INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4-SMR 471/20

COLLEGE ON MEDICAL PHYSICS

10 - 28 SEPTEMBER 1990

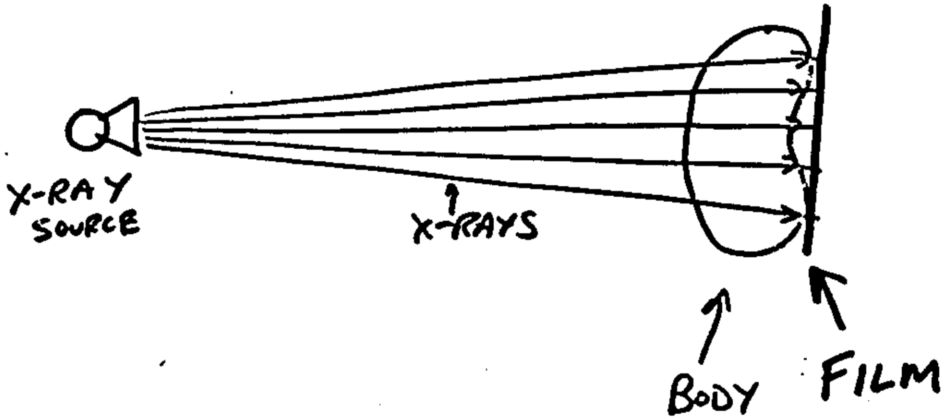
COMPUTED TOMOGRAPHY

J. R. Cameron

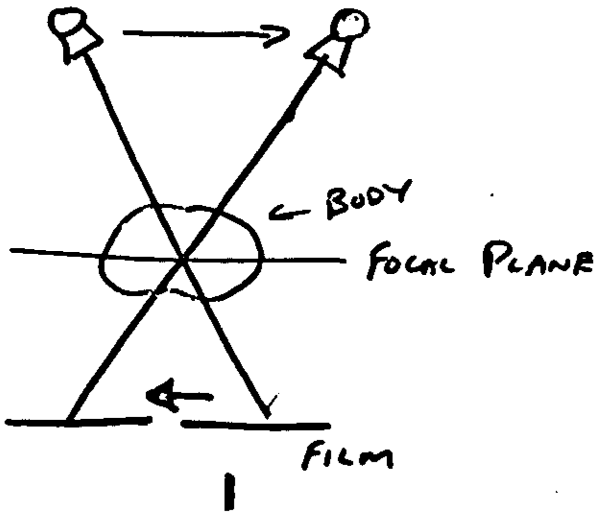
University of Wisconsin
Wisconsin
USA

COMPUTED TOMOGRAPHY

CONVENTIONAL RADIOGRAPHY (ROENTGEN 1895)

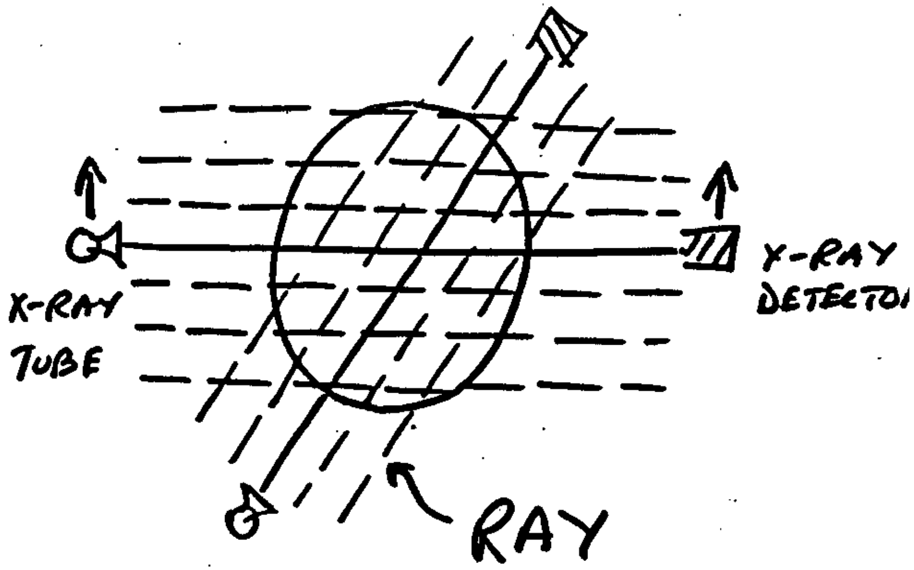


CONVENTIAL TOMOGRAPHY (1922)



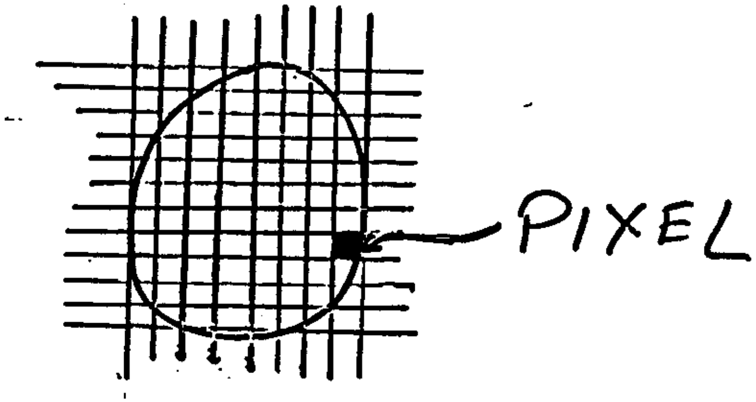
COMPUTED TOMOGRAPHY (1972

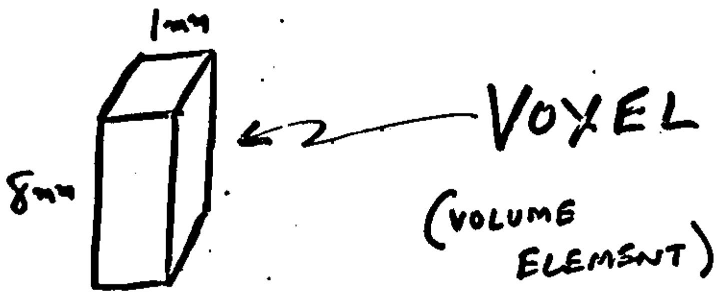
EMI HEAD SCANNER



VIEW: COMPLETE SET OF PARALLEL RAYS AT A PARTICULAR ANGL

C.T. PICTURE





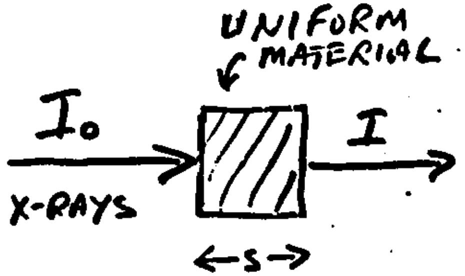
IN THE FINAL IMAGE EACH PIXEL IS GIVEN A NUMBER

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?

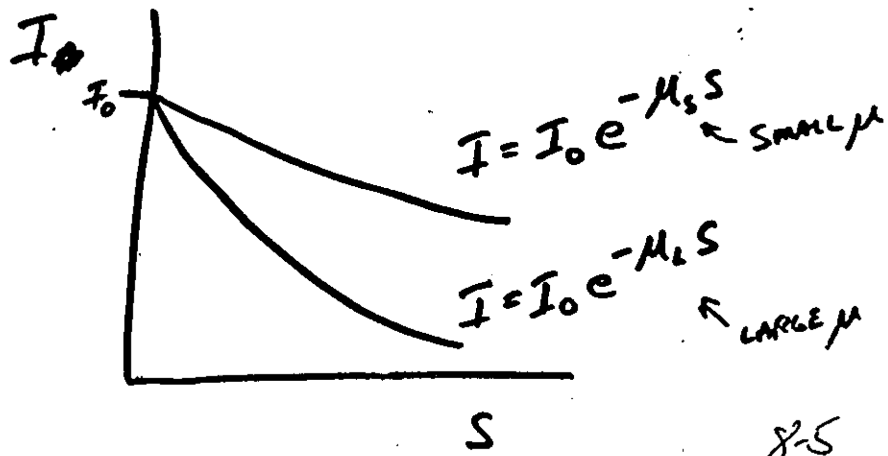
WHAT PROPERTY ARE THE X-RAYS MEASURING?

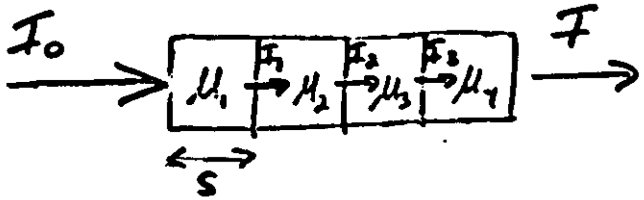
— LINEAR ATTENUATION COEFFICIENT —



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

↑ X-RAY INTENSITY





$$I_1 = I_0 e^{-\mu_1 s}$$

$$I_2 = I_1 e^{-\mu_2 s}$$

$$I_3 = I_2 e^{-\mu_3 s}$$

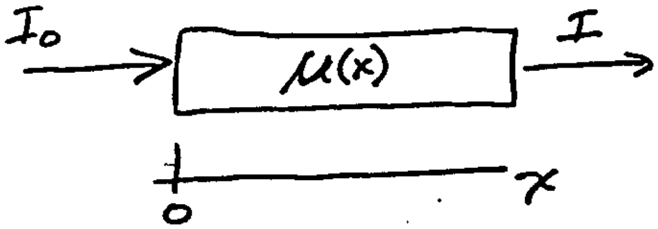
$$I = I_3 e^{-\mu_4 s}$$

$$I = I_0 e^{-\mu_1 s} \cdot e^{-\mu_2 s} \cdot e^{-\mu_3 s} \cdot e^{-\mu_4 s}$$

$$I = I_0 e^{-(\mu_1 + \mu_2 + \mu_3 + \mu_4) s}$$

$$\frac{I}{I_0} = e^{-(\mu_1 + \mu_2 + \mu_3 + \mu_4) s}$$

$$\boxed{\log_e \frac{I_0}{I} = (\mu_1 + \mu_2 + \mu_3 + \mu_4) s}$$



$$I = I_0 e^{-\int \mu(x)\,dx}$$

$$\frac{I}{I_0} = e^{-\int \mu(x)\,dx}$$

$$\boxed{\log_e \frac{I_0}{I} = \int \mu(x)\,dx}$$

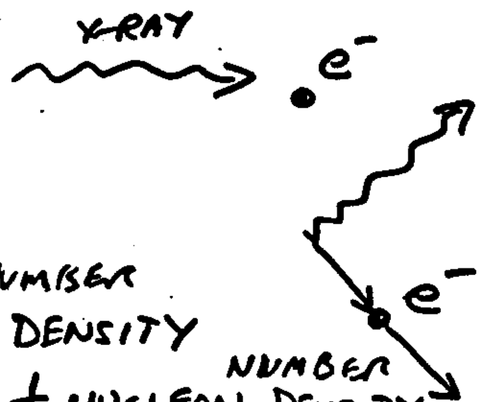
μ DEPENDS ON THE ENERGY OF THE X-RAYS (KVp)

AS ENERGY ↑ μ ↓

IS μ RELATED SIMPLY TO PHYSICAL DENSITY?

PRINCIPLY, 2 KINDS OF INTERACTIONS CAUSE THE X-RAY ATTENUATION:

COMPTON SCATTERING

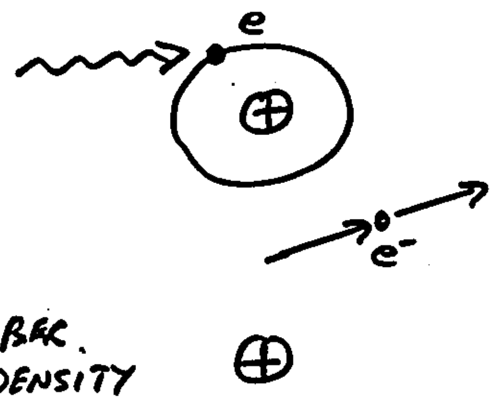


$\mu_{C.S} \propto$ ELECTRON NUMBER DENSITY

$\approx \frac{1}{2}$ NUCLEON NUMBER DENSITY

$\mu_{C.S} \propto$ TOTAL MASS DENSITY gm/cm^3 (APPROXIMATELY)

PHOTO ELECTRIC ABSORPTION



$\mu_{P.E} \propto Z^3 \cdot$ ELECTRON NUMBER DENSITY

THEREFORE $\mu = \mu_{CS} + \mu_{P.E}$ DEPENDS ON BOTH PHYSICAL DENSITY AND ON Z

ENERGY DEPENDANCE

IMAGE DISPLAY

160×160 256×256 MATRIX
320×320 512×512

EACH PIXEL OF THIS MATRIX IS ASSIGNED A NUMBER DERIVED FROM THE COMPUTED VALUE OF THE LINEAR ATTENUATION COEFFICIENT AVERAGED OVER THE VOXEL.

HOUNSFIELD SCALE

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

CAUTION! SOME OLDER SCANNERS USE 500

$H_2O \rightarrow CT\# = 0$

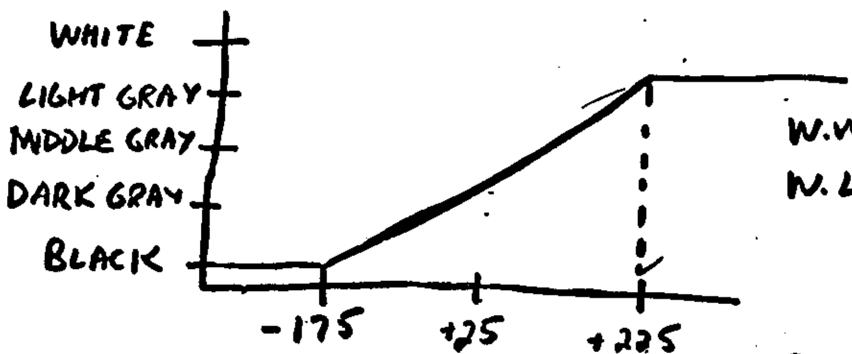
AIR $\rightarrow CT\# = -1000$

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

$1\% = 10$ CT#'s

DISPLAY ADJUSTMENTS

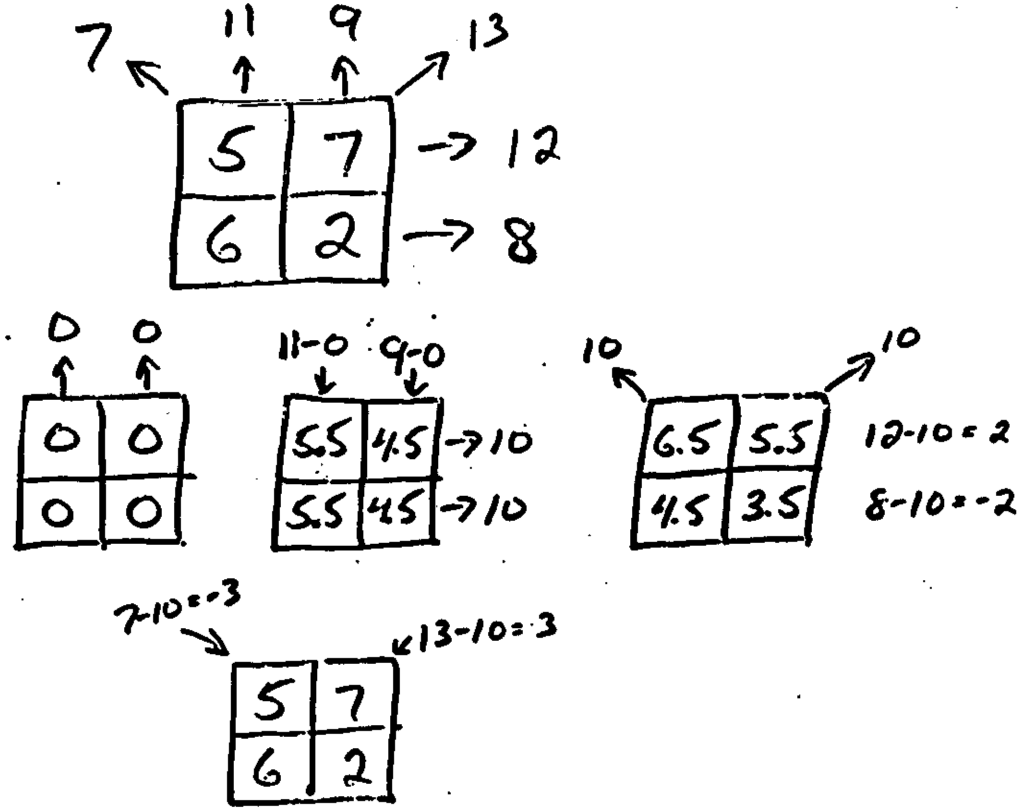
- WINDOW WIDTH – RANGE OF NUMBERS FROM WHITE TO BLACK
- WINDOW LEVEL – CT# DISPLAYED AS MIDDLE GRAY



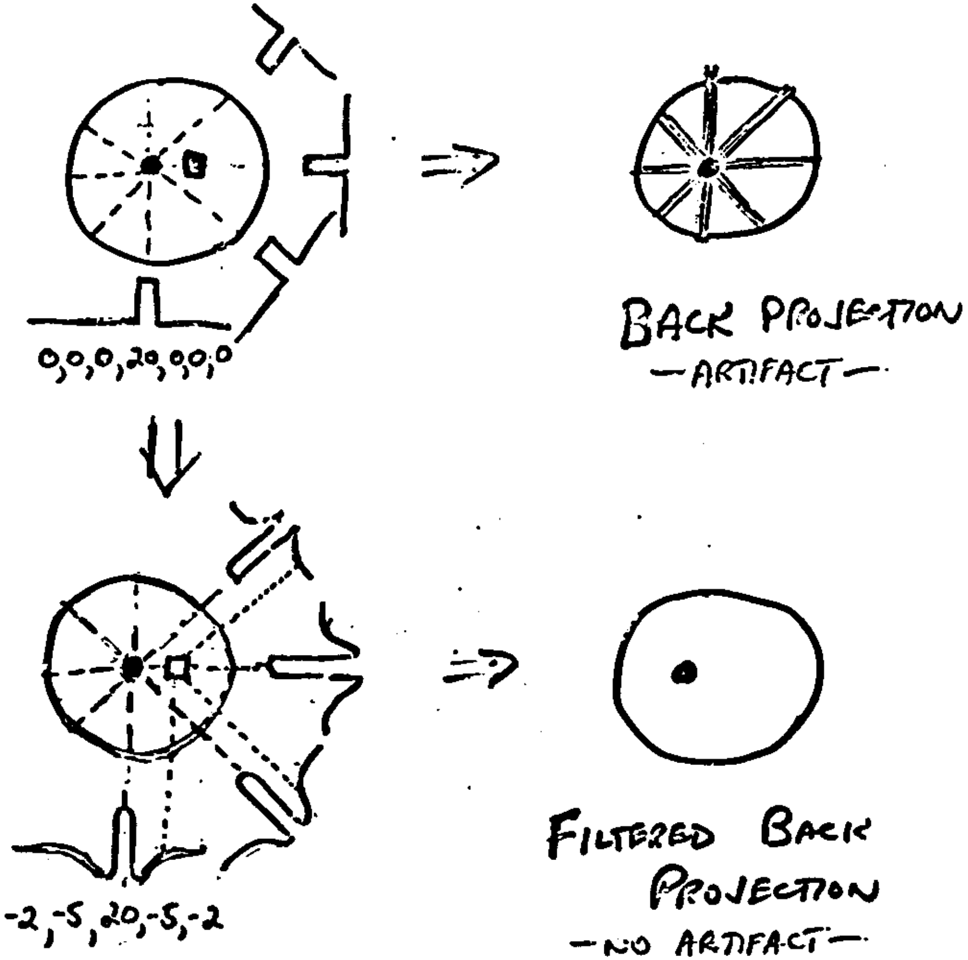
W.W = 400
W.L = +25

METHODS OF IMAGE RECONSTRUCTIO

ITERATIVE TECHNIQUE

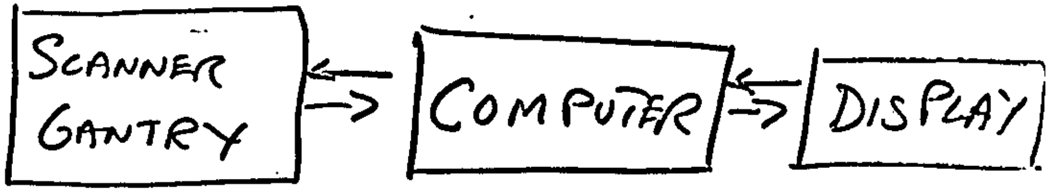


BACK PROJECTION



LL C.T. SCANNERS USE FILTERED BACK PROJECTION TO DO THE IMAGE RECONSTRUCTION

CT SCANNER



- X-RAY SOURCE
- DETECTOR
- DETECTOR ELECTRONICS
  - DATA AQUISITION
  - CORRELATION W. MECHANICAL MOTION
- MECHANICAL MOTION WITH PRECISE ALIGNMENT

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

- CONTROL CONSOLE
- IMAGE DISPLAY
- IMAGE DOCUMENTATION

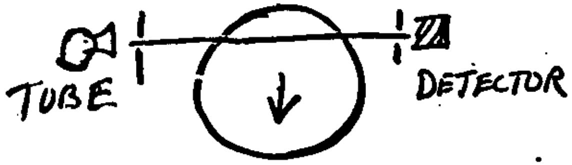
PATIENT TABLE
+ TABLE CONTROLS
SLICE LOCALIZATION

SCANNER TYPES

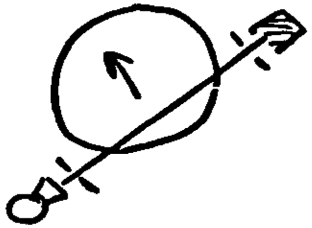
FIRST GENERATION:

TRANSLATE - ROTATE
PENCIL - BEAM
DUAL - SLICE

EMI



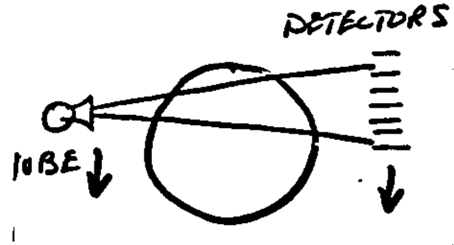
THEN ROTATE



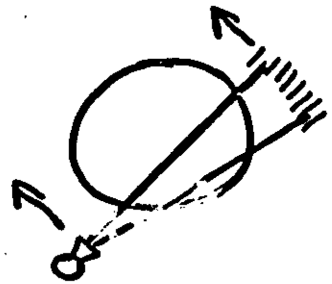
SECOND GENERATION

TRANSLATE - ROTATE
MULTIPLE DETECTORS

EMI



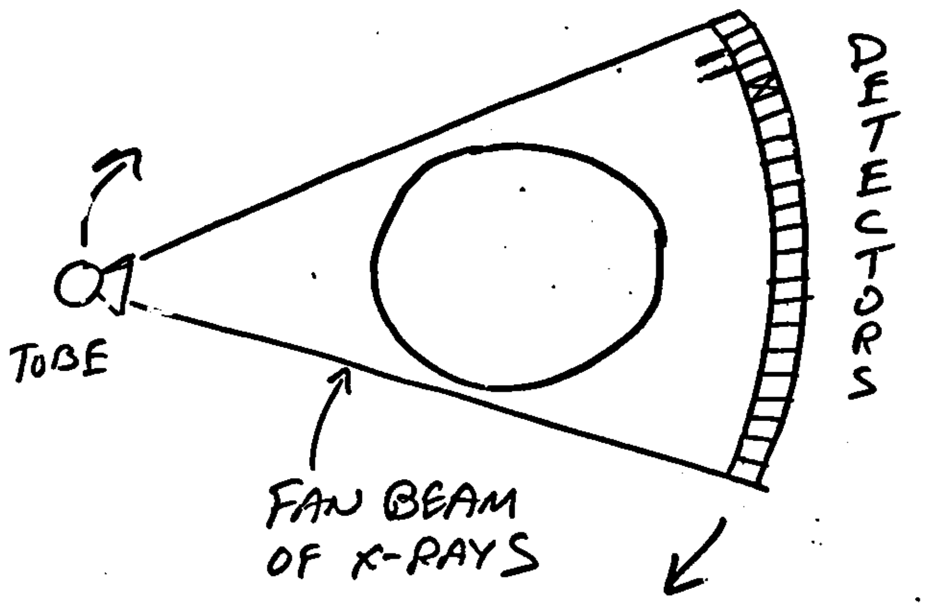
THEN ROTATE



THIRD GENERATION

ROTATING FAN BEAM
AND DETECTORS

GE; SIEMENS; PHILLIPS



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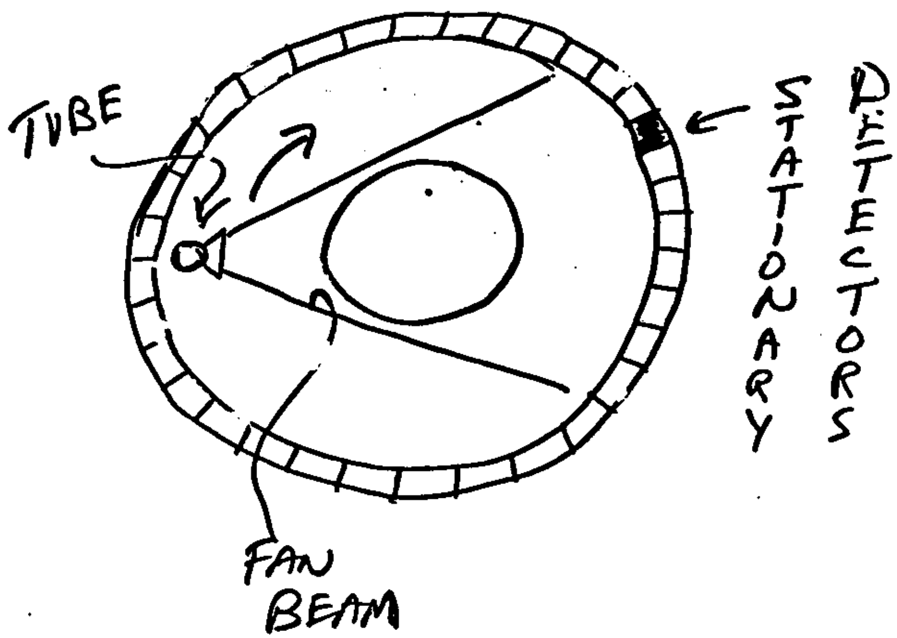
FOURTH GENERATION

ROTATING FAN BEAM
STATIONARY DETECTORS

PICKER, TECHNICARE, EMI



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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 (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.

OTHER ADVANTAGES OF NEWER SCANNERS:
FASTER RECONSTRUCTION, NARROWER SLICES,

8-18

CT SCANNER PERFORMANC

A. SCANNER COMPARISONS

B. ACCEPTANCE TESTING

C. QUALITY ASSURANCE

— IMAGE QUALITY —

— DOSIMETRY —

— PERFORMANCE OF NON-IMAGE COMPONENTS —

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7. SCANNER COMPARISONS

1. SCAN TIME OPTIONS
2. TUBE CAPACITY - X-RAY OUTPUT UTILIZATION → PROCEEDURE REPETITION RATE.
3. RECONSTRUCTION TIME + OPTIONS
4. COMPUTER STORAGE CAPACITY
5. COMPUTER/OPERATOR INTERACTIONS
   - EASE + SPEED OF OPERATION
   - OPERATORS CONSOLE / INDEPENDANT VIEWING CONSOLE
6. GANTRY OPENING / TILT
7. PATIENT POSITIONING SYSTEM
   - SLICE POSITION INDICATOR
   - SCOUT VIEW

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)

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

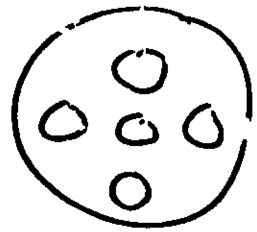
9. IMAGE DISPLAY QUALITY

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

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. 256x256, 512x512
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 POLYETHYLENE 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)

2. Image Sharpness

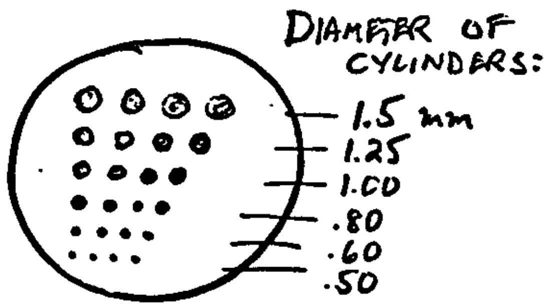
Determined by

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 –

Easy Check of Image Sharpness:

High Contrast Resolution



Air-filled cylinders show 100% contrast to background

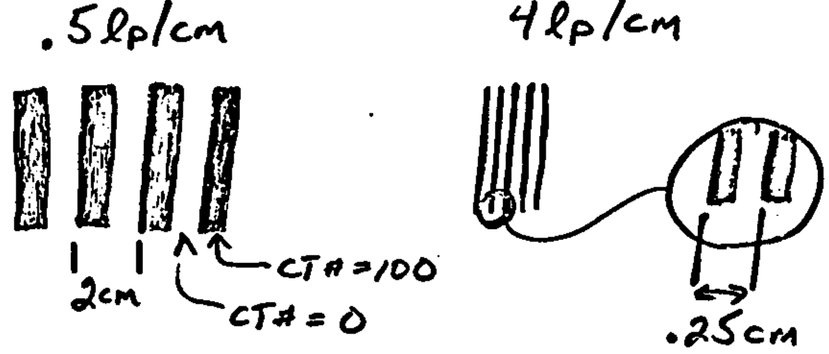
– Scan this phantom and observe the smallest rods which can be resolved.

Complete Check of Image Sharpness:

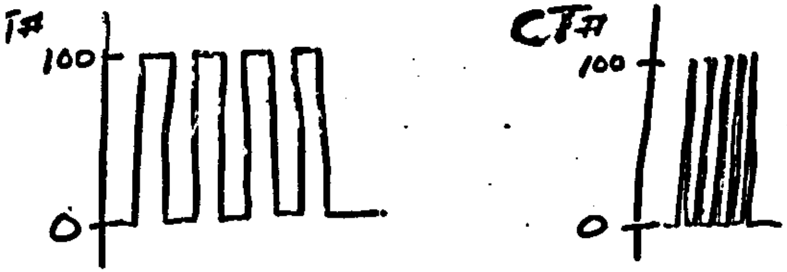
Modulation Transfer Function

– Usually derived from edge response or point respon

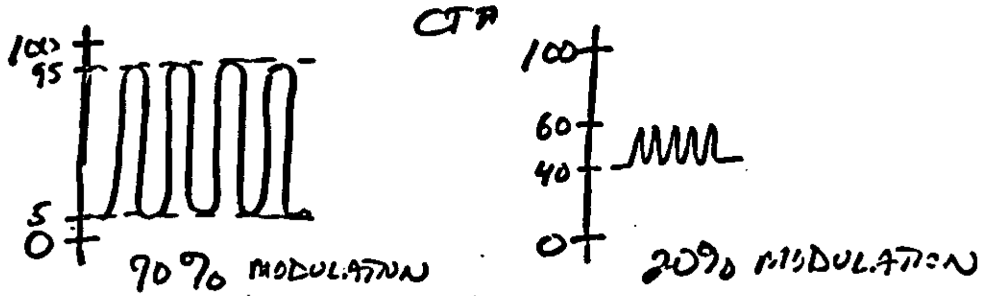
MEANING OF MTF:

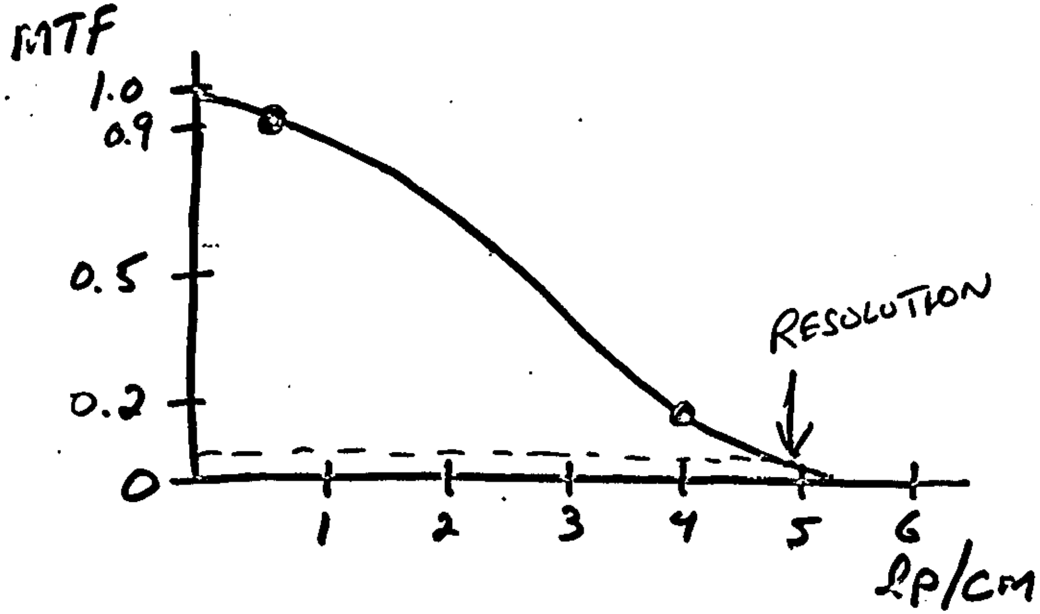


EAL
SPONSE:



ACTUAL
RESPONSE:

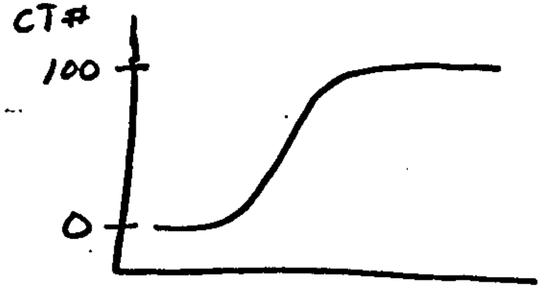




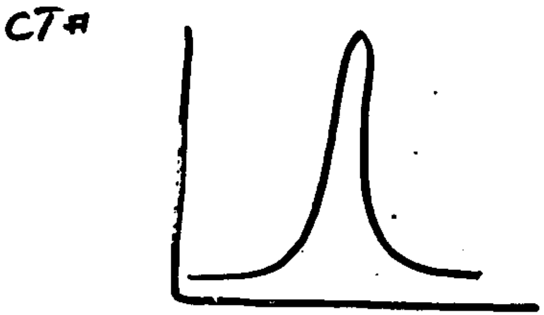
FOR PRACTICAL MEASUREMENT:

IMAGE EDGE OR WIRE:

GET EDGE RESPONSE:



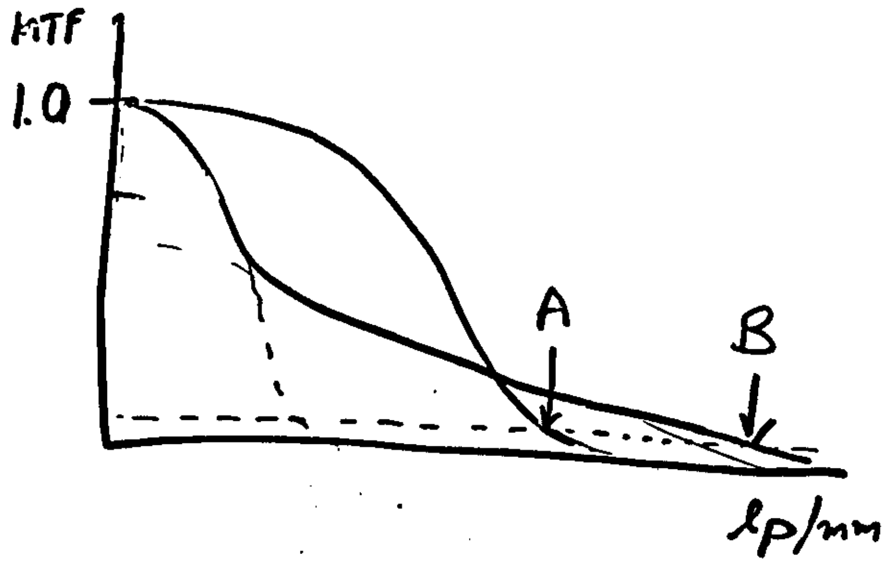
OR POINT RESPONSE:



CAN CALCULATE MTF FROM THESE

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

WHY IS MTF MORE INFORMATION THAN RESOLUTION?



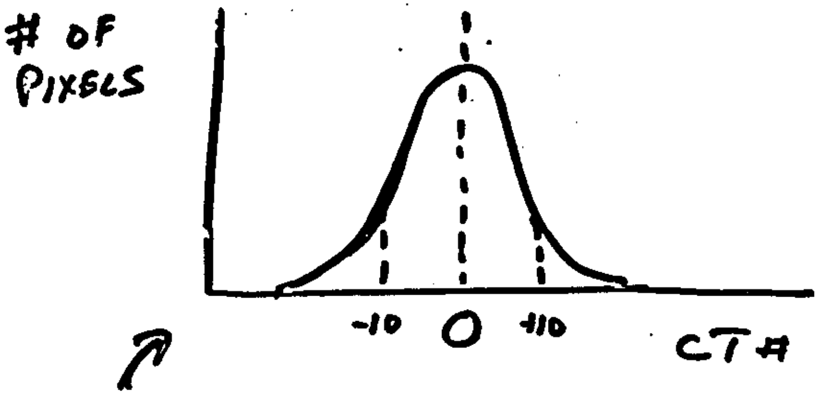
LOW CONTRAST PERFORMANCE

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

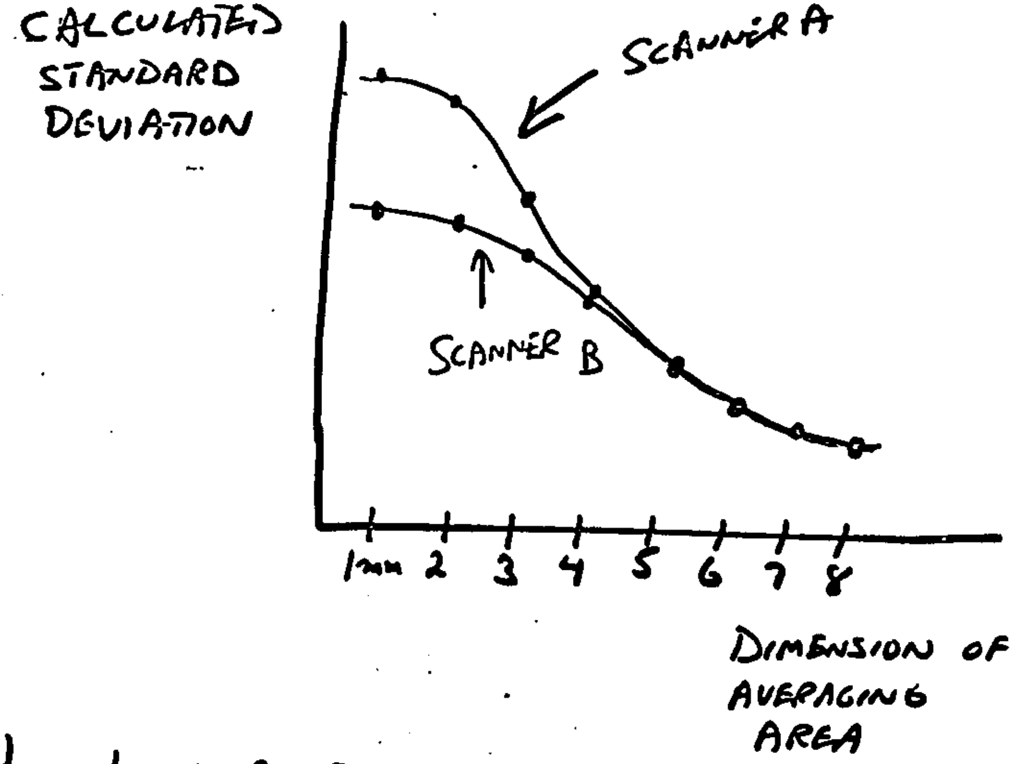
BUT

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

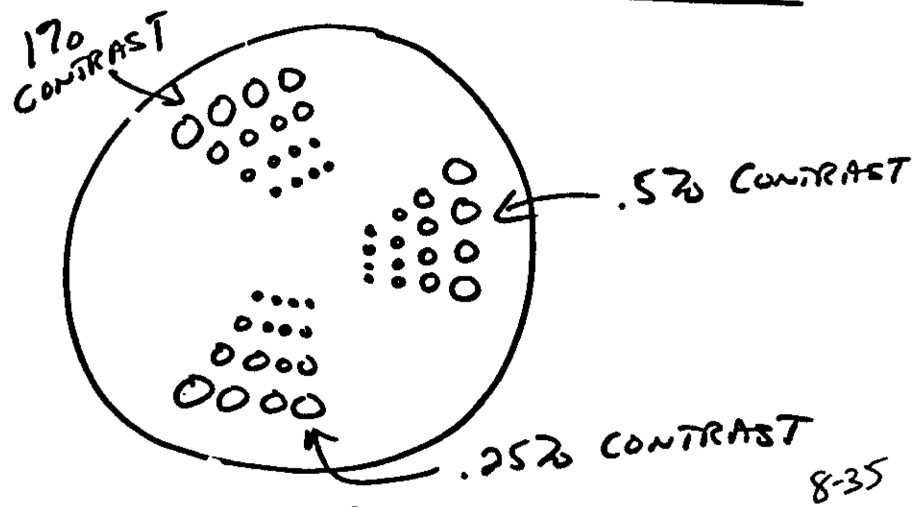
PIXEL NOISE

→ DAILY Q.A.

8-34



b. LOW CONTRAST DETECTABILITY



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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

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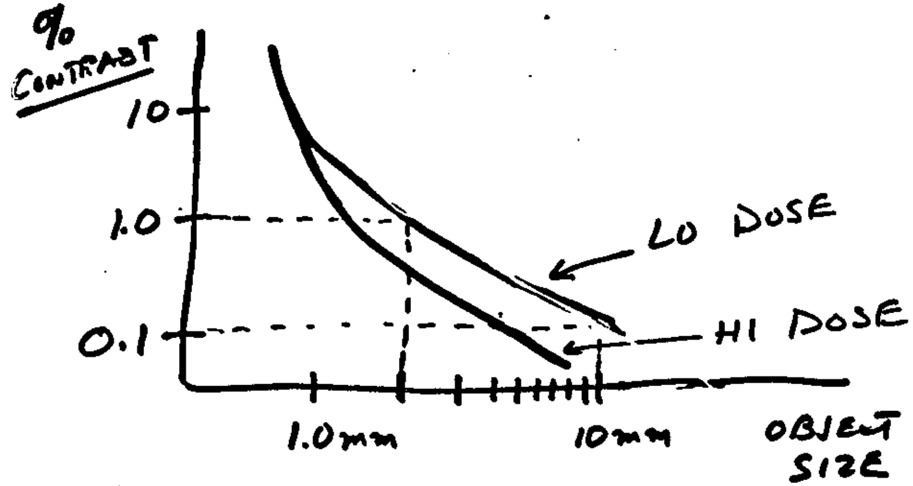
NOTE: LOW CONTRAST DETECTABILITY + PIXEL NOISE ARE BOTH DOSE DEPENDENT

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

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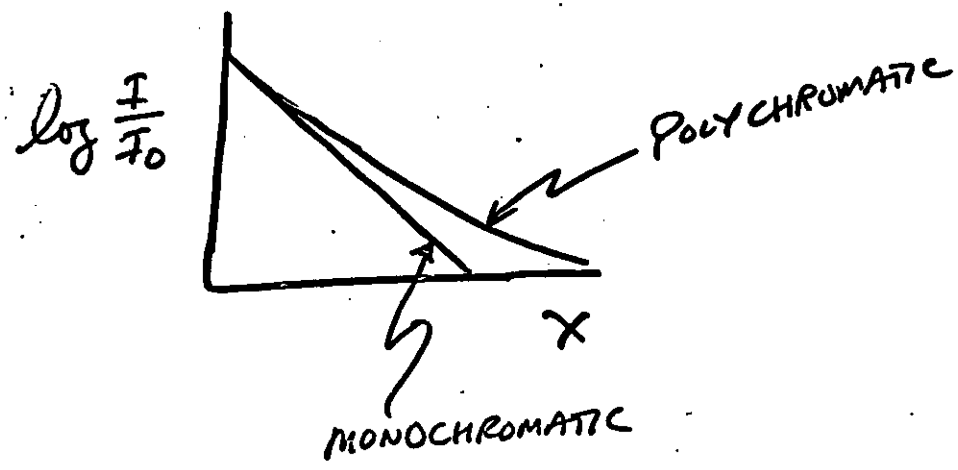
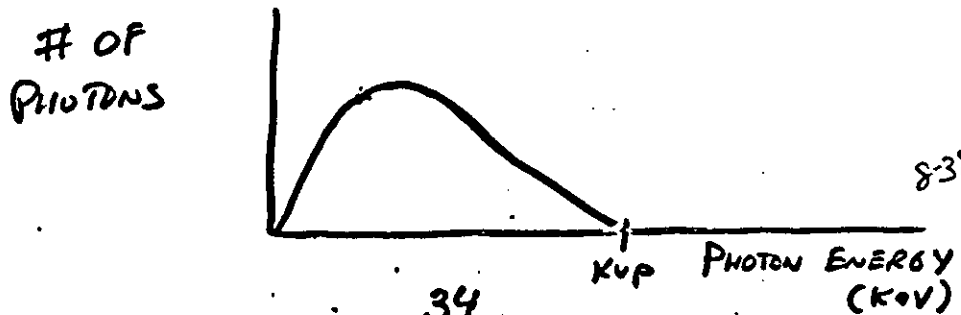
4. ARTIFACTS

A. BEAM HARDENING

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

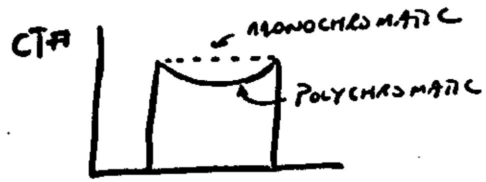
$$\log_e \frac{I}{I_0} = -\mu x$$





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

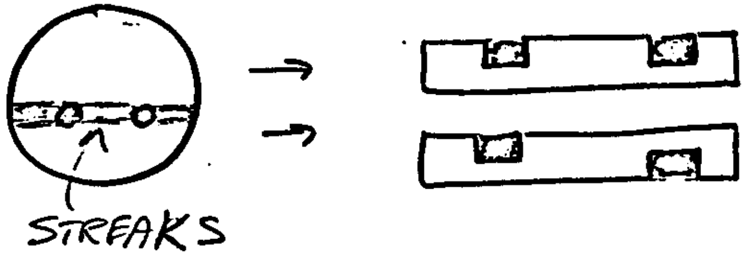
B. INCREASE FILTRATION OF X-RAY BEAM

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.

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"

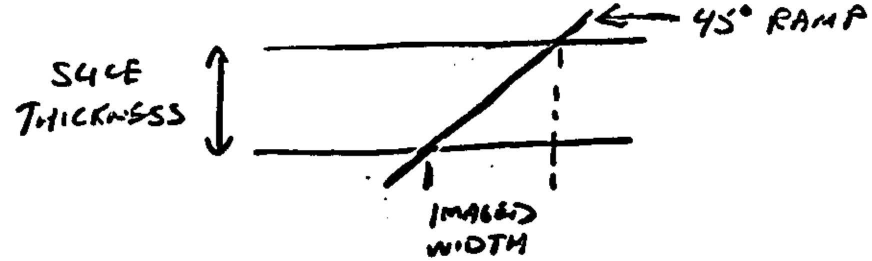
J. SLICE THICKNESS

- SENSITIVITY PROFILE

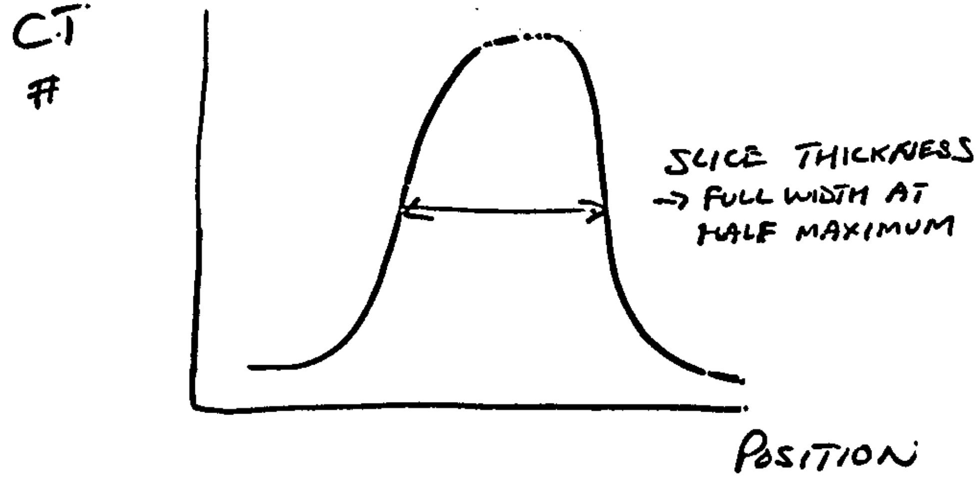
A. HELIX PLUG

B. 45° ALUMINUM RAMP (OR 26.6°)

C. 45° STRING OF BEADS

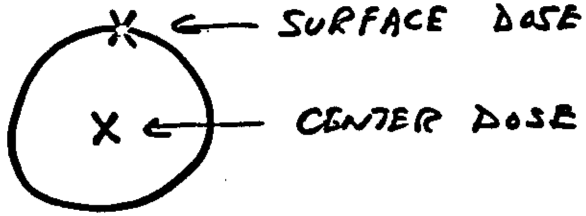


SLICE SENSITIVITY PROFILE (USING 45° RAMP)



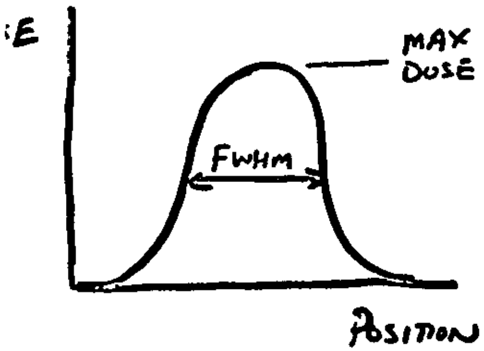
DOSIMETRY

VERY CONFUSING : MANY WAYS OF SPECIFYING DOSE.

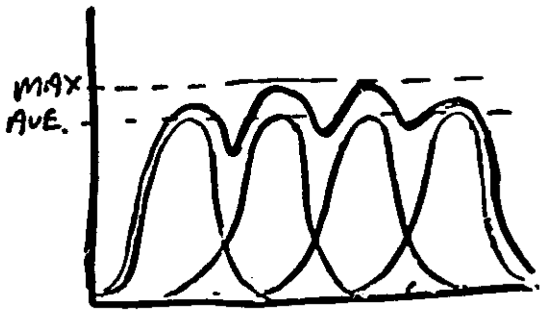


AT WHATEVER POSITION DOSE IS MEASURED THERE EXISTS A DOSE PROFILE ACROSS THE SLICE THICKNESS IRRADIATED

SINGLE SLICE



MULTI - SLICE

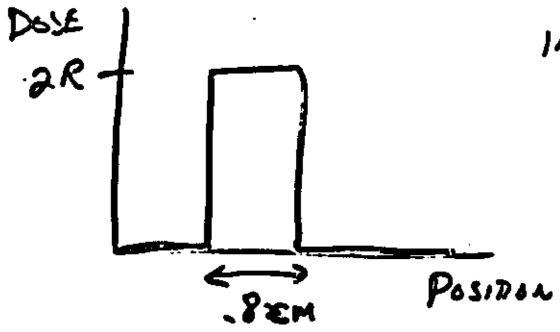


…IFIED: NOM. SLICE WIDTH | NOM. SLICE WIDTH SCAN INCREMENT

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

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 HELIX PLUG OR EQUIV.

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

8-47

Scanning principle

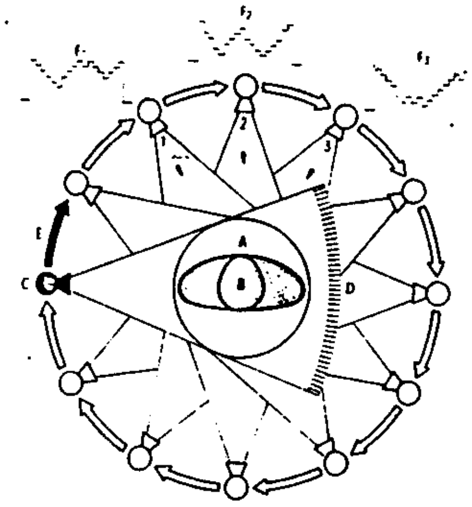


Fig. 8–1: Scanning principle

- A) Gantry aperture, scan field = 530 mm
- B) Patient
- C) OPTI 151 X-ray tube unit
- D) Detector system
- E) Direction of rotation
- $F_1 \ldots F_3$) Individual absorption profiles

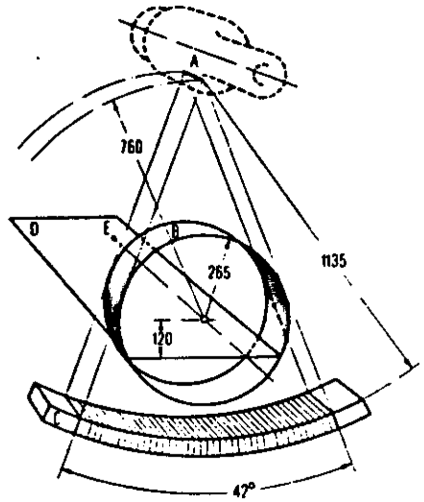
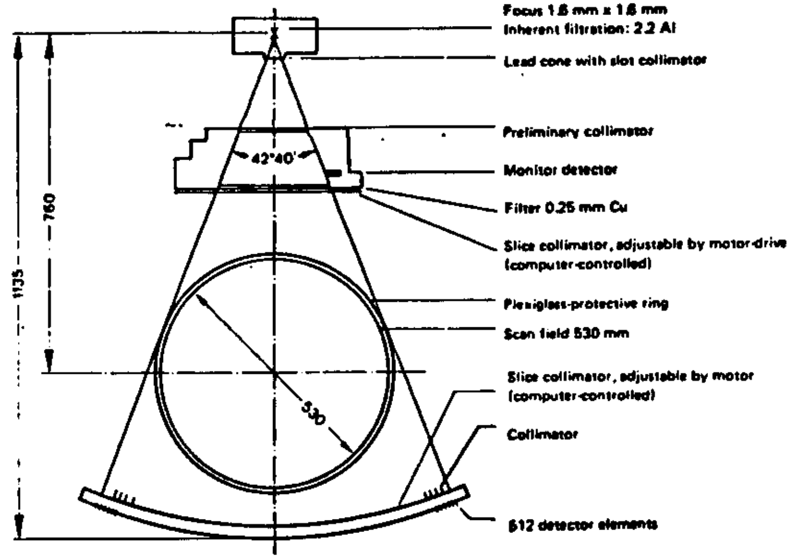


Fig. 8–2: Imaging geometry (lengths/mm) *)

- A) Focal spot
- B) Limitation of the examination region max. 8 mm
- C) Detector system with 512 solid-state detec-detectors
- D) Patient positioning plane
- E) Axis of rotation of the tube unit-detector unit
- *) Schematic view: numerical data are approximate values.

A detector system connected mechanically to the tube rotates continuously around the object to be scanned (Fig. 8–1). The object to be scanned is scanned and projected with a maximum of 1440 X-ray pulses during one scan with a rotation of 360°. The intensity distribution of each projection – the absorption profile – is recorded with the detector system, the 512 individual detectors of which are arranged after one another without any gaps (Fig. 8–2). This permits optimum utilization of the pulsed fan-shaped scan beam which covers the entire cross-section at each projection.

Layout of the tube unit-detector system



The geometric dimensions of the tube unit-detector system are conceived so that with the SOMATOM DR system the entire circular surface (gantry aperture) is covered by the fan beam. In this way all centering problems in patient positioning are avoided since the scan field diameter and the gantry aperture coincide.

The detector elements are distributed on an arc (Fig. 8–3) of 42°. In this way, the entire gantry aperture (530 mm) is covered.

Detector

The SOMATOM DR detector consists of 512 image-forming, independent detector elements in addition, there are 2 reference channels close to the tube. Each of the 512 detector elements is associated with its own integrator which sums the scan signal over the duration of the X-ray radiation pulse. These measured values are led in the pauses between pulses via a multiplex circuit to an analog-digital converter and are passed onto the image processor.
In this way, the following properties of the detector system are effective:

- High absorption and conversion of the quanta in the crystal.
- Effective scattered radiation suppression through thin collimator plates between the detector elements.
- Optimum dose efficiency through high absorption and favorable collimator geometry.
- Three slice thicknesses: adjustable from 2 to 8 mm.

Fan beam

The SOMATOM DR unit operates according to the fan-beam principle. The fan beam is measured by 512 detectors (see Fig. 8–4).

Scans even of large patients up to a diameter of approx. 530 mm can be carried out because of the large aperture angle of 42° of the fan beam.
The source-detector distance amounts to 1135 mm;
the source-skin distance lies between 500 mm and 760 mm depending on patient dimensions.

The fan beam scans through the complete circular angle of 360°. Approx. 40° are required for running up (reaching the scan speed) and braking the tube unit-detector system (see Fig. 8–5).

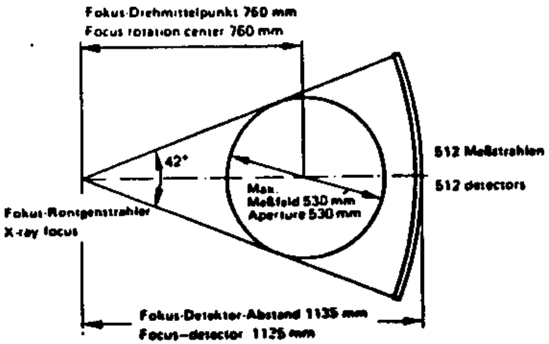


Fig. 8–4

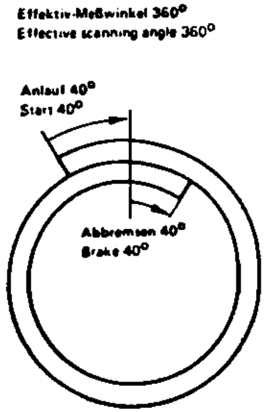


Fig. 8–5

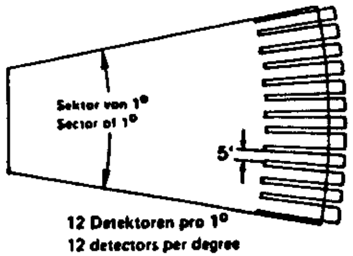


Fig. 8–6

A 1° sector of the fan beam is shown in Fig. 8–6. 12 detectors are associated with each sector. Their mutual angular distance amounts to 5'.

Gantry

The gantry contains the rotating tube unit-detector system. The measurement electronics in the gantry convert the analog scan signals arising with each high-voltage pulse in a linear analog-digital converter into digital data. These are subsequently transferred into the acquisition computer of the image processor.

The 3D light localizer is also in the gantry aperture for accurate slice positioning.

The gantry can be tilted by motor drive by ±20° to the vertical axis so that scans can be made obliquely to the patient axis (oblique tomography).

Patient table

To increase operating convenience, the patient table is accessible from all sides. Fold-out control consoles with the controls for patient table and gantry are located on the longitudinal sides.

The patient can already be positioned on a second tabletop outside the examination room and can be then moved with the transport trolley over the lowered patient couch using the interchangeable table top (optional item).

Corners and edges of the patient table are upholstered in soft material. The pads at the narrow sides are coupled with safety switches which switch off table movement automatically in case of a hazard. Please refer to the "Protective measures" section (see page 9–4) for details.

Control and evaluation console

The control and evaluation consoles consist of single modular components which can be combined according to functional requirements, operating convenience and equipment configuration.

Control console modules

- System module
- Control module
- Window module
- Loudspeaker module with intercom unit
- Program module
- Image and text monitor (black/white monitor 31 cm)
- Inpout keyboard and resistor matrix with input stylus

Evaluation console (optional item):

- Window module
- Program module
- Loudspeaker module
- Documentation console for MULTISPOT F and instant camera
- Image and text monitor (black/white monitor 31 cm)
- Black/white monitor 44 cm
- Color monitor

Image reconstruction in the image processor

The SOMATOM DR system can be supplied in two different basic types:

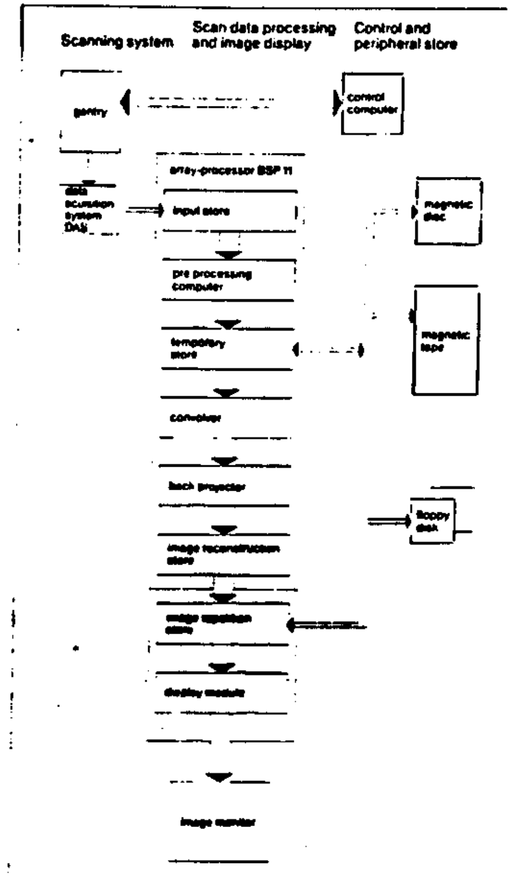
SOMATOM DR2 with 256 matrix
SOMATOM DR3 with 512 matrix.

The image processing system is employed in two extension stages depending on the matrix used. The difference lies in the number of back projectors and in the size of the image reconstruction and image repetition stores, see table below:

SOMATOM DR	Image matrix= pixels	Number of back projectors	Capacity of the image recon-struction store	Capacity of the image repetition store
Version 2	256 x 256	1	64 kW x 32 bit	64 kW x 32 bit
Version 3	512 x 512	4	256 kW x 32 bit	256 kW x 32 bit

The reconstructed tomogram can be recalled from the control console (NEW button) immediately after termination of scanning. During this procedure, the image is transferred from the image reconstruction processor into the image repetition store.

Digital scan data processing is performed in the BSP 11 array processor in normal scanning mode. The image reconstruction is made simultaneously according to the pipeline principle.
The raw data resulting from correction of the scan data is forwarded from the temporary store to the peripheral stores, to the convolver and then on to the image reconstruction stage.



block diagram

Image display

The CT values are transformed into grey steps which can be differentiated from one another for displaying a CT image on the 735-line/60 Hz image frequency monitor.
Since the human eye can differentiate only between 15–20 grey steps on a black/white monitor, it is thus not possible to perceive all details simultaneously on the monitor. However, a region of the absorption value scale can be selected with the aid of the window technique so that all structures of relevant density can be displayed on the screen in high contrast.

The attenuation values in HU (Hounsfield units) are scaled in the image store according to the following scale:

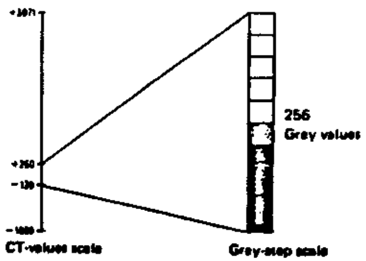
HU	Type of object
−1000	air
0	water
+3071	very dense bone

The image store has a depth of 16 bit:

12 pit for the CT density value
4 bit for graphical marking purposes

Matrix	Image store	Monitor	Image number
256	64 KW	256	1
512	4 x 64 KW	512	1
512	4 x 64 KW	256	1
256	4 x 64 KW	512	1 x 4 parallel
256	4 x 64 KW	512	4 x 1 in series

a) Window technique
Sections of the attenuation value scale can be spread out for better differentiation by window display of the CT values. A CT value or range is always associated with one grey step. The grey-step scale consists of a maximum of 256 steps. In the case of windows with an attenuation value range of 256 HU or less, the number of the grey steps displayed and of the CT values is the same. The position of the window center can be varied continuously from −1000 to +3071 CT units.

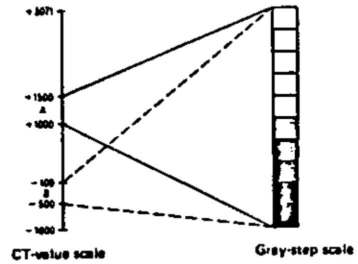


8.54

b) Programmable window selection
In addition to the selection of a single window of a density region in the tomogram, the SOMATOM DR system offers further possibilities:

- Automatic setting of the window centerline
  A 9-pixel region of interest of the tomogram can be marked on the monitor with the electronic pen and resistor panel. The window centerline is immediately adjusted to the mean CT value of this region. The position of a second window can be set in a similar manner.

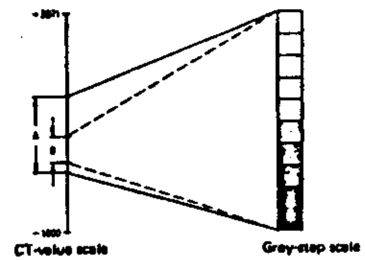
- Double window
  for the simultaneous display of two different regions, e.g. heart and lungs, two windows with different centerline and width can be selected.



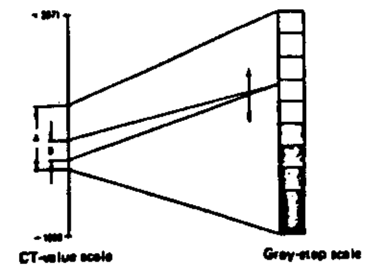
- The boundary between the two windows is displayed in black.

  In case of overlapping windows A and B, Window A has priority. Window A must be assigned to the higher CT values for optimum image display.

  Window within the window
  A window B can be selected inside the window A for differential display of a region in the tissue.

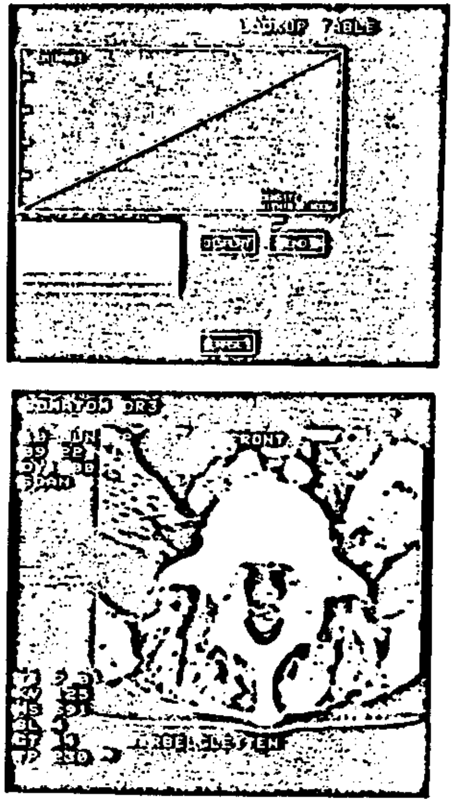


- Substitute value in the window
  A second region B can be highlighted with one gry step arbitrarily black, grey or whit within a window in the region A.

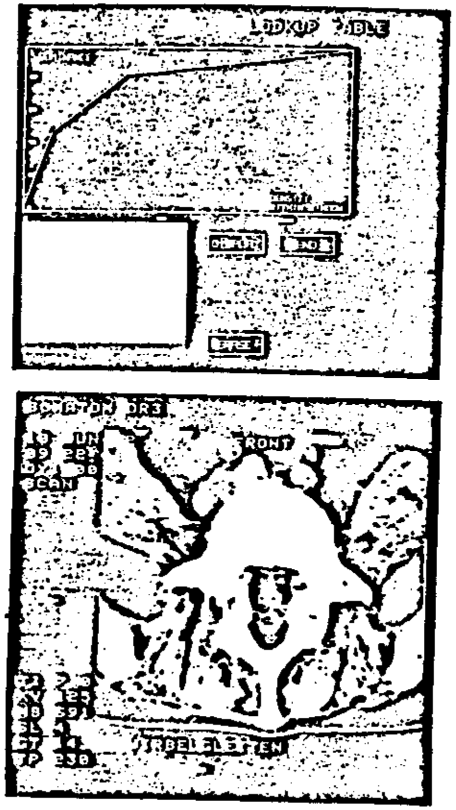


8.55

c) **Programmable grey-value distribution**
The transfer characteristic of the grey-value scale can be programmed by the user in any way via graphic input. In this way, the image display is adapted to the varying contrast reproduction of the screen or of the film in the case of documentation, or it can be individually altered.



Linear grey-value distribution



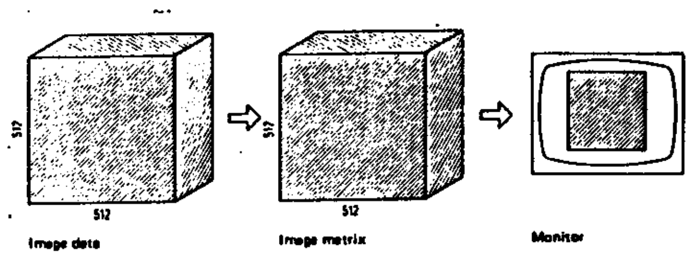
Contrast enhancement in the center of the grey-value scale

d) **Color display (optional item)**
Tomograms can be displayed in color on a 735-line color monitor. The attenuation values can be associated with the colors of the spectrum from blue to red (depending upon the window setting).

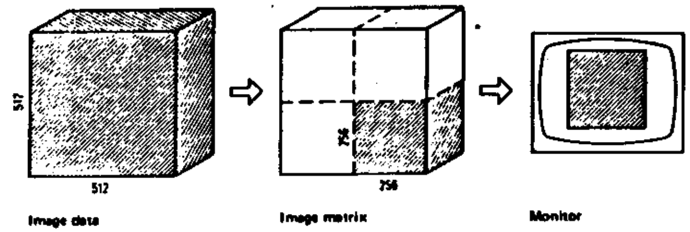
e) Relevant data for identification and evaluation are superimposed on the monitor and are stored together with the image data.

f) **Variable image display with differing size of the image matrix (only SOMATOM DR3)**
The modular construction of the image store permits several possibilities for image display. Four images of matrix size 256 can be stored in a large store by subdiving the store matrix with 512 x 512 pixels into 4 matrix regions with 256 x 256 pixels each.

Display of an image with 512 x 512 pixels in a large matrix:

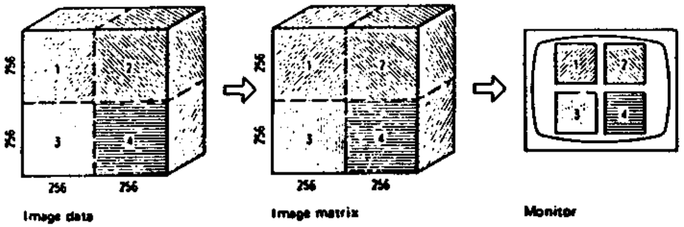


Display of an image with 512 x 512 pixels in a small matrix:

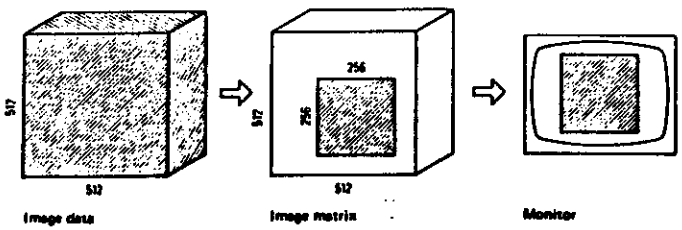


The display on the monitor always takes place in full format, i.e., with an image matrix reduced in size, the image is automatically displayed magnified 1 : 2.

Simultaneous display of four images with a large matrix:



Rapid magnification of an arbitrary image region in the 2 : 1 ratio:



g) CINE-CT (optional item)
Dynamic processes of SERIAL or CARDIO-CT scans can be displayed on the monitor with CINE-CT as a rapid image sequence. In this case, several images are stored in the large image matrix.

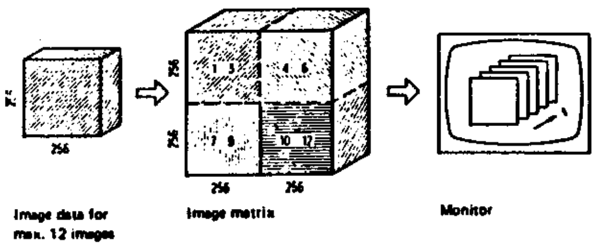
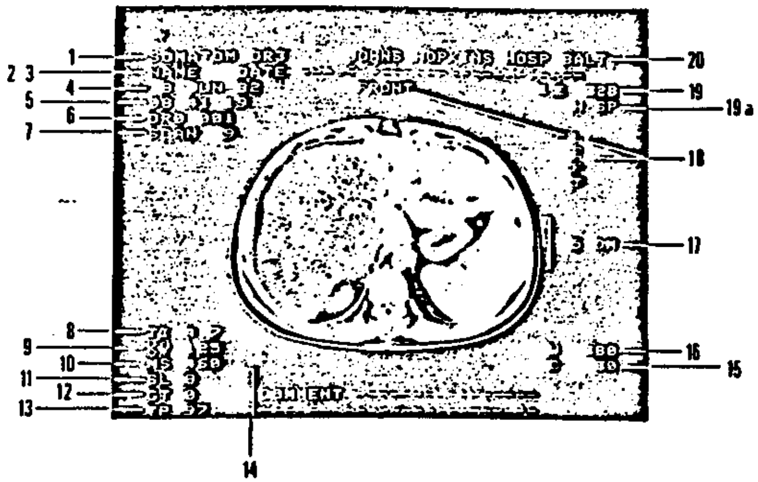


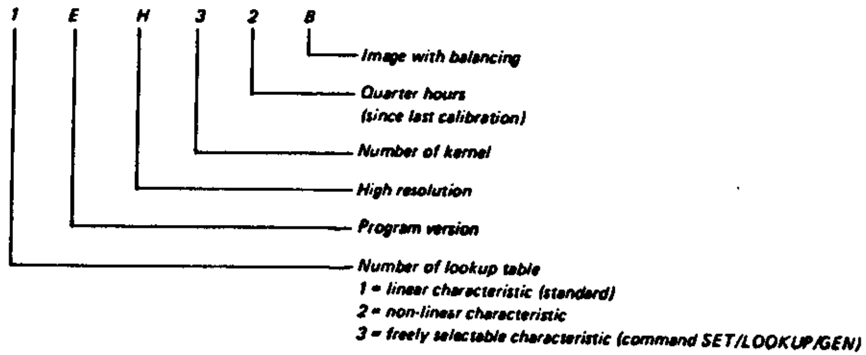
Illustration of the principle for a sequence of 12 images.



h) Data superimposed on the television picture

1 Scan unit
2 Patient's name
3 Patient data
4 Date of the scan
5 Clock time of the scan
6 Image filing, store, image number
7 Number of the slice in the slice sequence
8 TI: scan time (sec)
9 kV: tube voltage (kV)
10 MS: mAs-value per scan
11 SL: slice thickness
12 GT: gantry tilt in degress
13 TP: table position
14 Comments
15 Window center
16 Window width
17 Reference scan by cm
18 Note on image viewing
19 See explanation below
19a Patient position
H/. . . = HEAD FIRST/. . .
F/. . . = FEED FIRST/. . .
20 Hospital name

Explanation of number 19:



Peripheral data stores

The SOMATOM DR system is equipped with various peripheral data stores with differing storage capacity. The access times depend on function and store organization.

Processed image data can be stored in compressed and uncompressed form as well as raw data.

The storage space requirements can be reduced by compressing the image data by around 75 % compared to the uncompressed storage. The computational effort required for data transformation increases however, the storage and reading time.

The required capacities and access times of the data carriers are in accordance with the technical and clinical requirements as well as according to the data quantities that are generated.

Function of peripheral data stores:

- Temporary storage: Data filing in stores with short transfer times and rapid access. The duration of data filing is restricted to a short dwell time.
- Filing: Long-term storage of image or raw data which in contrast to temporary storage are not designed for rapid repeated access.

The functions and access times of the individual stores can be read off from the following table:

	Capacity	Function	Contents	Images (uncompressed image data) max. number matrix 256	max. number matrix 512	Writing, reading time Matrix 256/512 sec	Raw-data sets Number of projections 480	720	1440
Disk store I	5 MB	System Store	Operating system	–	–	–	–	–	–
Disk store II	5 MB	Data store	Arbitrary data	39	9	0.8/2.8	10	7	3
Disk store 67	67 MB	Temporary store	Image, raw data	504	126	0.5/1.8	134	90	44
Disk store 176 (alternative to 67)	176 MB	Temporary store	Image, raw data	1296	324	0.4/1.4	348	234	114
Floppy disk	0.5 MB	Archiving store	Image data	3/side or or approx. 10 to 12 compressed	approx. 3/side compressed	–	–	–	–
Magnetic tape store 75 (optional item)	28 MB	Archiving store	Image, raw data	195	50	Write-read speed 75 in/s	50	35	17
Magnetic tape store 125 (alternative to 75)	28 MB	Archiving store	Image, raw data	195	50	Write-read speed 125 in/s	50	35	17

High-voltage unit

The short scan time of approx. 1.4 sec and image reconstruction during scanning are prerequisite for a rapid scan sequence. To achieve this, the high-power constant potential generator and the OPTI 151 CT X-ray tube are used in the SOMATOM DR system.

The OPTI 151 CT X-ray tube is an oil-cooled rotating-anode tube with 1.6 mm x 1.6 mm focal spot (useful beam) and has been specially developed for CT application. The advantage of this rotating-anode X-ray tube is the high short-time rating, which enables a rapid scan sequence to be achieved! The X-ray tube is cooled by an external oil-cooling unit. In this way, a uniformly rapid scanning operation with high patient throughput can take place without heating up the anode disk beyond the permissible limit of 1,000,000 Ws (1,350,00 HU).
Computer-controlled anode disk thermal capacity monitoring indicates to the user the number of scans which are possible without additional X-ray tube cooling when the scan program is selected.

A built-in safety device prevents thermal overloading of the X-ray tube in the generator.

A thermal overload is signalled acoustically. Scanning is interrupted until the signal has been silenced.

Control processor PDP 11/44

Its tasks are:

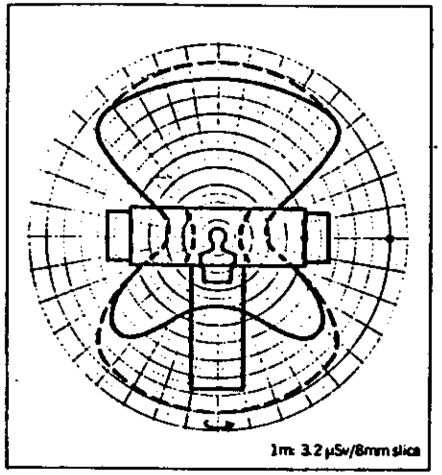
- Carrying out the operating dialog with the user
- Control of the individual movement operations of the gantry
- Supplying the image processor with program and control parameters
- Temporary storage of a raw-data set
- Administration and filing the reconstructed CT images
- Evaluation of the reconstructed CT images

The control processor contains an extensive scan program to perform these tasks. This is activated by the operator by means of the control keys on the control and evaluation console or through commands entered in the dialog.

The standard configuration of the control processor also includes a protocol printer which is used primarily for printing out absorption values or directories of filed data carriers but also for service purposes.

The scan program documents all errors that develop and thus permits selective error detection and localization.

Dose distribution in the room



——— in the horizontal plane (patient level)
– – – outside the patient level

Whole body standard scan:
125kV/320mAs/8mmslice
Head and body phantom

Overload protection
Overloading of the X-ray tube in continuous operation can only occur when too many scans have been carried out consecutively without pause (depending upon the scan mode).

When a cooling pause has to be made, this is monitored and output by the processor. The overall load of the X-ray tube depends on

a) the scan mode with which the rapid series was scanned
b) the previous loading of the X-ray tube.

Heart and Brain Examinations
If the unit is used, alone or in conjunction with other units, for brain or heart examinations, an extra connection must be made between the unit and a potential-equalization point such as the patient table before connections are made to the patient.

Broadcast-interference suppression
Corresponds to the German regulations which are largely adapted to the CISPR publications.

Protection type and protection class
The product is accordance with protection type IP 20 and protection class 1.

Technical data (continuation)

Patient positioning	
Patient table:	Examination table with mobile patient interchange system
Table height:	615 – 1080 (615 – 1111)* mm, adjustable by motor drive
Table longitudinal travel:	max. 1485 mm, motor-driven or with hand-wheel Computer-controlled in 1-mm steps, setting speed: 1485 mm in approx. 15 sec.
Setting accuracy:	Tolerance with stepwise adjustment: max. 0.25 mm/increment Tolerance with arbitrary slice positioning: max. ±0.5 mm
Positioning aids:	Head cradles adjustable for extreme sections Elastic patient support and attachment aids Positioning aids for infants
Computer system and data stores	
Control computer:	PDP11/44 central processor unit with 256 kB MOS store, 8 kB Cache store, real-time clock, LA38 protocol printer, parallel interfaces for process control
Image processor:	BSP11 array processor for simultaneous image reconstruction
Disk stores:	System store, 5 MB Data store, 5 MB Image/raw-data store, 67 MB, alternatively; Image/raw-data store, 176 MB
Floppy disk store:	2 drive, 0.5 MB
Magnetic tape stores:	Archiving store, 28 MB for image/raw-data, write/read speed alternatively 75 or 125 ips
Scan data	
Slices per scan:	1
Scan time:	1.4sec; 2.1sec; 3.2sec; 4.5sec; 5.2sec; 7.0sec; 14sec
Number of projections:	240; 320 with 240° scan angle 480; 720; 1440 with 360° scan angle
Scan sequence:	max. 12 scans per minute with 480 projections (SERIO-CT)

Tube voltage: 96 kV; 125 kV

mAs product: 96 – 1036 mAs at 125 kV:
125 – 1350 mAs at 96 kV

Image reconstruction and display

Display field: 5.3 cm to 53 cm diameter, continuously variable

Zooming: Zoom factor 1 – 10

Processing time for image reconstruction: 0 to 2.5 seconds depending on number of projections

Convolution kernels: Can be selected, several convolution kernels are assigned to each scan mode

Image matrix: Version DR2: 256 x 256 pixels
Version DR3: 512 x 512 pixels

Pixel size in the object: Image matrix 256: 2 . . . 0.2 mm corresponding to zoom factor 1 – 10
Image matrix 512: 1 . . . 0.1 mm corresponding to zoom factor 1 – 10

Text monitor: 735 lines, black/white, 31 cm screen

Image monitor: 735 lines, black/white, 31 cm screen

Color display for retrofitting: 735-line color monitor

CT-value scale: –1000 to +3071 HU (Hounsfield units)

Number of grey steps: 1 – 256

Window centerline: –1000 to +3071 HU, continuously variable, or automatic setting with electronic pen and resistor plate

Window width: 2 to 4049, HU adjustable in even increments

Double window: Double grey-scale display of two CT value ranges in one image

Window within the window: Double grey-scale display of two CT value ranges. Region of window B within the limits of window A

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Highlighting: Accentuation of a selected CT value range for display with one grey value from black to white

Programmable grey-value distribution: Arbitrarily programmable transfer characteristic of the grey value scale

Image documentation:
- MULTISPOT F multi-format camera for 8" x 10" or 11" x 14" cutfilm with 735-line monitor
- Documentation console with 24-cm monitor, 735 lines for Polaroid or 100-mm cutfilm camera and miniature film camera, 35-mm film.

Room climate: Room temperature 22° C ± 3° C
Temperature gradient 2° C/h
Relative air humidity:
55 % ± 10 %, free of condensation

Cooling water: Water pressure min. 1.75 bar, max. 5 bar
Water flow at cooling-oil temperature ≥ 35° C with 1 to approx. 3 l/min depending on water temperature

Minimum space requirement: 55 m^2

Minimum transport requirements:
Door height: 212 cm
Door width: 100 cm
Elevator depth: 300 cm
Elevator capacity: 1580 kg

Power supply
Nominal generator ratings.

3-phase, 50/60 Hz	380	420	440	480	V
Connection value	42	46	49	53	kVA
Internal power supply line impedance required	135	220	180	250	mΩ

Power supply ratings of units and computer components: 300 V; 50 Hz approx. 14 kVA
Rating depending on unit configuration. With power supplies with fluctuating voltage values and frequencies, an appropriate system transformer must be provided in the building'

Rated current connection: Corresponds to the series fuse
80 A at 380/420/440/480 V (per phase)
100 A at 380 V (per phase)

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Special notes:

1. The MODE command contains, apart from loading, the control parameters, loading tables and similar scan preparations, the offset measurement as well.

2. The following special points must be observed when entering the command:

   Entry without set number is permissible only in two cases:

   MODE — Load the last used parameter set

   MODE/SELECT — Change the loading the last used parameter set

   but:
   MOD n = MOD/TOM n: Load the tomogram set No. n

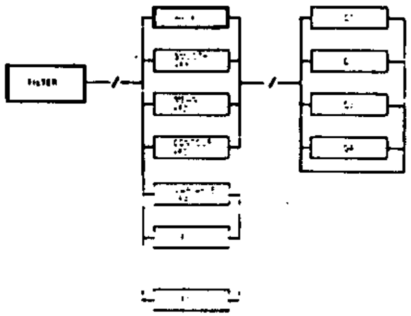
3. The scan parameters for the SOMATOM DR are indicated in the following table. In the case of the SOMATOM DR1, scan modes No. 1 and No. 2 are inapplicable.

Scan mode No.	Scan time [sec]	Projections	Scan angle [deg]	Recommended Slice thickness [mm]	Pulse angle [W_S]	mAs 96 kV	mAs 125 kV	Skin dose (mGy) 96 kV	Skin dose (mGy) 125 kV
1	1.4	240	240	8	30 60	75 125	60 100	3 4	4 7
2	2	320	240	8	30 60	200 340	150 260	7 12	10 17
3	3	480	360	8 8	30 60	150 300	120 230	5 10	8 16
4	4	480	360	4 2	90 135	450 680	350 520	16 24	23 35
5	5	720	360	8 8 4	30 60 75	230 450 580	170 350 450	8 15 20	12 23 31
6	7	720	360	4 2	90 135	680 1030	520 780	23 35	35 53
7	14	1440	360	8 4/2 2	30 60 90	450 900 1350	350 700 1050	15 31 47	23 47 70

4. Convolution kernels offered and their effects

Convolution kernel No.	Provided for	Identification
1	Phantom	Mathematical normal kernel
2	Body	Routine operation (abdomen, vertebral column, pelvis)
3	Head	Routine operation
4	Body	Very much smoothing for special applications
5	Body	kernel 2 + smoothing, particularly for quick scan and split reconstruction
6	Head	kernel 3 + smoothing, particularly for quick scan and split reconstruction
7	Body	Edge enhancement (cervical spine, chest)
8	Head	Edge enhancement

With the command FILTER, a subsequent image manipulation can be carried out.
Ten different selectable filter functions are available.
In this way, the desired image appearance can be selected for the task concerned.



• Examples of images see page 15–5

HELP	–	Filter list
SMOOTH (F 1)	–	Smoothing filter (Gaussian)
MEAN (F 2)	–	Averaging smoothing filter
CONTOUR (F 3)	–	Contour filter with 3 x 3 image-point matrix •
VARIABLE (F 4)	–	Variable smoothing filter (Gaussian)
F 5	–	Edge-enhancing filter •
F 6	–	Edge-enhancing smoothing filter •
F 7	–	Shading filter
F 8	–	Smoothing by averaging with 2 x 2 image-point matrix
F 9	–	Median filter
F 10	–	Contour filter with 5 x 5 image-point matrix •

Q1
Q2
Q3
Q4 } – **Quadrant specification;**
If this is missing, the displayed image is filtered

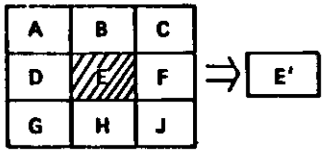
The filter functions F1 to F4 are applied through the image computer BSP11, F5 to F10 are applied through the host computer PDP11.

The computing time required depends on:

a) the matrix used (256 or 512)
b) the computer used: BSP11 or PDP11

Note:
on the evaluation console (DSC), all filters are computed in the PDP11 (with out F4 !). Filter function F4 is used on DMC only !

A 3 x 3 pixel matrix always forms the basis for the "SMOOTH, MEAN, CONTOUR" filters; see the diagram.



Because of differing weighting and combination of the individual matrix terms, the following filter functions arise:

SMOOTH = F 1
Smoothing filter (Gaussian)

$$E' = \frac{1}{16} \cdot [A + 2B + C + 2D + 4E + 2F + G + 2H + J]$$

MEAN = F 2
Smoothing filter via mean value formation

$$E' = \frac{1}{8} \cdot [A + B + C + D + F + G + H + J]$$

CONTOUR = F 3

Contour filter

$$E' = 2 \cdot \sqrt{[(A+B+C)-(G+H+J)]^2 + [(A+D+G)-(C+F+J)]^2}$$

VARIABLE = F 4 (only DMC, not DSC)

For this filter kernel, the filter range (= matrix diameter) must be determined via the dialog.

INSERT MATRIX RANGE FOR TERM 1 ([0], 3, 5, 7, 9): xx <CR>
INSERT MATRIX RANGE FOR TERM 2 ([0], 3, 5, 7, 9): xx <CR>

The resulting matrix point is calculated as below:

$$P(x,y) = \frac{\sum_{r=0}^{\max(R1,\,R2)} P(r) \cdot \left[\frac{S1}{2(\frac{r}{R1})^2} + \frac{S2}{2(\frac{r}{R2})^4}\right]}{\sum_{r=0}^{\max(R1,\,R2)} \left[\frac{S1}{2(\frac{r}{R1})^2} + \frac{S2}{2(\frac{r}{R2})^4}\right]}$$

In the formula:

- P (x, y) = Central point which is filtered
- P (r) = Pixel within the stated matrix
- R1/R2 = Radius of the image matrix for Term 1, Term 2
  Matrix range designates the matrix diameter

This gives:

Matrix range	R1, R2	Number of the points used
0	0	0
3	1	9
5	2	21
7	3	37
9	4	61

- S1, S2 = Weighting factor for Term 1, Term 2
- r = Radius of the pixel

F 5 Edge-enhancing filter

$$E' = 1/2 \cdot (-2A + B - 2C + D + 6E + F - 2G + H - 2J)$$

F 6 Edge-enhancing, smoothing filter

$$E' = \begin{cases} 2E - \text{filter } 1 & (\text{for } 2E - \text{filter } 1 > 30) \\ \text{Filter } 1 & (\text{for } 2E - \text{filter } 1 \leq 30) \end{cases}$$

F 7 Shading filter

$$E' = (-A - B - C + D + 3E - F + G + H - J)$$

F 8 Smoothing filter via averaging with a 2 x 2 pixel matrix

$$E' = 1/4 \cdot (A + B + D + E)$$

F 9 Median filter : smoothing, however, with minimum edge modification

E' = Central value from 3 x 3 pixel matrix

Note:
The central value of a 3 x 3 matrix is obtained by arranging the values in ascending sequence and by taking over the fifth value in each case.

F 10 Contour filter with 5 x 5 pixel matrix

$$E' = G_i = \sqrt{(G_{i-2,\,j-2} - G_{i+2,\,j+2})^2 + (G_{i-2,\,j+2} - G_{i+2,\,j-2})^2}$$

i = column number, consecutive
j = line number, consecutive