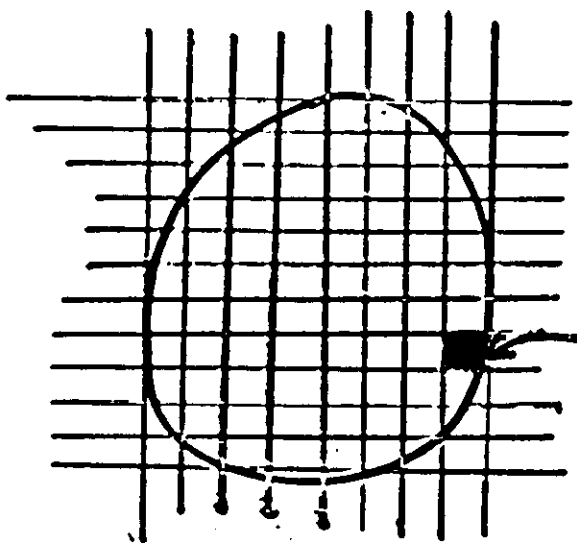
COMPUTED TOMOGRAPHY (1972)

EMI HEAD SCANNER

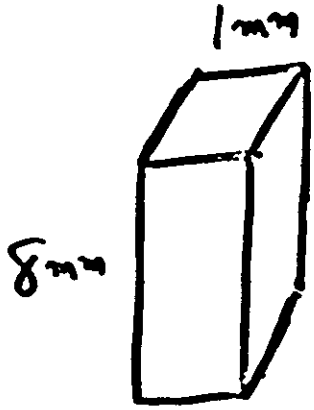


VIEW: COMPLETE SET OF PARALLEL RAYS AT A PARTICULAR ANGLE

C.T. PICTURE



PIXEL



VOXEL

(VOLUME ELEMENT)

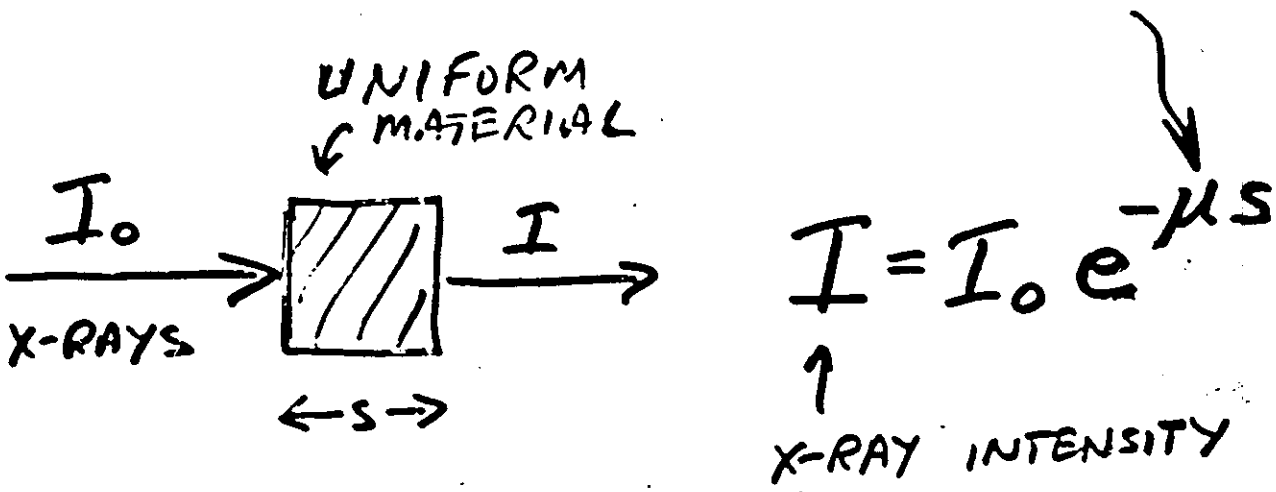
IN THE FINAL IMAGE EACH PIXEL IS GIVEN A NUMBER

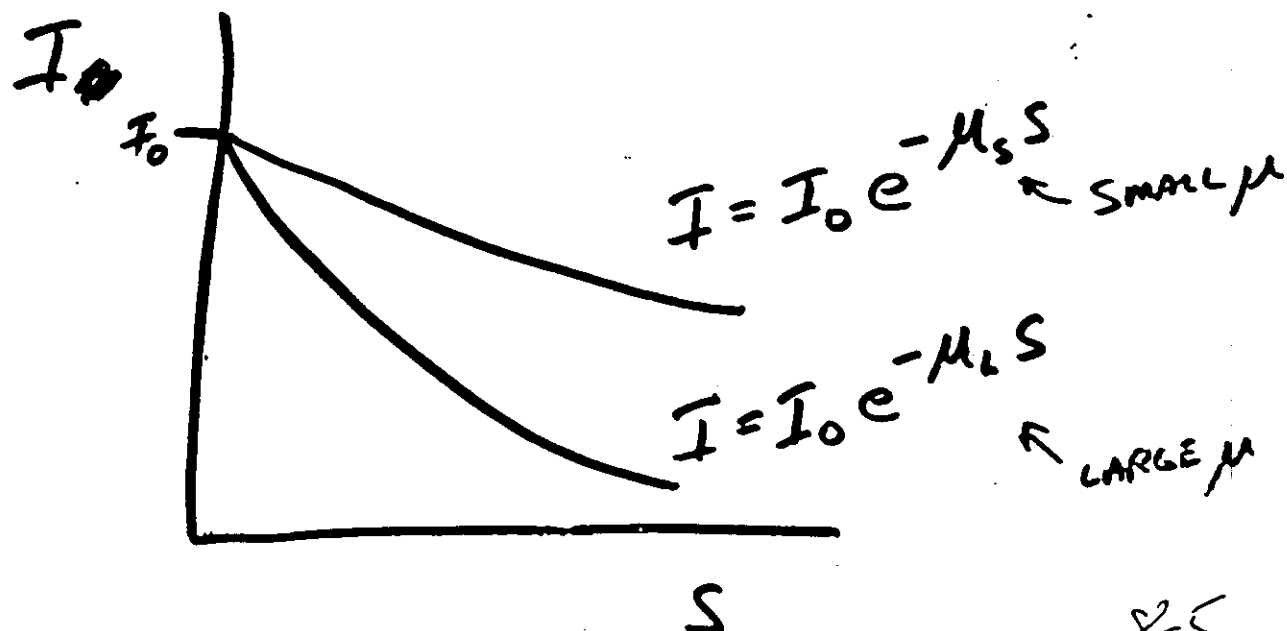
THIS NUMBER IS THEN TRANFORMED INTO A SHADE OF GRAY ON THE DISPLAY → LARGER THE NUMBER, THE WHITER THE GRAY

WHAT DO THE PIXEL NUMBERS REPRESENT ?

WHAT PROPERTY ARE THE X-RAYS MEASURING ?

— LINEAR ATTENUATION COEFFICIENT —





8-5

HOUNSFIELD SCALE

$$CT\# = \frac{\mu - \mu_{H_2O}}{\mu_{H_2O}} \times 1000$$

↖ CAUTION! SOME OLDER SCANNERS USE 500

$H_2O \rightarrow$ CT# = 0

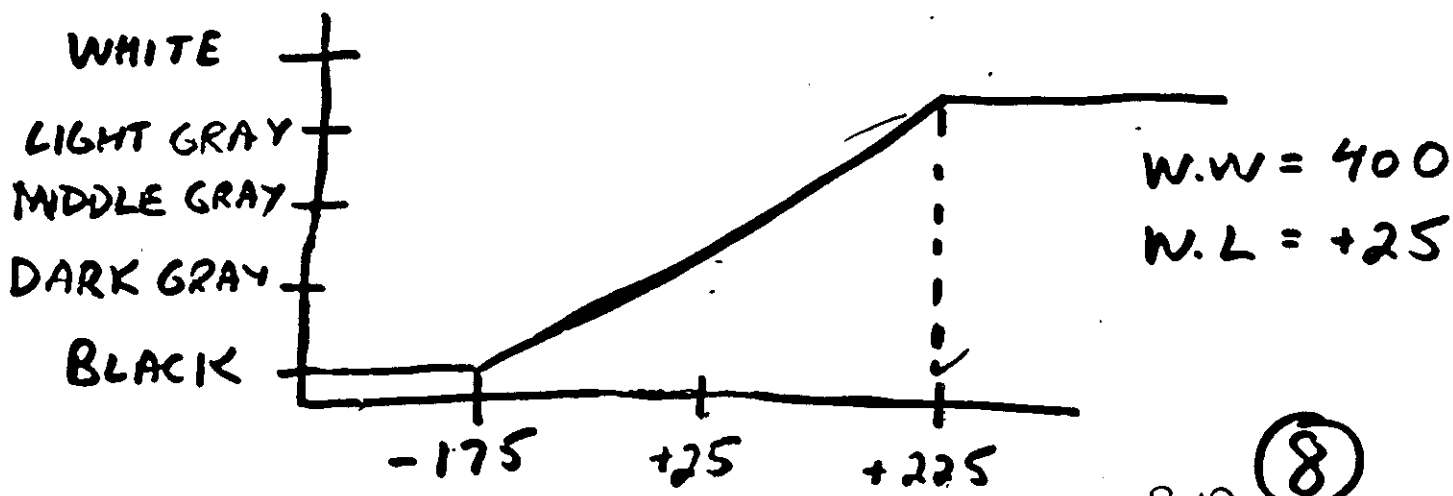
AIR → CT# = −1000

BONE → $\mu \approx 2\mu_{H_2O} \rightarrow$ CT# = +1000

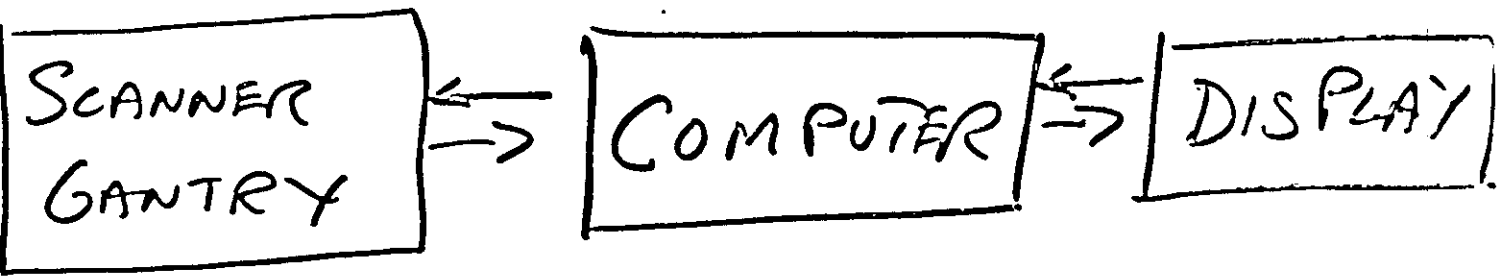
1% = 10 CT#'s

DISPLAY ADJUSTMENTS

- WINDOW WIDTH – RANGE OF NUMBERS FROM WHITE TO BLACK
- WINDOW LEVEL – CT# DISPLAYED AS MIDDLE GRAY



CT SCANNER



X-RAY SOURCE
DETECTOR
DETECTOR ELECTRONICS
| DATA AQUISITION
| CORRELATION W. MECHANICAL MOTION

MECHANICAL MOTION WITH PRECISE ALIGNMENT

PATIENT TABLE
+ TABLE CONTROLS
SLICE LOCALIZATION

- IMAGE PROCESSING
- IMAGE STORAGE
- INTERACTIVE W. DISPLAY: IMAGE RETREVAL
- INTERACTIVE W. SCANNER GANTRY CONTROL OF MOTION

- CONTROL CONSOLE
- IMAGE DISPLAY
- IMAGE DOCUMENTATION

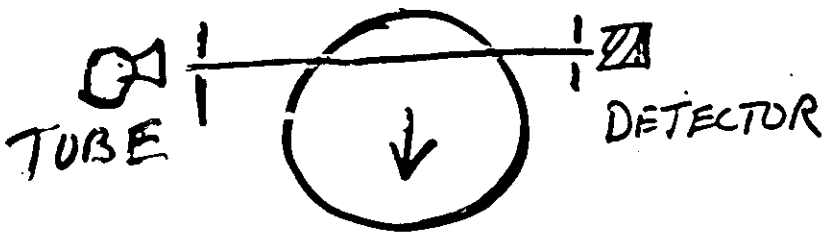
8-13

SCANNER TYPES

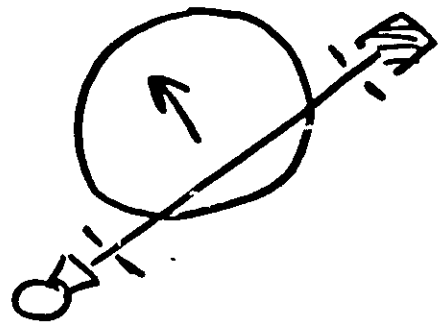
FIRST GENERATION:

TRANSLATE - ROTATE
PENCIL - BEAM
DUAL - SLICE

EMI



THEN ROTATE

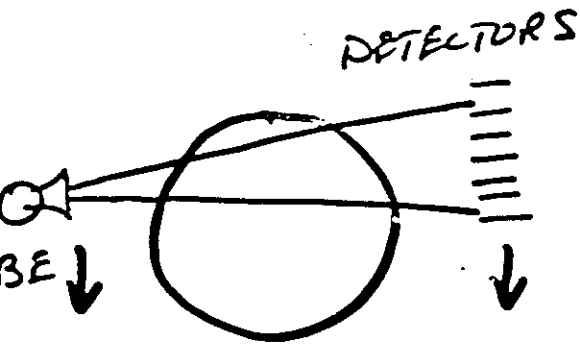


8-14

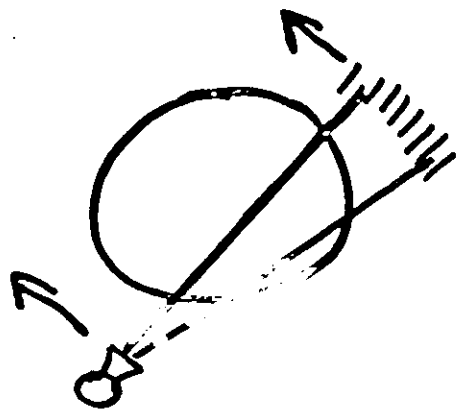
SECOND GENERATION

TRANSLATE- ROTATE
MULTIPLE DETECTORS

EMI



THEN ROTATE

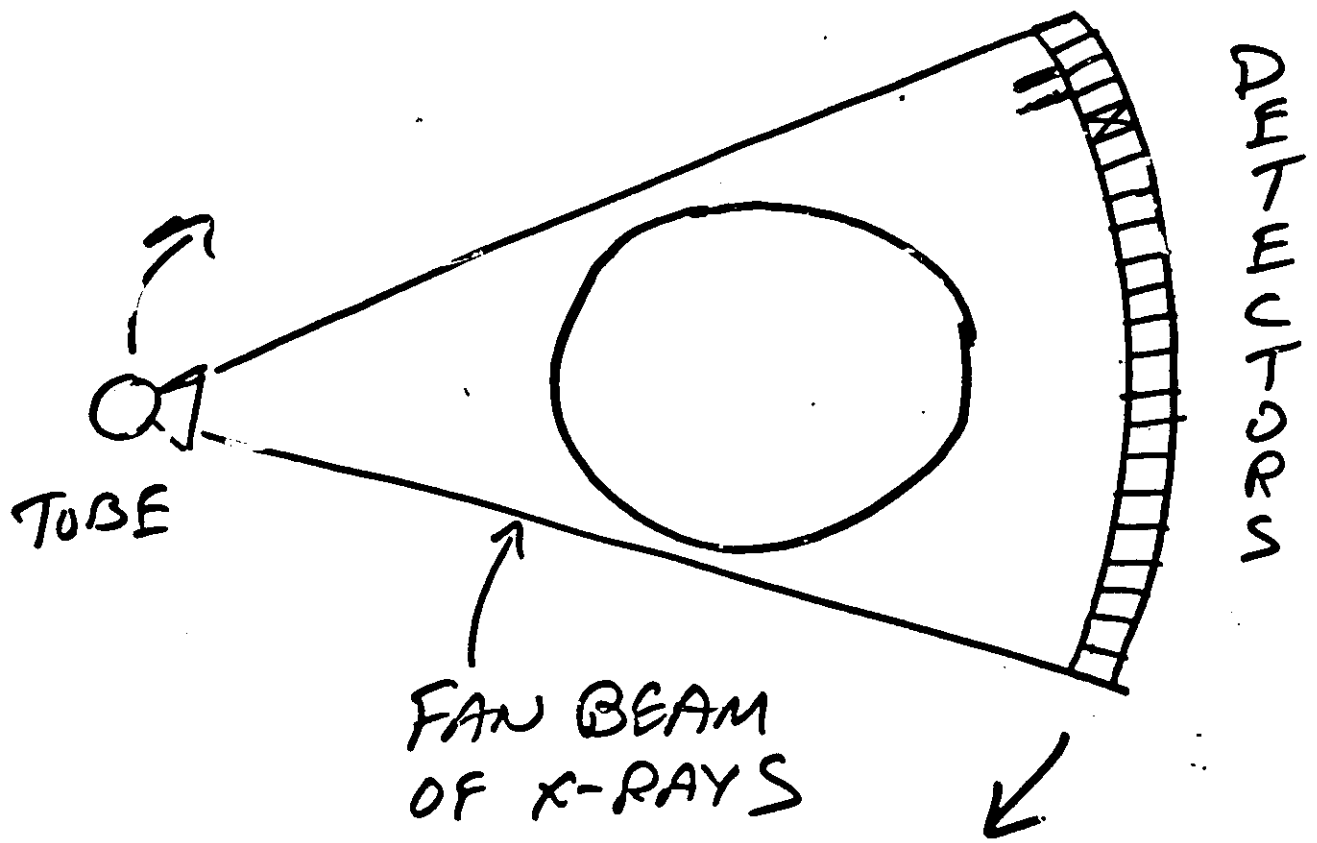


8-15

THIRD GENERATION

ROTATING FAN BEAM AND DETECTORS

GE ; SIEMENS ; PHILLIPS

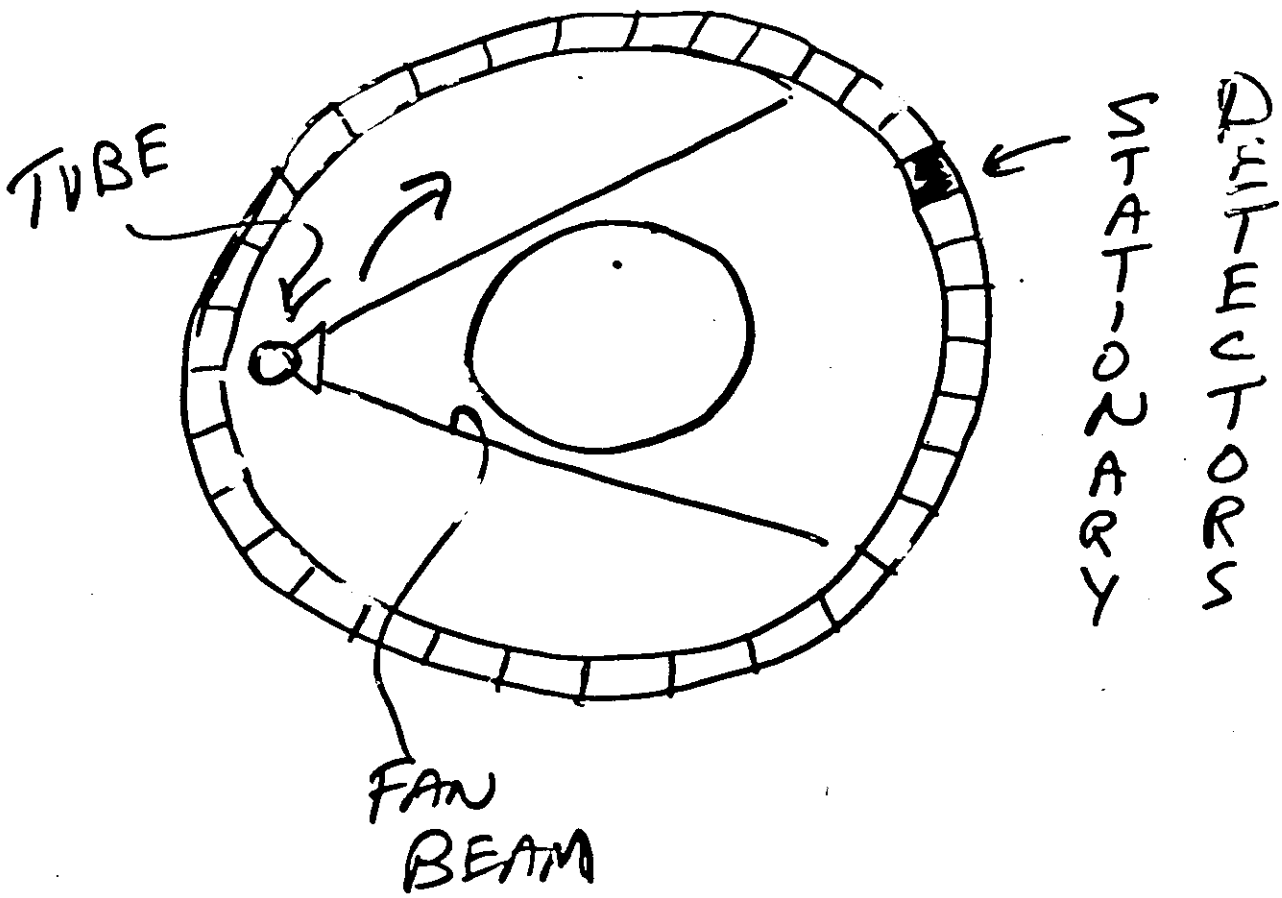


8-16

FOURTH GENERATION

ROTATING FAN BEAM
STATIONARY DETECTORS

PICKER, TECHNICARE, EMI



8-17

ENERATION	ADVANTAGES	DISADVANTAGES
1st	CHEAP, EXCELLENT SCATTER REJECTION	VERY SLOW (~4 min.): PATIENT MOTION BLURS PICS + CAUSES STREAKS, DUAL SLICE GEOMETRY IS BAD
2nd	FASTER ($\frac{1}{3}$ → 1 min.) ONLY SLIGHTLY WORSE SCATTER REJECTION.	MORE EXPENSIVE, STILL SLOW ENOUGH THAT PATIENT MOTION IS A MAJOR PROBLEM
3rd	VERY FAST (3-10 sec) MOTION ARTIFACTS GREATLY REDUCED GOOD SCATTER REJECTION	VERY EXPENSIVE, DETECTORS CANNOT BE CALIBRATED DURING SCAN → RING ARTIFACT; BAD DETECTOR → RING ARTIFACT / BUT DEFECTS CAN BE MINIMIZED BY GOOD ENGINEERING.
4th	VERY FAST (≤ 5 sec.) MOTION ARTIFACTS GREATLY REDUCED; DETECTORS CAN BE CALIBRATED DURING SCAN; BAD DETECTOR → NO ARTIFACT	MOST EXPENSIVE; POORER SCATTER REJECTION; PHYSICALLY LARGE; GREATEST POTENTIAL FOR COMPONENT MALFUNCTION: LARGE NUMBER OF EXPENSIVE SCINTILLATION DETECTOR + ELECTRONICS.

THER ADVANTAGES OF EWER SCANNERS:
FASTER RECONSTRUCTION, NARROWER SLICES,

8-18

CT SCANNER PERFORMANCE

A. SCANNER COMPARISONS

B. ACCEPTANCE TESTING

C. QUALITY ASSURANCE

— IMAGE QUALITY —

— DOSIMETRY ——

— PERFORMANCE OF — NON-IMAGE COMPONENTS

8-19

A, B & C

1. CT # ACCURACY
   a. H_2O : CT # = 0
   b. SCAN UNIFORMITY
   c. CONTRAST SCALE ACCURACY

2. IMAGE SHARPNESS
   a. HIGH CONTRAST RESOLUTION
   b. EDGE RESPONSE - POINT RESPONSE
      → MODULATION TRANSFER FUNCTION

3. LOW CONTRAST PERFORMANCE
   a. NOISE
   b. LOW CONTRACT DETECTABILITY
      (CONTRAST- DETAIL CURVES)

8-21

4. ARTIFACTS (STREAKING)

5. SLICE THICKNESS
   - SENSITIVITY PROFILE

6. DOSIMETRY
   a. INTEGRAL DOSE
   b. BEAM WIDTH
   c. DOSE PROFILE

7. ACCURACY OF PATIENT POSITIONING DEVICE

8. ACCURACY OF TABLE TRAVEL

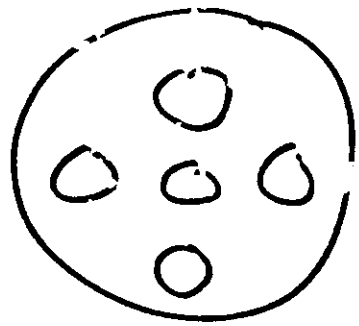
9. IMAGE DISPLAY QUALITY

10. IMAGE DOCUMENTATION SYSTEM QUALITY

C.T. PHANTOMS

1. SOLID PHANTOMS

- EPOXY RESIN BASED TISSUE SUBSTITUTES



ADVANTAGES:

A. LIGHTWEIGHT
B. EASY TO USE
C. STABLE, NO WATER LEAK

2. WATER FILLED PHANTOMS

A. WATER IS HOMOGENEOUS
B. HEAVY
C. MORE DIFFICULT TO USE

8-23

CT SCAN PARAMETERS ADJUSTABLE BY OPERATOR + AFFECTING IMAGE QUALITY AND DOSIMETRY

1. KVP
2. mA OR mAs
3. SCAN TIME
4. SLICE THICKNESS
5. RECONSTRUCTION ALGORITHM
6. PIXEL SIZE < RECONSTRUCTION FIELD OF VIEW / # OF PIXELS, eg. 256×256, 512×512
7. IMAGE MANIPULATION - SMOOTHING + SHARPENING

8-24

1. CT# ACCURACY

→ SCAN UNIFORM PHANTOM OF WATER OR WATER EQUIV. MATERIAL.

→ CHECK CT# IN CENTRAL AREA AND FOUR OUTLYING AREAS

→ SCAN PHANTOM WITH PLEXIGLAS ROD (12% CONTRAST) AND PERHAPS MATERIALS SUCH AS POLYSTHYLENE AND TEFLON AND OBTAIN CT#'S
- CHECK FOR ACCURACY

$$CT\# = \frac{\mu - \mu_{H_2O}}{\mu_{H_2O}} \times 1000$$

$$CT\#_{P.G} = 0.12 \times 1000 = 120$$ (8-25)

IMAGE SHARPNESS

DETERMINED BY

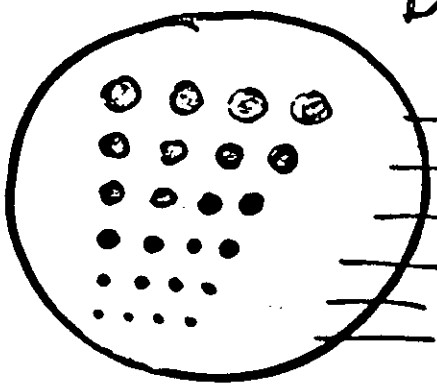
1) SEPARATION OF THE RAYS IN A VIEW
2) FOCAL SPOT SIZE
3) DETECTOR APERTURE
4) DATA SMOOTHING INTRODUCED IN THE IMAGE RECONSTRUCTION PROCESS OR IN POST-RECONSTRUCTION IMAGE MANIPULATION.
5) PIXEL SIZE

- PIXEL SIZE BY ITSELF DOES <u>NOT</u> INDICATE THE SYSTEM RESOLUTION—

8-26

EASY CHECK OF IMAGE SHARPNESS:

HIGH CONTRAST RESOLUTION



AIR-FILLED CYLINDERS SHOW 100% CONTRAST TO BACKGROUND

- SCAN THIS PHANTOM AND OBSERVE THE SMALLEST RODS WHICH CAN BE RESOLVED.

COMPLETE CHECK OF IMAGE SHARPNESS:

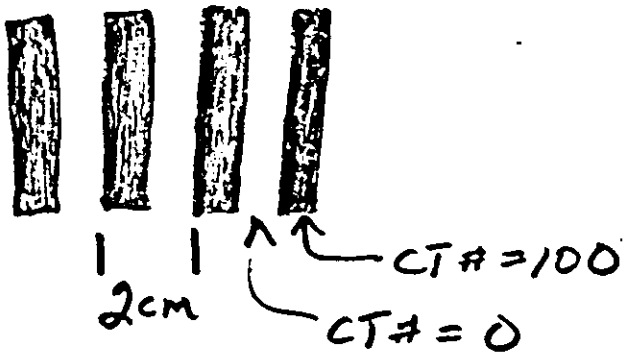
MODULATION TRANSFER FUNCTION

- USUALLY DERIVED FROM EDGE RESPONSE OR POINT RESPONSE

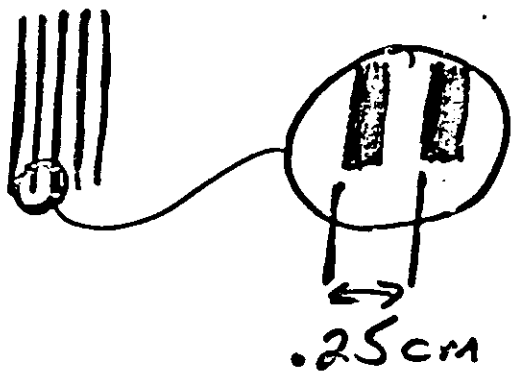
8-27

MEANING OF MTF:

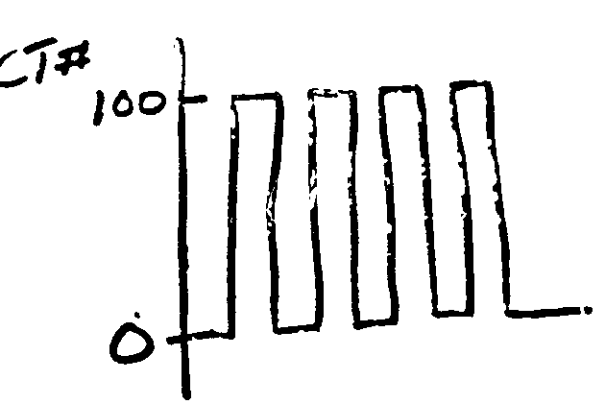
.5 lp/cm

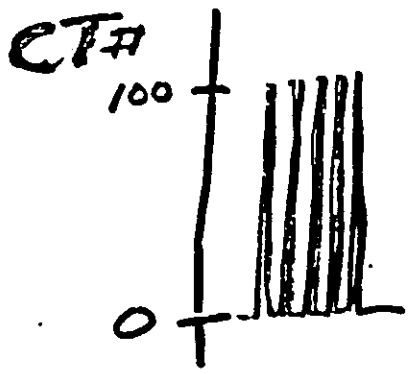


4 lp/cm

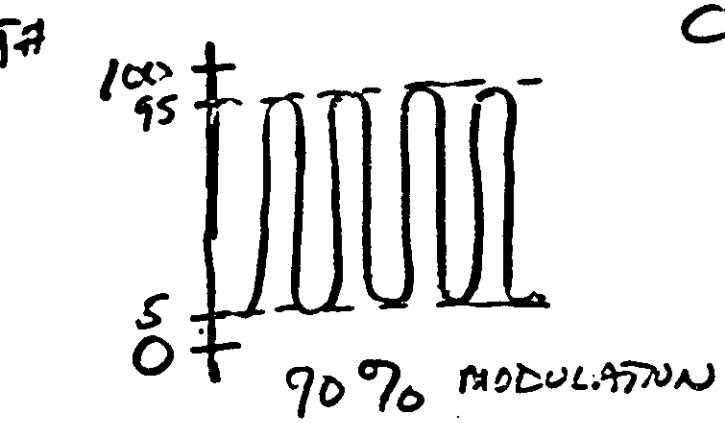


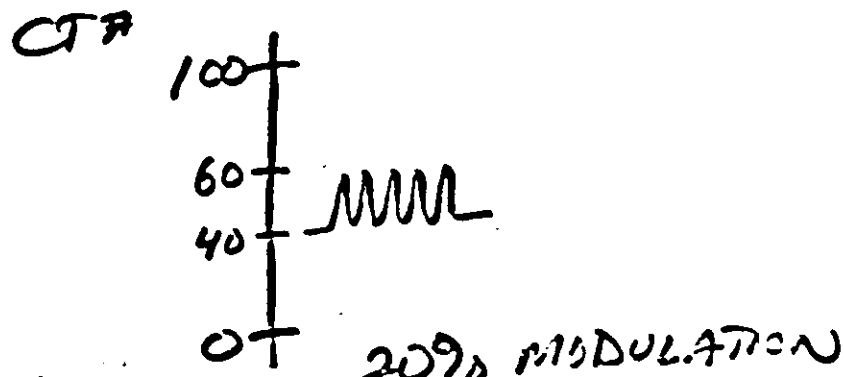
IDEAL RESPONSE:



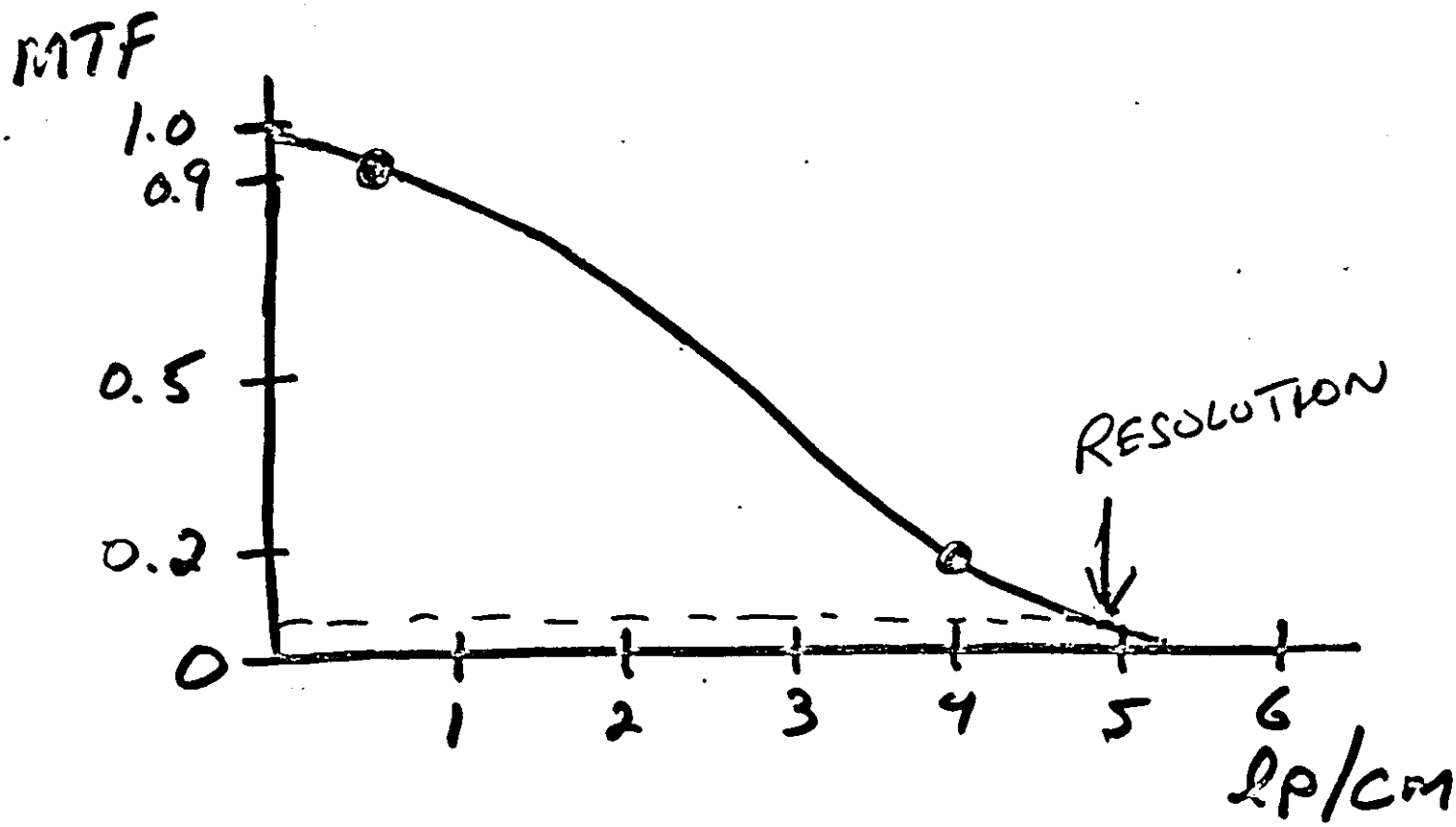


ACTUAL RESPONSE:



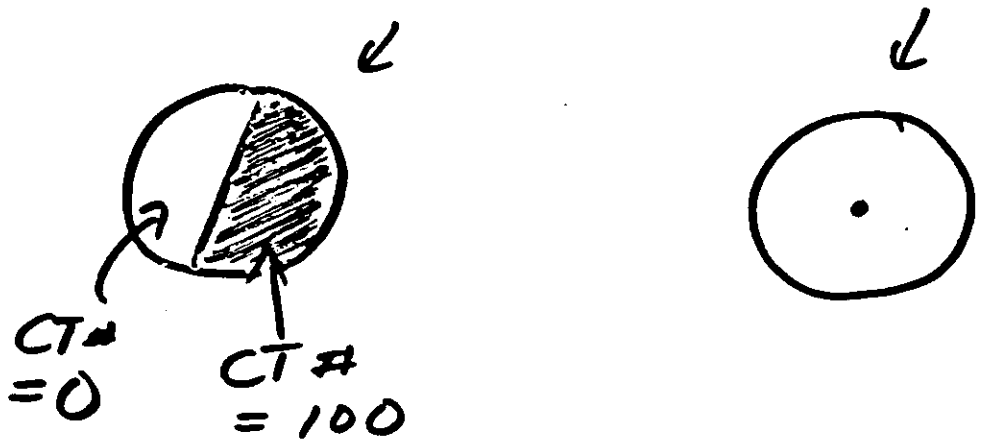


8-28

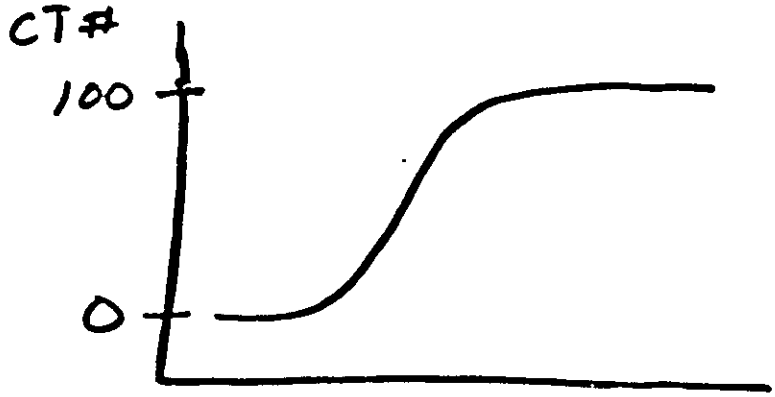


FOR PRACTICAL MEASUREMENT:

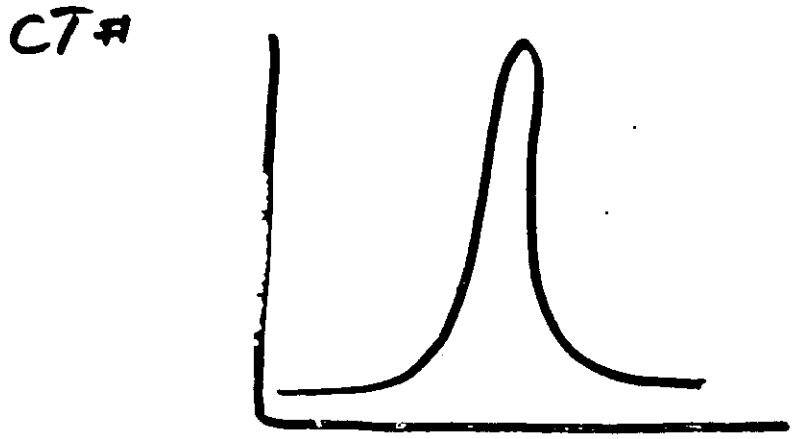
IMAGE <u>EDGE</u> OR <u>WIRE</u>:



GET EDGE RESPONSE:



OR POINT RESPONSE:



CAN CALCULATE MTF FROM THESE

EDGE RESPONSE —DIFFERENTIATE→ LINE SPREAD FUNCTION —FOURIER TRANSFORM→ MODULATION TRANSFER FUNCTION

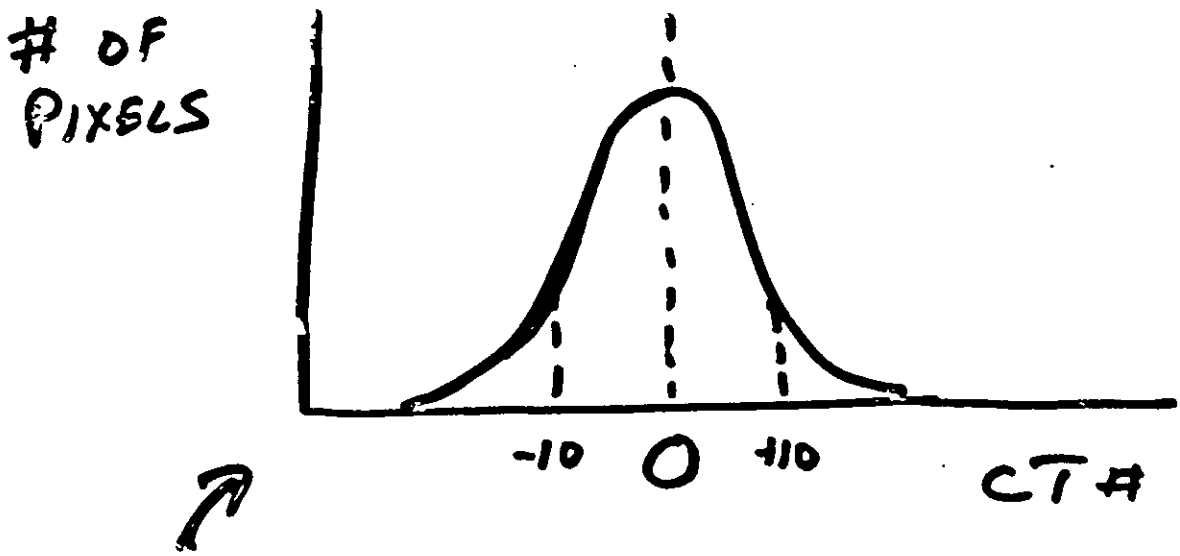
LOW CONTRAST PERFORMANCE

a. NOISE

COUNTING X-RAY PHOTONS

$N \pm \sqrt{N}$: QUANTUM NOISE

IMAGE OF A UNIFORM WATER PHANTOM:



HERE THE PIXEL NOISE CAN BE EXPRESSED AS A STANDARD DEVIATION OF 10 CT NUMBERS (1%).

ONE OF THE MOST IMPORTANT PROPERTIES OF A CT SCANNER IS ITS ABILITY TO DETECT LOW CONTRAST LESIONS. THIS ABILITY IS DIRECTLY AFFECTED BY THE SCANNER'S NOISE CHARACTERISTICS. HOWEVER, A STATEMENT OF THE STANDARD DEVIATION OF THE NOISE IS NOT, ALL BY ITSELF, A SUFFICIENT INDICATOR OF THE SCANNER'S LOW CONTRAST PERFORMANCE

FOR EXAMPLE, PIXEL NOISE CAN BE SIGNIFICANTLY REDUCED BY AVERAGING NEIGHBORING PIXELS, THUS REDUCING RESOLUTION. IN MANY CASES, THOUGH, THIS WILL NOT SIGNIFICANTLY AFFECT LOW CONTRAST PERFORMANCE

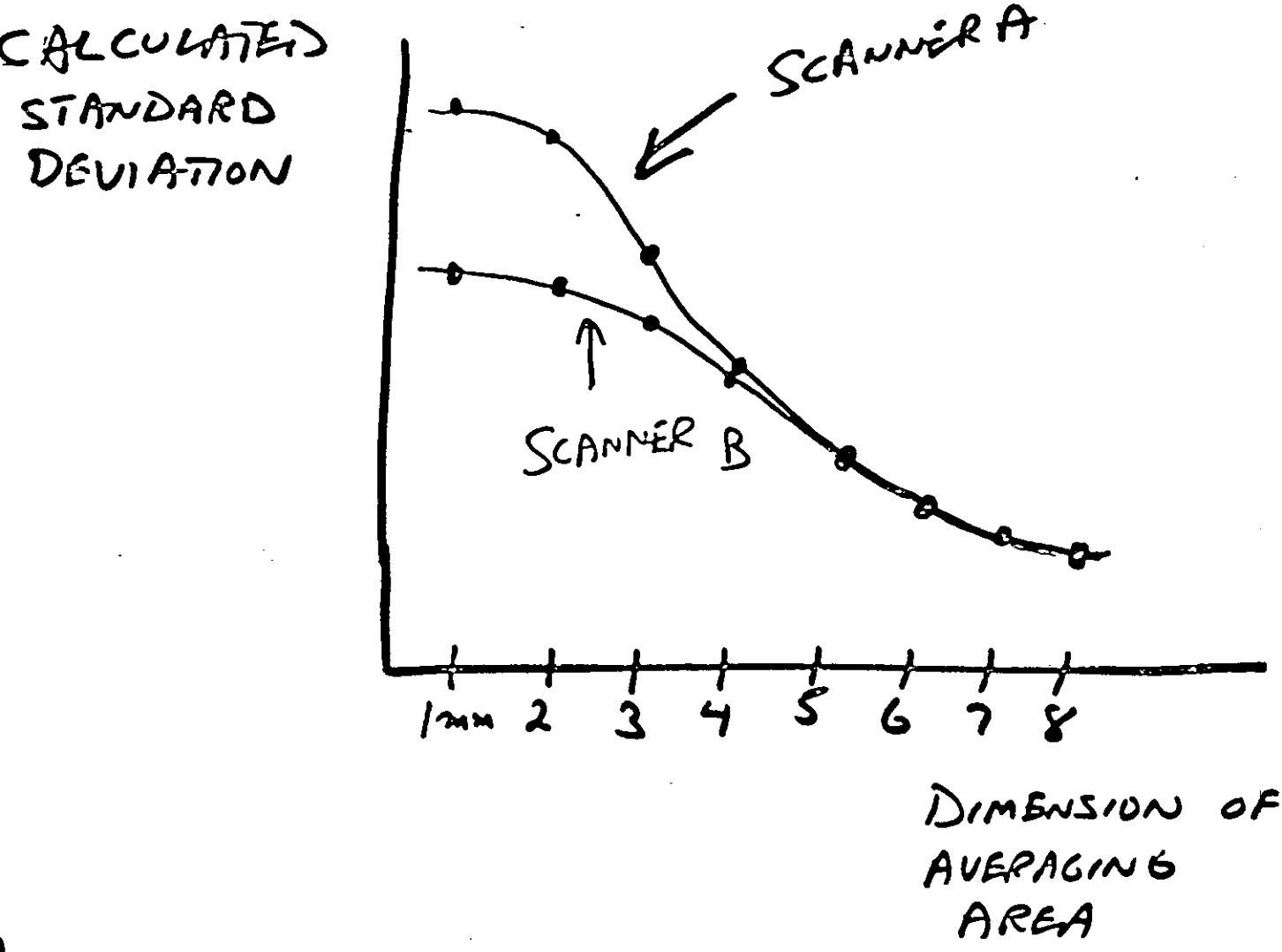
BUT

PIXEL NOISE IS A GOOD MONITOR OF LOW CONTRAST IMAGE PERFORMANCE FOR A PARTICULAR SCANNER SET AT FIXED RESOLUTION RECONSTRUCTION TECHNIQUES

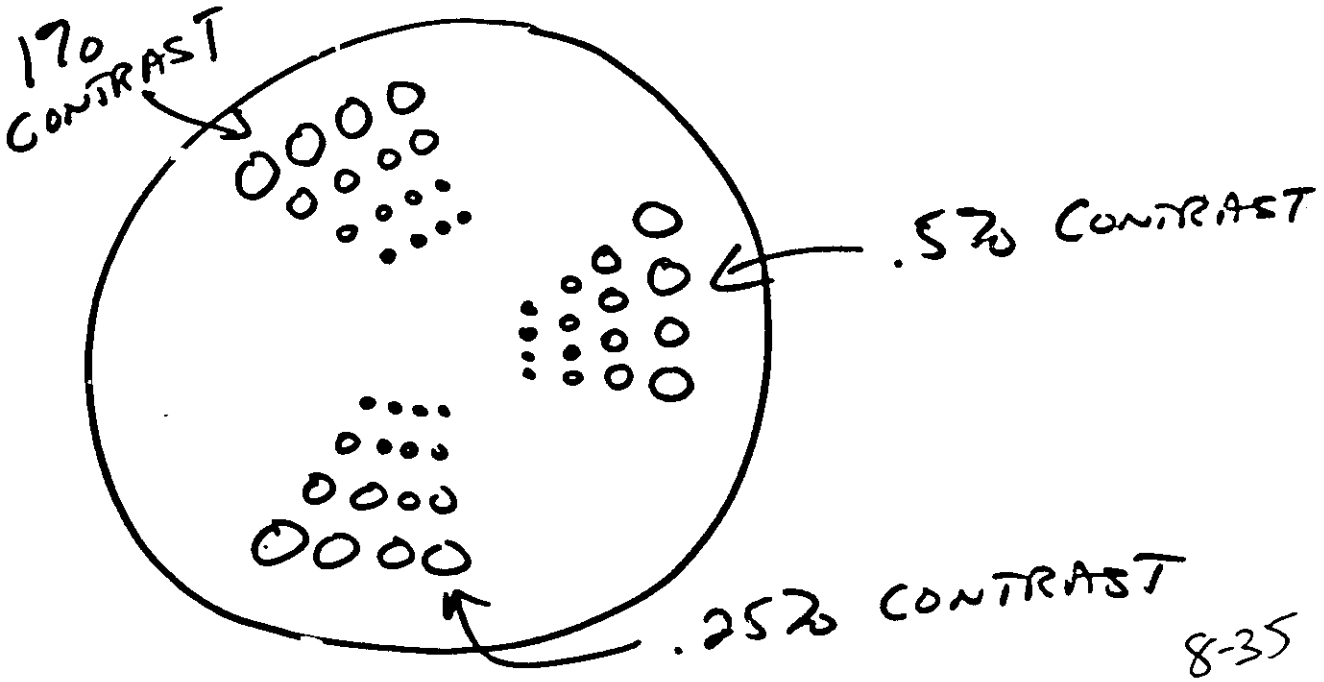
PIXEL NOISE

→ DAILY Q.A.

8-34



B. LOW CONTRAST DETECTABILITY



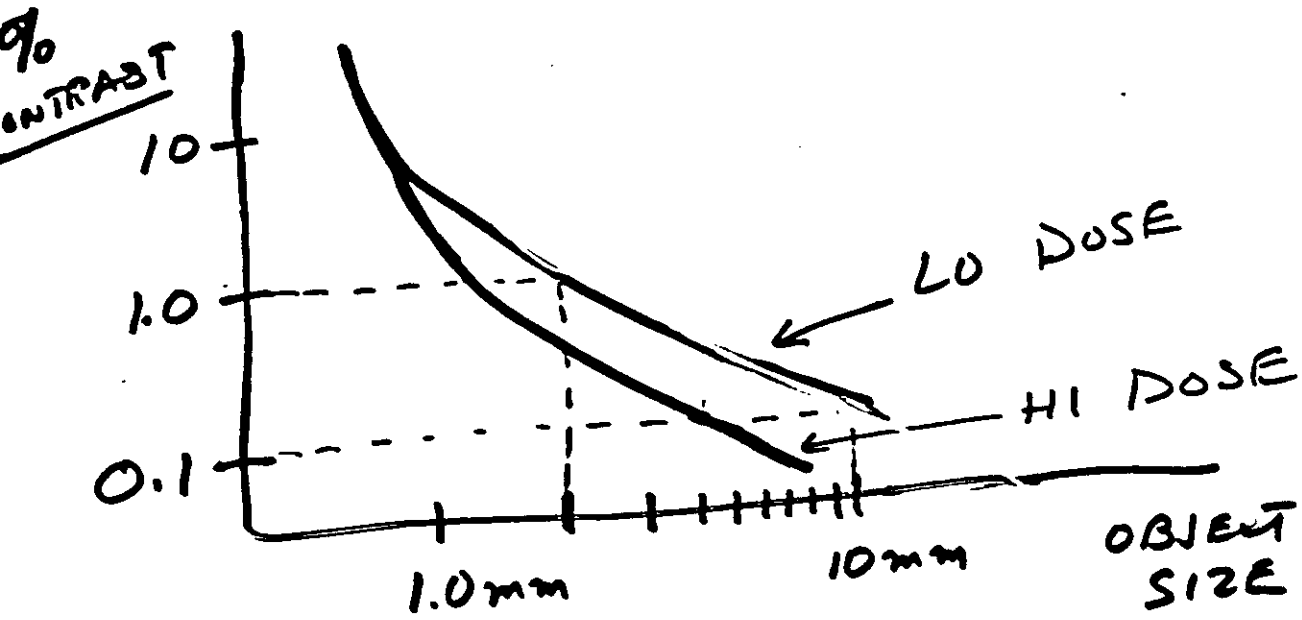
Low Contrast Detectability Phantoms

- Somewhat Subjective
- Valuble for comparing different scanners
- Valuble for monitoring for changes in single C.T. unit.
- Low Contrast means below 1% contrast

OTE: LOW CONTRAST DETECTABILITY
+ PIXEL NOISE ARE BOTH
DOSE DEPENDENT

A HIGHER DOSE GIVES BETTER
LOW CONTRAST DETECTABILITY
AND LOWER NOISE

CONTRAST DETAIL DOSE CURVES



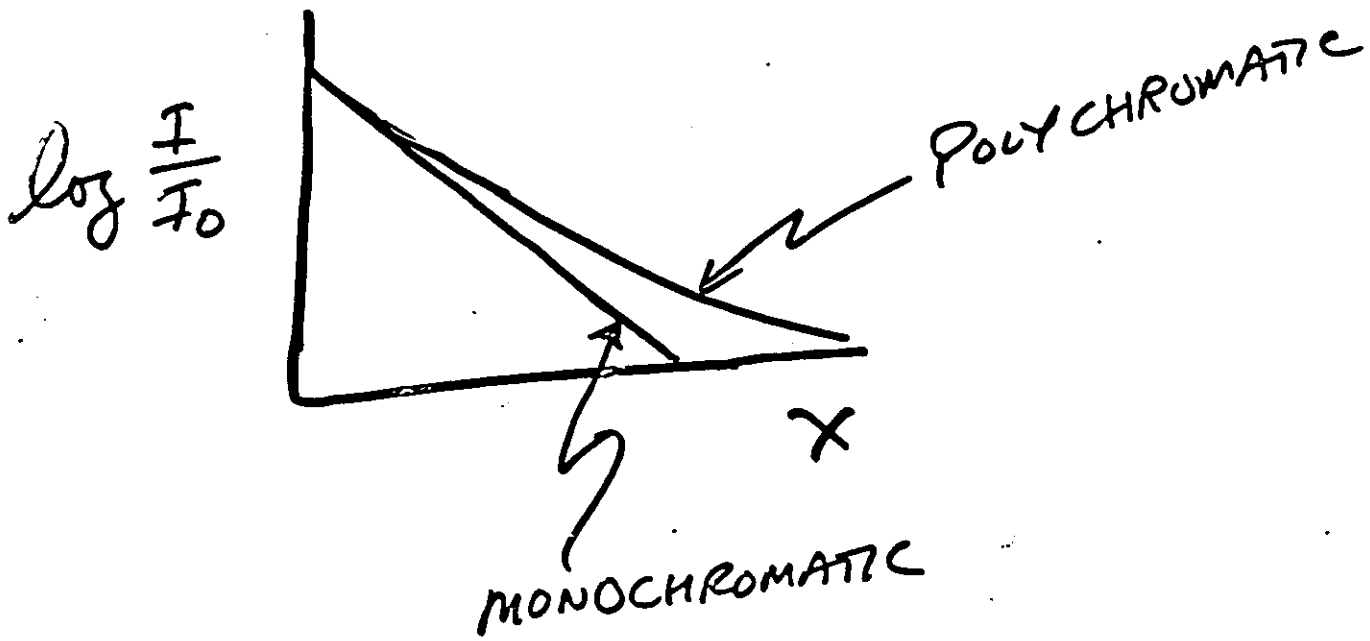
WHEN DISCRIBING LOW CONTRAST
PERFORMANCE CHARACTERISTICS, THE
DOSE MUST BE SPECIFIED

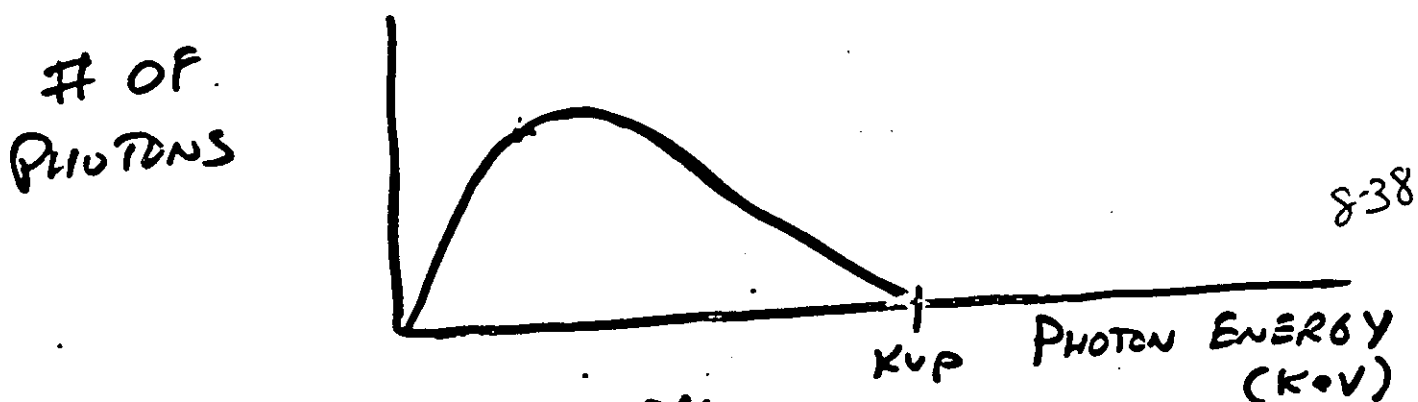
4. ARTIFACTS

A. BEAM HARDENING

$$I = I_0 e^{-\mu x}$$

$$\log_e \frac{I}{I_0} = -\mu x$$

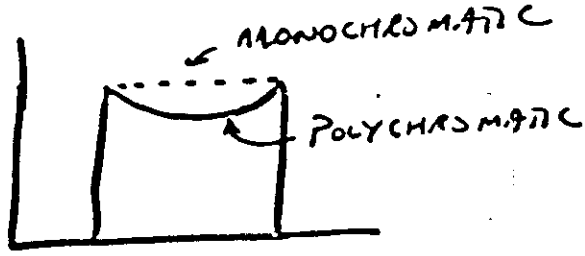




8-38

EFFECTS OF BEAM HARDENING

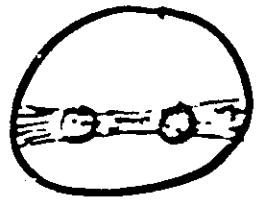
1. CUPPING



2. SHADING (IF OBJECT IS NOT CENTERED IN SCAN)

3. STREAKING (BETWEEN 2 DENSE OBJECTS)

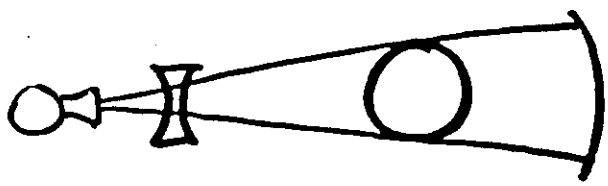
4. SKULL BLEED IN



A. SKULL APPEARS MUCH THICKER THAN IT ACTUALLY IS.
B. HARD TO SEE SOFT TISSUE NEAR SKULL.

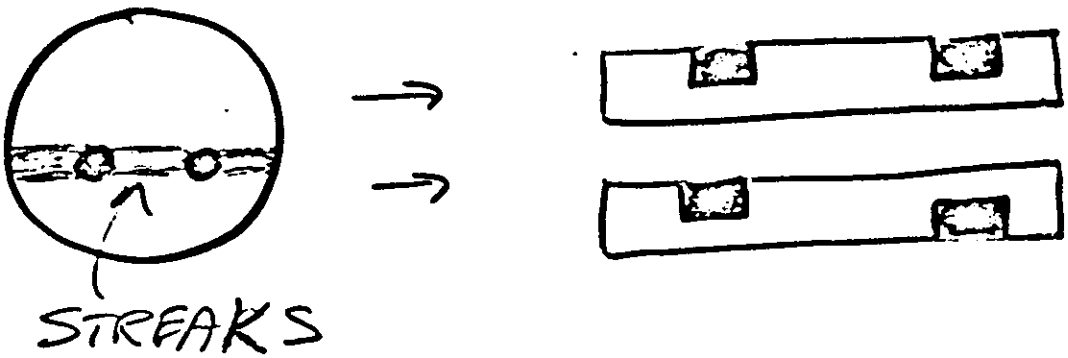
SOLUTION:

A. USE APPROXIMATE BEAM HARDENING CURVE
B. INCREASE FILTRATION OF X-RAY BEAM
C. FUDGE DATA
D. USE FILTER "WEDGES", "BOW-TIE"



E. POST RECONSTRUCTION CORRECTIONS

B. Partial Volume Artifact



SOLUTION: THIN SLICES

C. MECHANICAL MISALIGNMENT.

1. TUNING FORK ARTIFACT

   ↳ 180° SCANNERS (1st + 2nd GENERATION)

2. STREAKING

3. IMAGE BLURRING

D. SCATTER ARTIFACT

E. NOISE ARTIFACT

→ PARTICULARLY NOTICEABLE WHEN SCANNING THROUGH PELVIC REGION

F. ANODE WOBBLE ARTIFACT

- PRODUCES FINE PATTERNS IN IMAGE

G. PATIENT MOTION

1. INTERNAL: HEART, LUNGS, G.I.
2. EXTERNAL

STREAKS OFF HI (OR LOW) DENSITY OBJECTS CAN BE DUE TO ANY OF THE ABOVE ARTIFACTS.

THIS STREAKING IS WORST OFF METAL CLIPS & FILLINGS; ALSO INTESTINAL GAS + BONE.

8-41

H. RING ARTIFACT

- CAN APPEAR ON 3rd GENERATION SCANNERS DUE TO MISCALIBRATION OF THE DETECTORS OR A DRIFT IN THEIR RESPONSE.
- APPARENT ON THE SCANS OF THE UNIFORM PHANTOM.

I. OTHER DETECTOR OR COMPUTER MALFUNCTIONS

1. STREAKS, OFTEN NOT CONNECTED TO HI OR LOW CONTRAST OBJECTS
2. IMAGE "BREAK-UP"

8-42

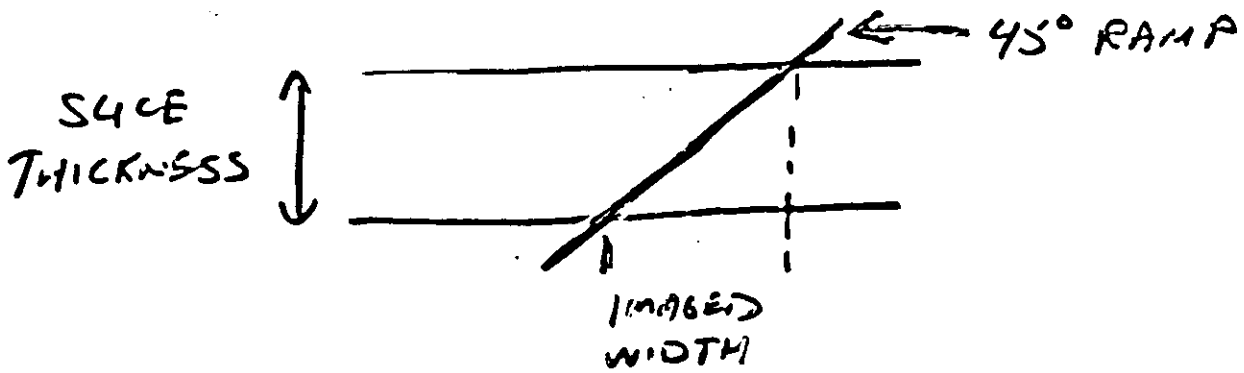
5. SLICE THICKNESS

- SENSITIVITY PROFILE

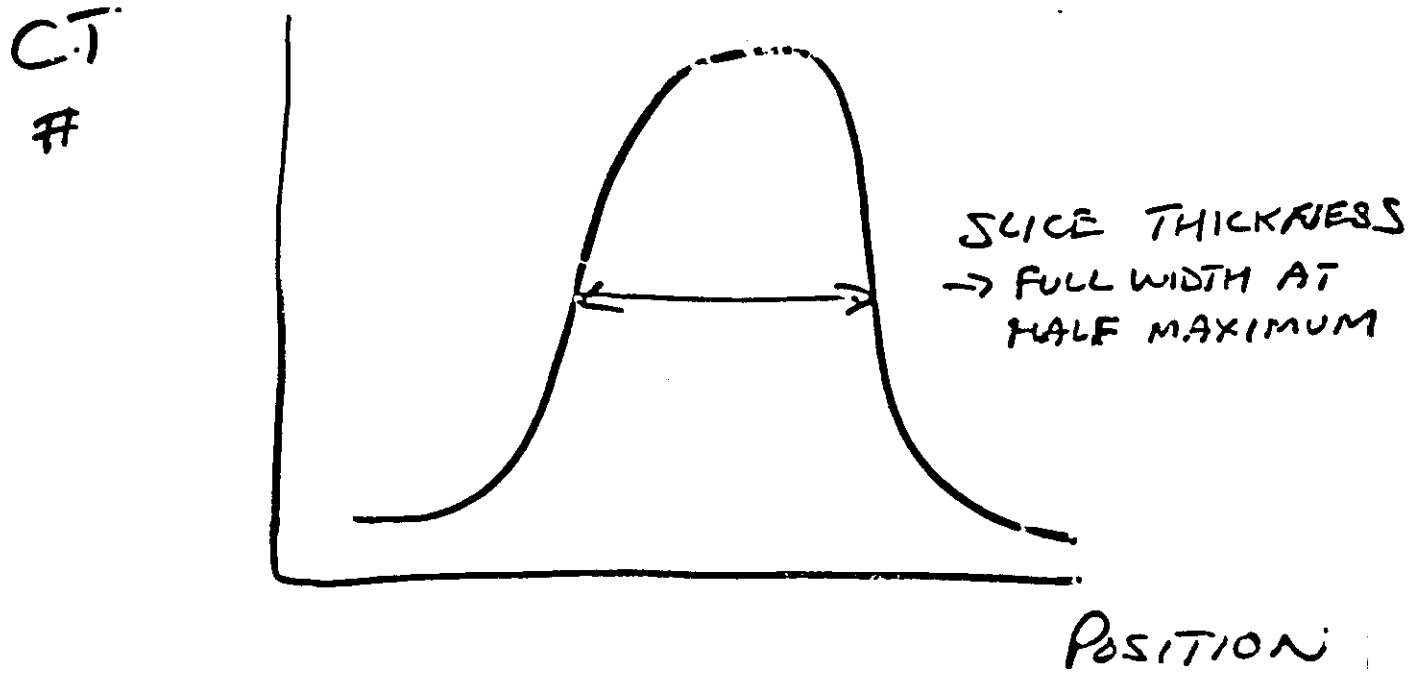
A. HELIX PLUG

B. 45° ALUMINUM RAMP (OR 26.6°)

C. 45° STRING OF BEADS

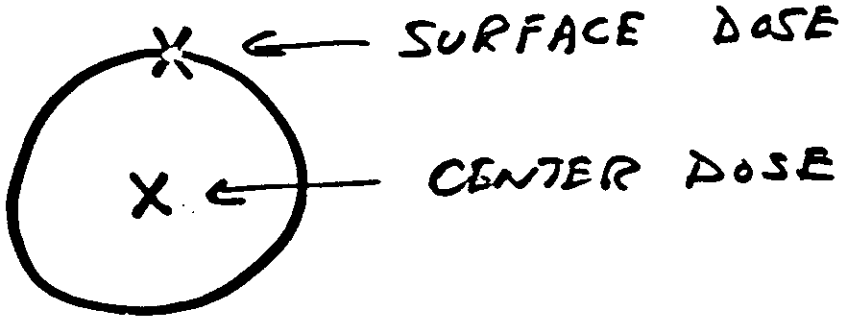


SLICE SENSITIVITY PROFILE (USING 45° RAMP)



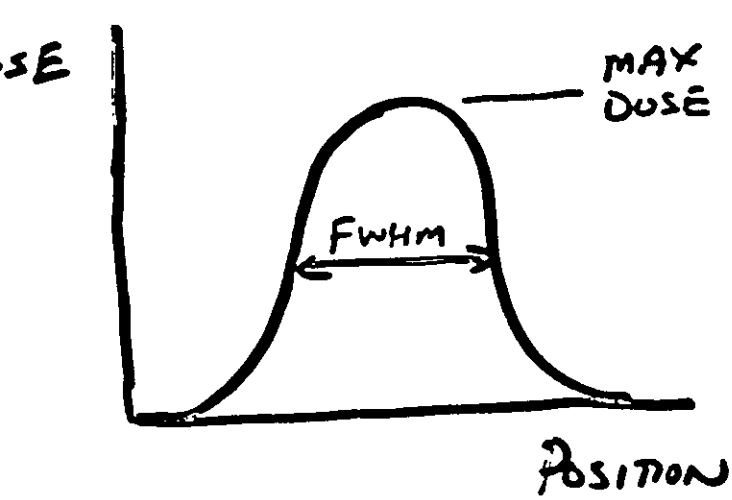
DOSIMETRY

VERY CONFUSING : MANY WAYS OF SPECIFYING DOSE.

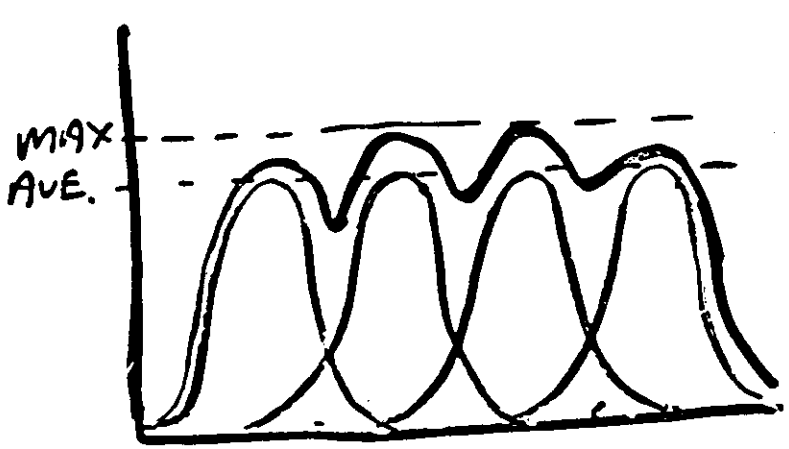


AT WHATEVER POSITION DOSE IS MEASURED THERE EXISTS A DOSE PROFILE ACROSS THE SLICE THICKNESS IRRADIATED

SINGLE SLICE



MULTI - SLICE

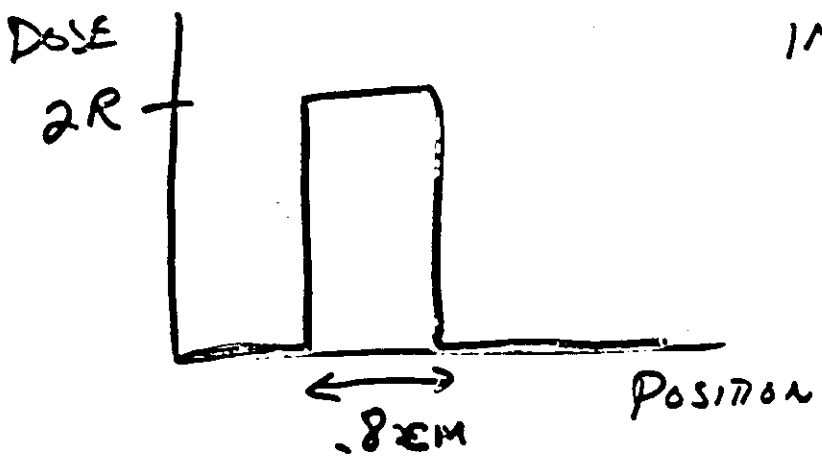


CIFIED: NOM. SLICE WIDTH | NOM. SLICE WIDTH
SCAN INCREMENT

INTEGRAL DOSE

- INTEGRAL OF SINGLE SLICE DOSE PROFILE

IDEAL EXAMPLE:



INTEGRAL DOSE
$= 2R \times .8cm$
$= 1.6\ R \cdot cm$

DOSE PROFILE MEASURED USING FILM OR TLD'S (ON EDGE IN HOLDER)

INTEGRAL DOSE USING ION CHAMBER
→ MUCH QUICKER

DOSE PROFILE SHOULD NOT BE SIGNIFICANTLY WIDER THAN SENSITIVITY PROFILE

8.45

7. ACCURACY OF PATIENT POSITIONING DEVICE

8. ACCURACY OF TABLE TRAVEL
   - TAPE RULER BY TABLE TO MEASURE TRAVEL
   - USE BOTH LIGHT & HEAVY "PATIENT"

9. IMAGE DISPLAY QUALITY
   A. CONTRAST
   B. BRIGHTNESS
   C. LINEARITY - HORIZ & VERT. GAIN.
   D. FLICKER OR JUMPINESS
   E. FOCUS

10. IMAGE DOCUMENTATION SYSTEM QUALITY
   A.-E. AS ABOVE
   F. DUST ON T.V. SCREEN
   G. PROCESSOR Q.A.

8-46

DAILY Q.A

1. SCAN UNIFORM PHANTOM.
   MEASURE CT# AND STANDARD DEVIATION IN CENTRAL AREA AND FOUR OUTLYING AREAS.

   DETERMINE:
   A. CT# ACCURACY, INCLUDING SPATIAL UNIFORMITY
   B. IF STAND. DEV. IS BELOW MAX. LIMIT.

2. SCAN PHANTOM WITH OTHER MATERIALS INSERTED SUCH AS PLEXIGLASS AND WITH HOLLY PLUG OR EQUIV.

   DETERMINE:
   A. CT# ACCURACY FOR MATERIAL SCANNED
   B. IMAGED SLICE THICKNESS

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