INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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SMR.300/44

College on Medical Physics
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CAT Phantom

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** These notes are intended for internal distribution only

CT SECTION ORGANIZATION 1

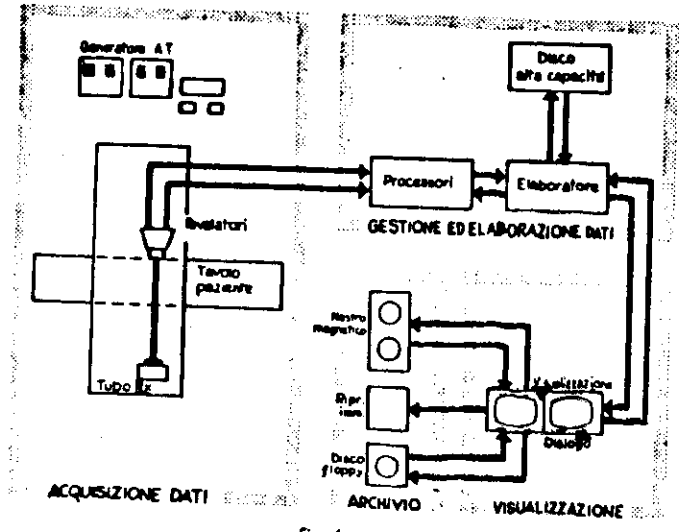


Fig 1

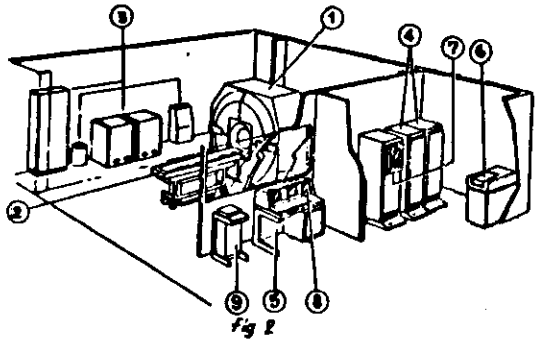
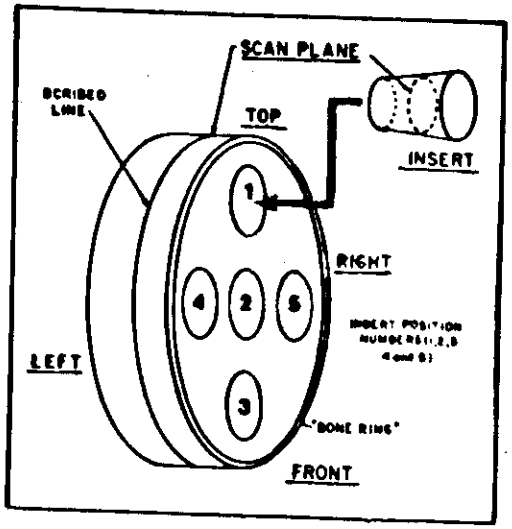


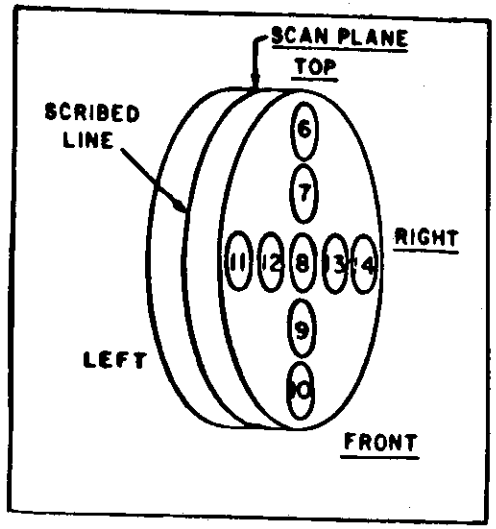
Fig 2

1. SCANNER
2. PATIENT TABLE
3. GENERATOR
4. COMPUTER
5. VIEWING AND CONTROL CONSOLLE
6. HIGH CAPACITY DISK UNIT
7. TAPE UNIT
8. FLOPPY DISK
9. MULTIFORMAT (HARD-COPY)

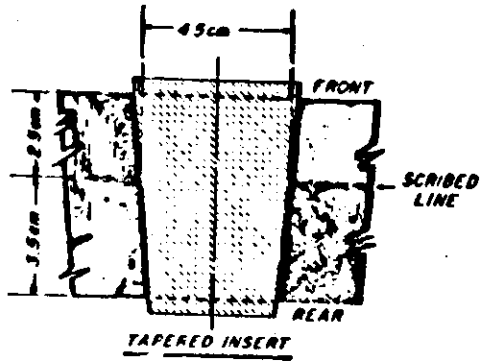
RMI HEAD/BODY PHANTOM 2



Head Phantom configuration.



Body Phantom Configuration.



HOUNSFIELD SCALE

CT ALLOWS ONE TO RELATE THE NUMERICAL VALUES OF THE PIXELS OF THE IMAGE TO THE CHARACTERISTICS OF THE TISSUE EXAMINED.

TO ALLOW A COMPARISON OF THE LINEAR ATTENUATION COEFFICIENTS RELATED TO THE NUMERICAL VALUES OF THE IMAGE THEY ARE NORMALIZED ACCORDING TO A SCALE (**HOUNSFIELD SCALE**) WHERE THE H_2O VALUE IS ZERO.

EACH MATERIAL (OR BIOLOGICAL TISSUE) IS CHARACTERIZED BY A NUMBER (**CT NUMBER**) DEFINED BY THE FOLLOWING RELATIONSHIP:

$$\text{CT NUMBER} = 1000 \cdot \frac{\mu_x - \mu_{H_2O}}{\mu_{H_2O}}$$

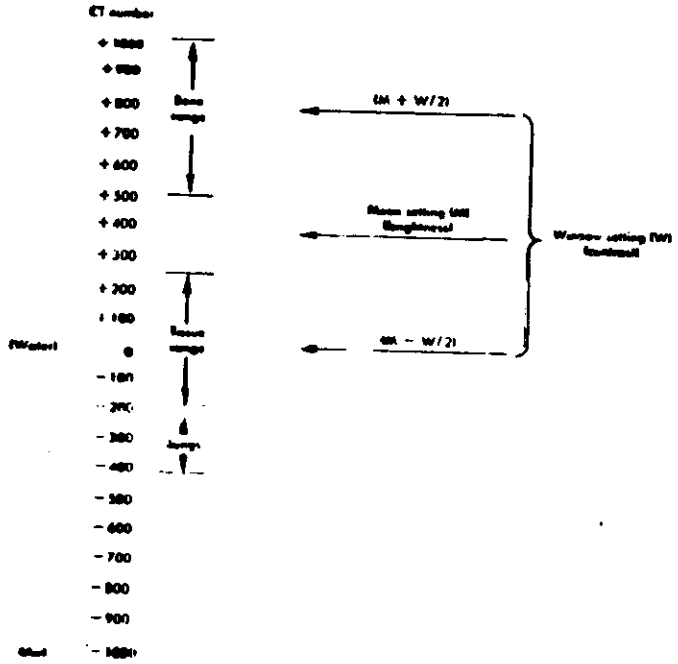
WHERE:

μ_x IS THE LINEAR ATTENUATION COEFFICIENT OF THE MATERIAL

AND

μ_{H_2O} IS THAT OF WATER

CT NUMBERS



THE VISUAL ANALYSIS OF THE IMAGE OBTAINED FROM A CT SCAN IS BASED ON THE ASSIGNMENT OF DIFFERENT GREY LEVELS TO THE CT VALUES.

THE HIGHER THE ATTENUATION OF THE X RAY BEAM, THE HIGHER WILL BE THE CT NUMBER AND THE ASSOCIATED GREY LEVEL.

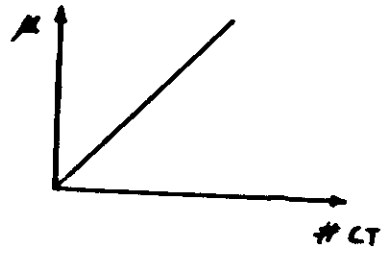
MAIN PARAMETERS RELATED TO THE IMAGE QUALITY

1. CONTRAST SCALE
2. SPATIAL UNIFORMITY
3. CT NUMBER LINEARITY
4. NOISE
5. SPATIAL RESOLUTION
6. CONTRAST RESOLUTION
7. SLICE THIKNESS
8. DOSE

1. CONTRAST SCALE

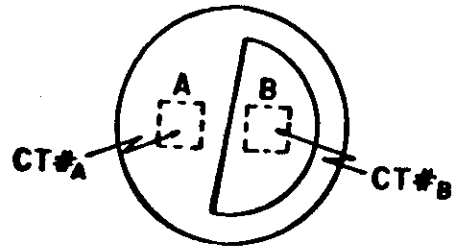
$$CS = \frac{\Delta \mu}{\Delta CT}$$

IS THE SLOPE OF THE STRAIGHT LINE REPRESENTING THE LINEAR ATTENUATION COEFFICIENT μ AS A FUNCTION OF CT NUMBERS.



$$CS = \frac{\mu(B) - \mu(A)}{CT\#(B) - CT\#(A)}$$

THIS SLOPE IS DETERMINED EXPERIMENTALLY BY SCANNING TWO MATERIALS HAVING KNOWN μ VALUES.



AREAS OF INTEREST TO MEASURE

CT SCALE FACTOR

$$CT\,\#\text{ OF SUBSTANCE } x = \frac{\mu(x) - \mu(H_2O)}{\mu(H_2O)} \cdot \text{CT SCALE FACTOR}$$

THE NOMINAL VALUE OF THE CT SCALE FACTOR IS 1000 IN HOUNSFIELD UNIT.

IT'S IMPORTANT TO CALCULATE THE ACTUAL VALUE OF CT SCALE FACTOR IN EACH CT SYSTEM.

IT FOLLOWS FROM THE RELATIONSHIP:

$$\text{CT SCALE FACTOR} = \frac{CT\#(B) - CT\#(A)}{\Delta\mu \,/\, \mu_{H_2O}}$$

WHERE $\Delta\mu = \mu(B) - \mu(A)$

2. SPATIAL UNIFORMITY

IS THE ABILITY OF THE SYSTEM OF PROVIDING, FOR A GIVEN OBJECT, THE SAME LINEAR ATTENUATION VALUE IRRESPECTIVE OF THE POSITION OCCUPIED BY IT ON THE SCAN PLANE.

IT IS DEFINED AS FOLLOWS:

$$SU = \frac{CT_{MAX} - CT_{MIN}}{\text{CT SCALE FACTOR}}$$

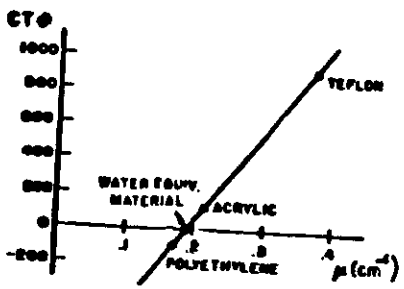
WHERE:

CT_{MAX}, CT_{MIN} = MAXIMUM AND MINIMUM VALUES OF THE CT NUMBERS, AS CALCULATED OVER REGIONS OF INTEREST (AT LEAST 25 PIXELS) LOCATED AT THE CENTER AND ON THE BORDER OF THE IMAGE OF THE PHANTOM.

SPATIAL UNIFORMITY IS DETERMINED EXPERIMENTALLY USING THE PLAIN INSERT OF THE RMI PHANTOM OR USING A PHANTOM FILLED WITH DISTILLED WATER.

3. CT NUMBER LINEARITY 9

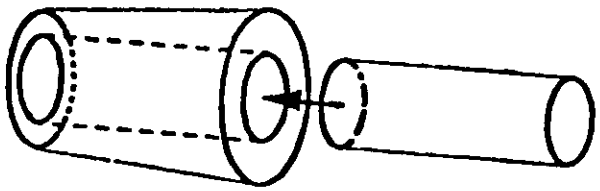
IT EXPRESSES THE LINEARITY OF THE RELATION BETWEEN CT NUMBERS AND LINEAR ATTENUATION COEFFICIENT.



IN AN IDEAL SYSTEM THIS RELATION IS LINEAR AND IS OBTAINED DIRECTLY FROM THE DEFINITION OF CT NUMBERS.

THE LINEARITY IS DETERMINED BY SCANNING MATERIALS WHOSE μ VALUES ARE KNOWN AND DISTRIBUTED OVER A WIDE RANGE, AND BY PLOTTING CT VALUES VERSUS μ VALUES.

THE LEAST SQUARES METHOD ALLOWS ONE TO EVALUATE THE INTERPOLATING STRAIGHT LINE.

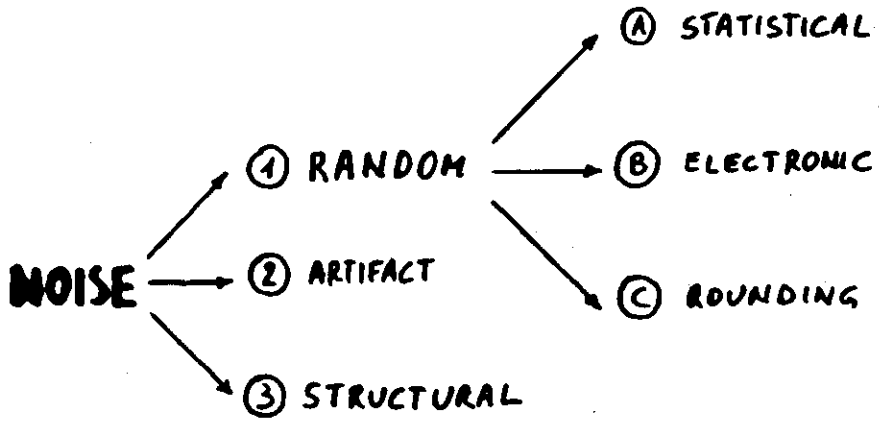


LINEARITY INSERT ROD OF KNOWN μ

4. NOISE 10

IT IS THE MAIN FACTOR LIMITING THE CONTRAST RESOLUTION.

IT RESULT FROM MANY DIFFERENT FEATURES OF THE SYSTEM.



① RANDOM NOISE

NOISE 1

(11)

(A) STATISTICAL (OR QUANTUM) NOISE

DUE TO THE DISCRETE NUMBER OF X PHOTONS CAPTURED BY THE DETECTORS.
STATISTICAL NOISE IS THE MAIN LIMITING FACTOR IN A CT SYSTEM ; IT POSES MINIMUM LIMITS TO THE X-RAY DOSES THAT CAN BE RADIATED TO THE PATIENT TO OBTAIN IMAGES OF SATISFACTORY QUALITY.
THEREFORE, HIGH DOSES ARE REQUIRED TO OBTAIN LAW QUANTUM NOISE IMAGES.

(B) ELECTRONIC NOISE

IT DEPENDS ON THE S/N RATIO OF THE CIRCUIT ELEMENTS AND ON THE NOISE OF THE A/D CONVERSION CIRCUITS.

(C) ROUNDING NOISE

IT DEPENDS ON THE FINITE NUMBER OF SIGNIFICANT FIGURES USED BY THE PROCESSING SYSTEM WHERE THE ALGORITHM OF IMAGE RECONSTRUCTION IS IMPLEMENTED.

② STATISTICAL NOISE

IT DEPENDS ON THE FEATURES OF THE RECONSTRUCTION ALGORITHM AND RESULTS IN THE PRESENCE OF A PATTERN OF WELL DEFINED STRUCTURE SUPERIMPOSED TO THE IMAGE.
EXAMPLE : "STAR" ARTIFACTS DUE TO POOR CORRECTION OF BACK PROJECTION ALGORITHM WHERE HIGH-DENSITY STRUCTURES ARE PRESENT ; BONES, METAL PROSTHESIS, ETC

③ STRUCTURAL NOISE

VARIATION IN THE MEAN CT NUMBERS OVER WIDE REGIONS OF THE IMAGE, DUE TO THE INFLUENCE OF STRUCTURES ON PLANES CONTIGUES TO THAT CONSIDERED OR TO THE RANDOM MICROINHOMOGENIES OF THE MEDIUM EXPLORED.

EXPERIMENTAL DETERMINATION OF NOISE

NOISE CAN BE EXPRESSED AS THE STANDARD DEVIATION OF THE CT NUMBERS OF A LARGE REGION OF INTEREST.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (CT\#(i) - \overline{CT\#})^2}{N - 1}}$$

THE TEST FOR CT IMAGE NOISE CAN BE DONE SIMULTANEOUSLY WITH THE SPATIAL UNIFORMITY TEST, USING THE SAME SCAN IMAGE.

NOISE CAN ALSO BE EXPRESSED AS:

$$\text{NOISE} = \frac{\sigma}{\text{CT SCALE FACTOR}} \times 100\ \%$$

SPATIAL RESOLUTION

IT IS THE MINIMUM DISTANCE REQUIRED FOR TWO OBJECTS OF HIGH CONTRAST TO BE DISTINGUISHED AS SEPARATED FROM EACH OTHER.

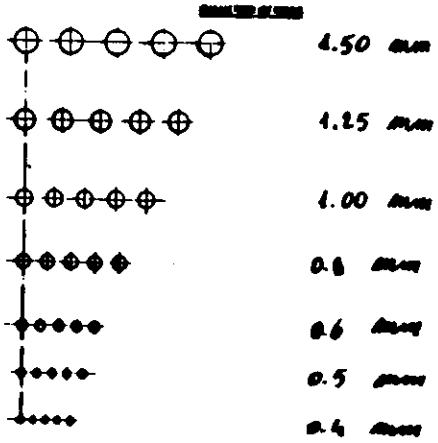
GEOMETRIC FACTORS AFFECTING SPATIAL RESOLUTION:

- FOCAL SPOT AMPLITUDE
- APERTURE OF EACH DETECTOR
- SPACING BETWEEN DETECTORS
- DISTANCE BETWEEN X-RAY TUBE AND OBJECT
- DISTANCE BETWEEN X-RAY TUBE AND DETECTORS

OTHER FACTORS:

- RECONSTRUCTION ALGORITHMS
- DISPLAY PARAMETERS

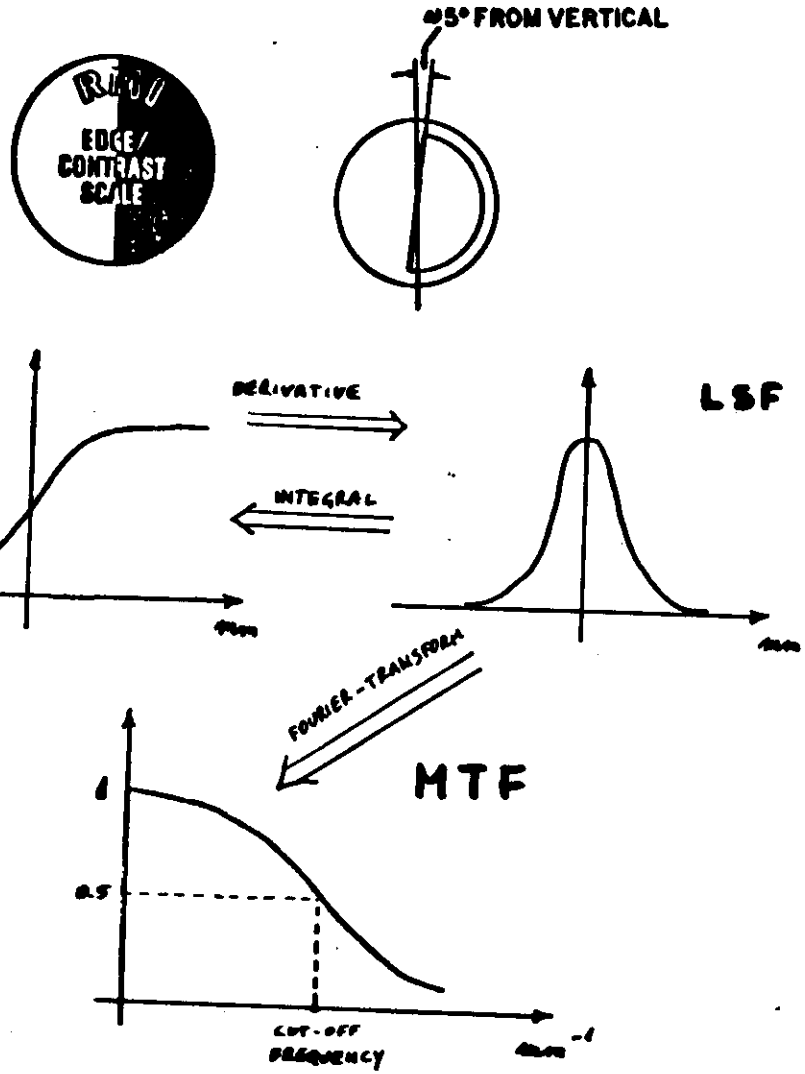
HIGH CONTRAST RESOLUTION 15 TEST



IN THIS TEST A ROW OF RODS MAY BE CONSIDERED RESOLVED IF ALL FIVE RODS CAN BE PERCEIVED WITH SOME DISCERNIBLE SPACING OF LOWERING OF DENSITY BETWEEN THEM.

FIXED PROTOCOL IS RECOMMENDED.

MODULATION TRANSFER FUNCTION (MTF)



SPATIAL RESOLUTION CAN BE EXPRESSED AS THE FREQUENCY AT WHICH MTF IS THE 50 % OF ITS MAXIMUM VALUE.

6. CONTRAST RESOLUTION 17

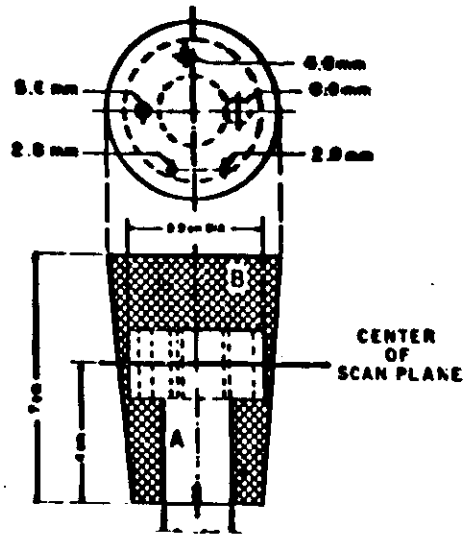
IT IS THE MINIMUM DIFFERENCE IN ATTENUATION COEFFICIENT DETECTABLE FOR OBJECT OF PRE-FIXED DIAMETER.

IT DEPENDS ON :

1. SIZE OF THE LOW-CONTRAST OBJECT
2. IMAGE NOISE
3. DISPLAY PARAMETERS (LEVEL, WINDOW WIDTH, AND SO ON)

IT CAN BE EXPRESSED AS THE MINIMUM DIAMETER DETECTABLE FROM THE IMAGE OF THE RMI LOW CONTRAST INSERT.

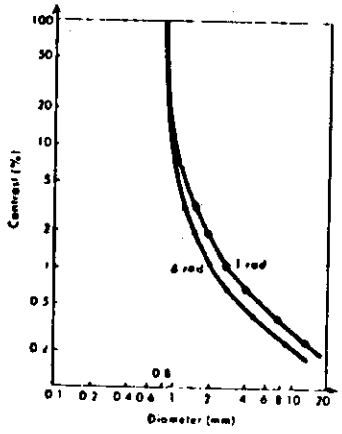
FIXED PROTOCOL IS RECOMMENDED.

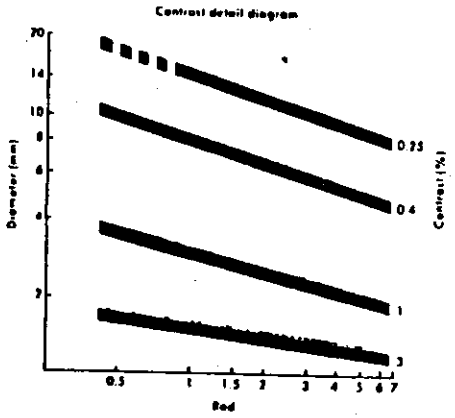


A
013A
$\Delta\mu = 0.6\%$

B
013A
$\Delta\mu = 0.5\%$

CONTRAST DETAIL CURVE 17 b

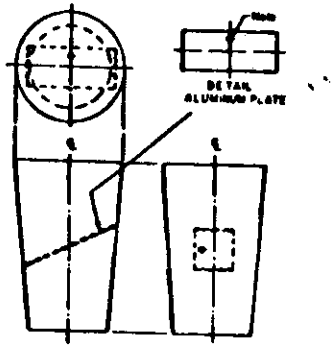




REPRESENT CONTRAST RESOLUTION AS A FUNCTION OF :

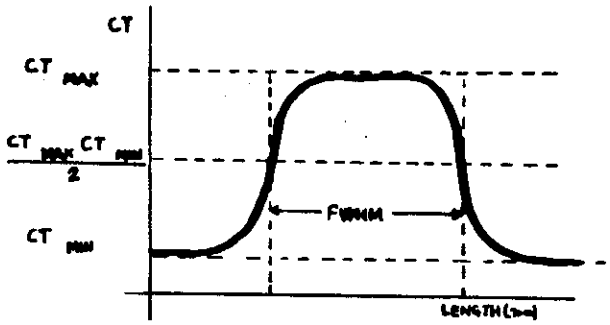
- % OF CONTRAST
- OBJECT SIZE
- DOSE

7. SLICE THIKNESS



ACTUAL THIKNESS CAN DIFFER FROM NOMINAL.

ALUMINIUM RAMP INSERT ALLOWS A DIRECT DETERMINATION OF THE SLICE WIDTH AS THE FULL WIDTH HALF MAXIMUM (FWHM) OF THE SENSITIVITY PROFILE.



8. RADIATION DOSE

IT IS THE ENERGY ABSORBED PER MASS UNIT DUE TO X-RAY RADIATION.

IT IS OF PRACTICAL INTEREST TO DETERMINE

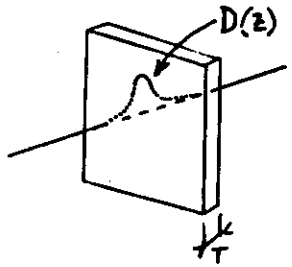
a) THE SURFACE MAXIMUM DOSE:
THE DOSE AT THE SURFACE OF THE BODY (IN DIAGNOSTIC APPLICATION: SKIN)

b) THE MAXIMUM DOSE AT THE ROTATION AXIS:
DOSE INSIDE THE BODY CORRESPONDING TO THE ROTATION AXIS OF THE SYSTEM TUBE–DETECTORS.

c) CTDI (CT DOSE INDEX)

$$CTDI = \frac{1}{T} \int D(z)\, dz$$

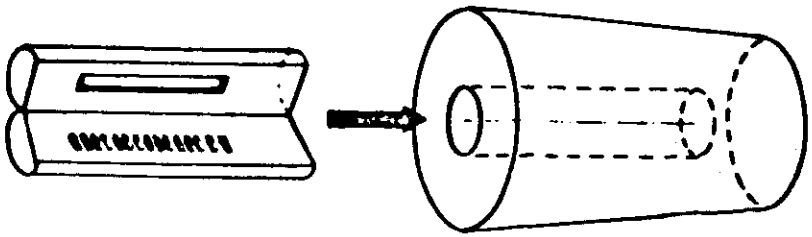
WHERE:



$D(z)$ = POINT DOSE ALONG Z AXIS

T = NOMINAL THIKNESS OF THE SLICE

EXPOSURE MEASUREMENT 20



DOSE INSERT

RMI SUGGESTS THE USE OF THE DOSE-INSERT FOR DOSIMETRY MEAUSERMENT.

THIS INSERT CAN ACCEPT A HOLDER THAT CAN BE LOADED WITH 15 TLD CHIPS (FOR EXAMPLE Li F) TO COVER A 40 MM WIDTH.

THE CENTER TO CENTER SEPARATION BETWEEN THE TLD CHIPS RANGE FROM 2 MM (IN THE CENTER) TO 4 MM (ON THE BORDER).

THE VALUES OBTAINED FROM THE TLD ALLOWS ONE TO PLOT A CURVE GIVING THE DOSE PROFILE ALONG Z AXIS.