Early Days of CT: Innovations
(Both Good and Bad)

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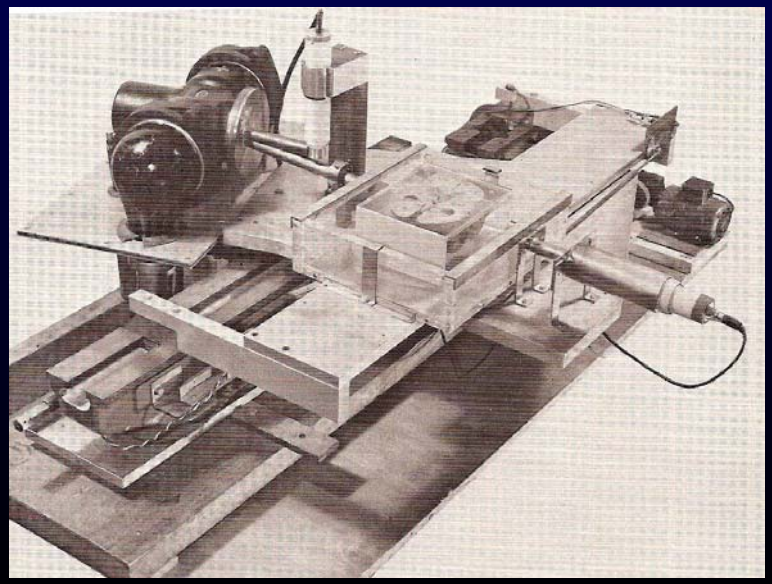
The Names: An Incomplete List

- Johann Karl August Radon 1887-1956
- William Henry Oldendorf 1925-1992
- Allan McLeod Cormack 1919-2004
- Godfrey Newbold Hounsfield 1919-2004
- Robert Ledley 1924-

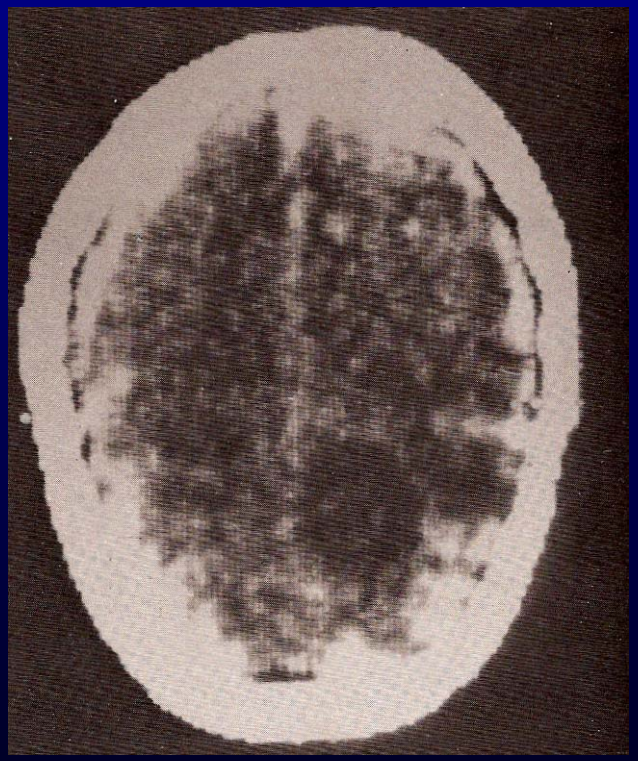
Sir Godfrey Hounsfield

- Elected to Royal Society 1975
- Nobel prize 1979 shared with Allan Cormack

1919-2004

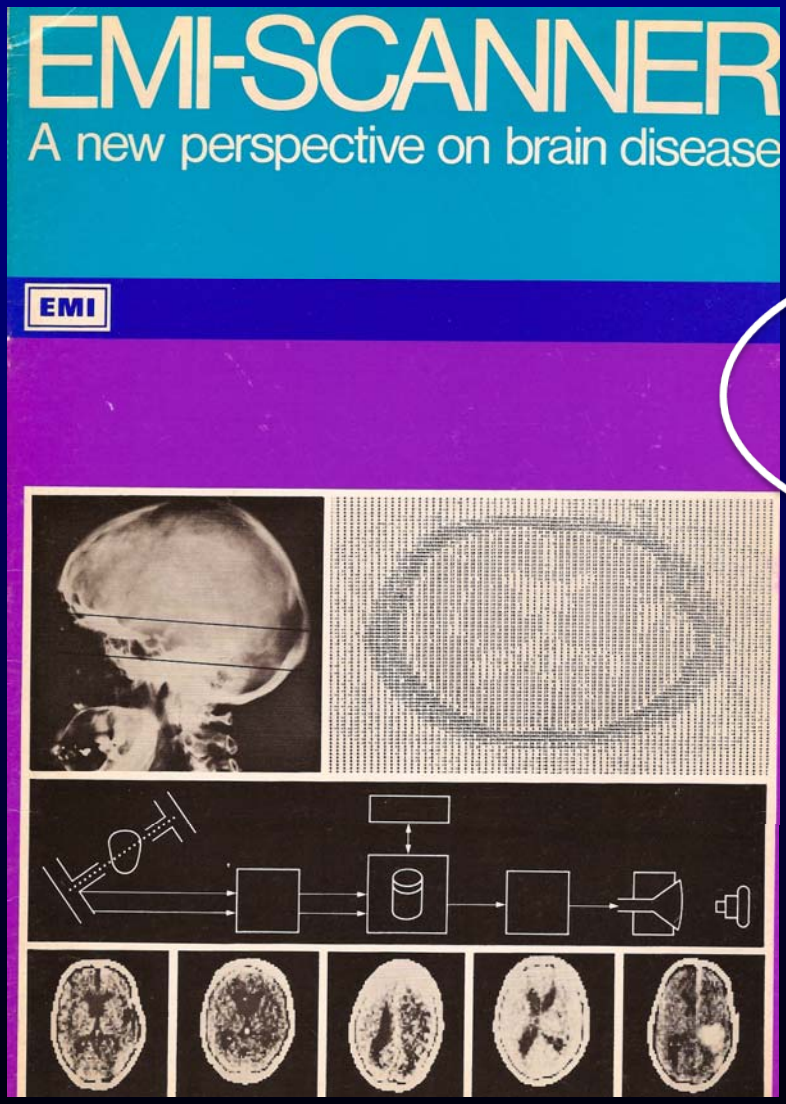


EMI Head Scanner



First clinical image (Atkinson-Morley Hospital London

EMI Head Scanner



1972 sales brochure

Capability:
To be capable of simultaneously scanning two contiguous sections through a live human head and processing the readings taken to give a picture display on a viewing unit.

Range of X-ray absorption coefficient:
+500 to −500 (see the scale used on Figure 5)

Resolution of X-ray absorption coefficient:
$\pm\frac{1}{2}\%$

Time of single scan (2 contiguous sections):
Variable between approx. $4\frac{1}{2}$-20 minutes.

Radiation Dosage to the skin for a complete head examination of 3 or 4 scans each of 5.5 minutes duration:
120kV – Mean dose 1.25R Maximum dose 1.91R
140kV – Mean dose 1.55R Maximum dose 2.26R

Radiation Dosage to the skin for a complete head examination of 3 or 4 scans each of 4.0 minutes duration:
120kV – Mean dose 0.91R Maximum dose 1.39R
140kV – Mean dose 1.13R Maximum dose 1.64R

Gonad Dose for a complete scan:
Less than 0.1 mR.

X-ray tube Voltage/current:
100kV – 40mA max.
120kV – 32mA max.
140kV – 27 mA max.

X-Ray tube focal spot size:
12 mm×1.3 mm

Mean X-ray beam width:
0.8 cm or 1.3 cm

Detectors:
Sodium iodide crystals+photomultipliers

Rubber head cap life:
Up to three months depending upon use

Power requirements:
400 volts±10% 50HZ 3 phase supply mains, 7KVA.
230 volts±10% 50HZ single phase 4 kw.
or
190 volts±10% 60HZ 3 phase supply mains, 7KVA
110 volts±10% 60HZ single phase 4 kw.

Water supply to oil cooler:
To be capable of supplying a maximum flow of 4 imp/. pints/minute (2.3 litres/minute)

Initial warm-up time of X-ray tube:
Less than 10 minutes

Operating temperature range:
10°C – 35°C

Configuration of head receptacle:
23.5 cm diameter hole. The edge of the widest X-ray beam will scan the head approximately 2.4 cm from the edge of this hole.

X-ray tube leakage:
10 mR per hour at 1 metre from the tube (excluding scatter from patient)

Computation Time:
Approximately 7 minutes per picture

Storage disc capacity:
About 60 pictures

Picture Matrix:
80×80

Display Size:
Rectangular 140 mm x 101 mm ($5\frac{1}{2}$ inches x 4 inches)

Refresh rate:
Approximately 10 per second

Reference number display:
The picture reference number appears above the X-ray picture on the C.R.T. and shows the patient's number and slice number.
A and B represent lower and upper slice respectively.

Camera:
Polaroid Print size 76 mm x 95 mm (3 inches x $3\frac{3}{4}$ inches)

Dose information

Sizes

Scanning Unit

Minimum Length required including space for table movement and equipment door opening:
393.4 cm (155 in)

Minimum Height required for rotation:
175.2 cm (69 in)

Minimum Width required for rotation:
152.4 cm (60 in)

Weight:
Approx. 635 kg (1400 lb.)

Maximum Floor Loading:
1.13 kg/sq cm (16 lb/sq in)

Viewing Unit

Maximum Width:
108.8 cm (42.87in)

Maximum Height:
110.4 cm (43.5 in)

Maximum Depth including Desk:
68.6 cm (27 in)

Weight:
Approx. 159 kg (350 lb)

EMI Head Scanner

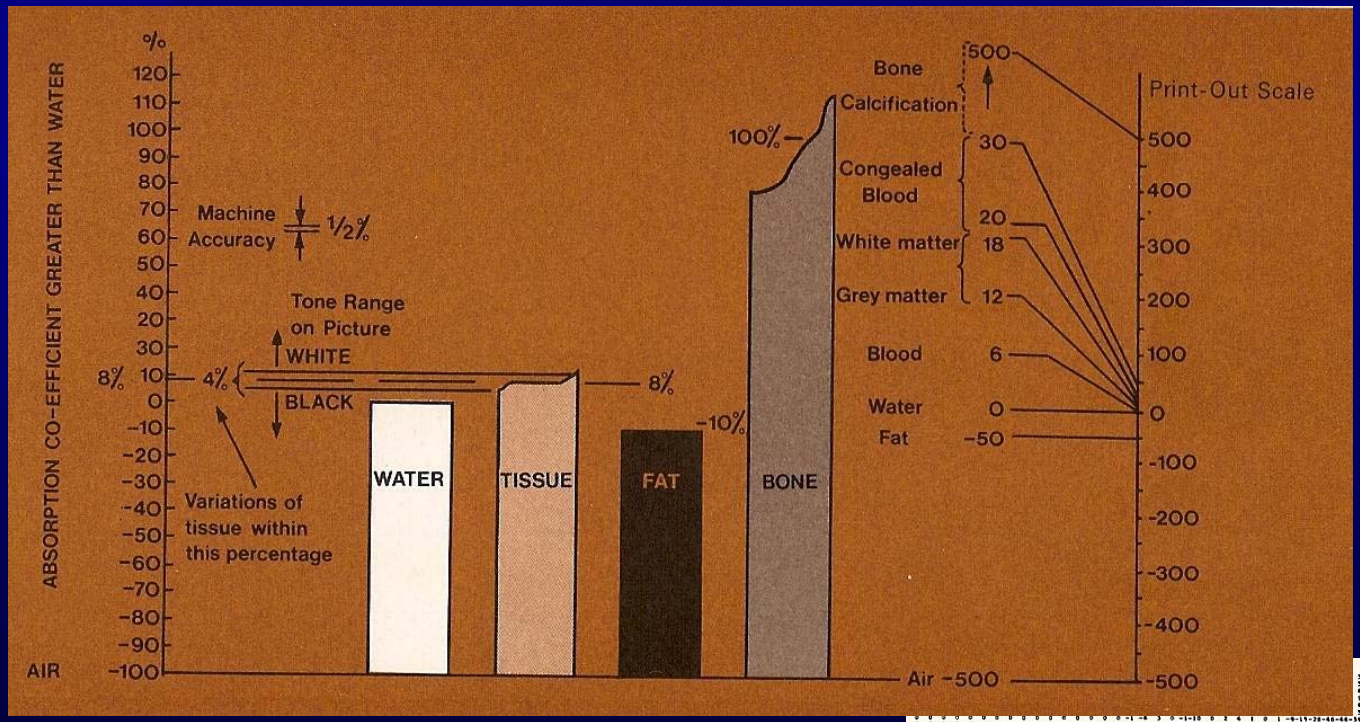
X-Ray Controls

Geometry:	Translate rotate, pencil beam
Scan time:	4.5-20 min
Rotation Angle:	1°
Number of views:	180
Samples per view:	160
Total samples:	28,800
Matrix:	80 x 80
FOV:	23.5 cm
Pixel size:	3 x 3 mm
Slice thickness:	13 mm or 8 mm
X-ray tube:	Fixed anode
Technique Factors:	100 (40), 120 (32), 140 (27) [KVp (mA)]
Detectors:	NaI-PMT
Cost:	~$350,000

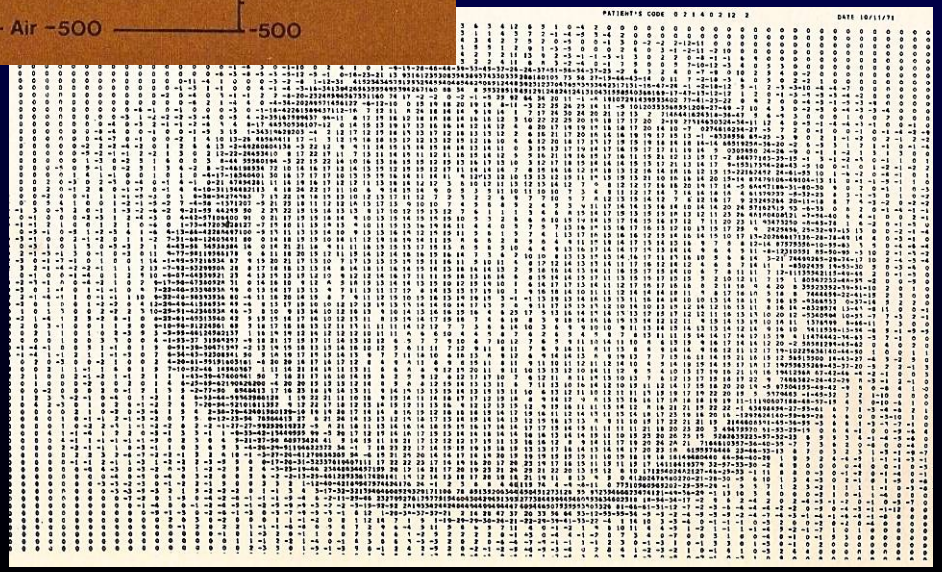
Question: What machine was the first multislice CT?

Answer: EMI head scanner! It had 2 detectors along the Z-axis.

EMI Head Scanner



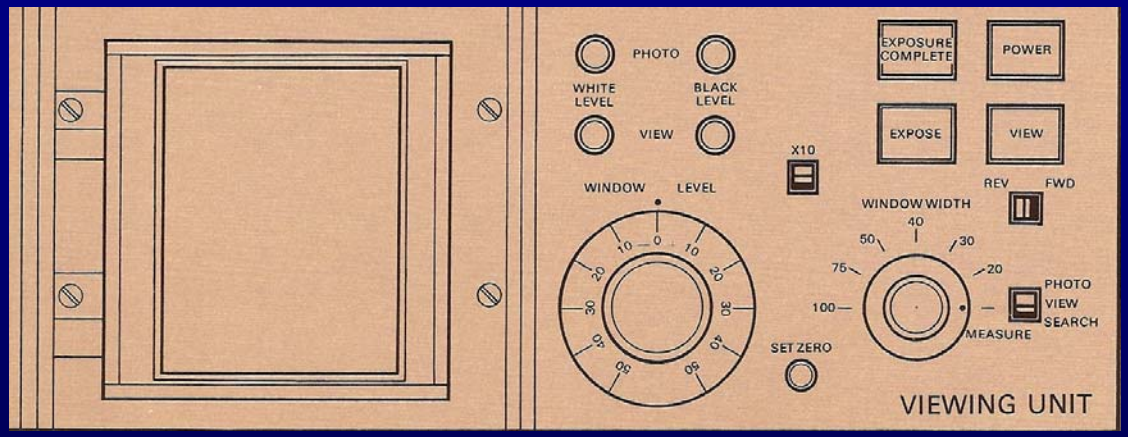
‘Print out scale’
± 500



First truly digital device in radiology

1972 sales brochure

EMI Head Scanner



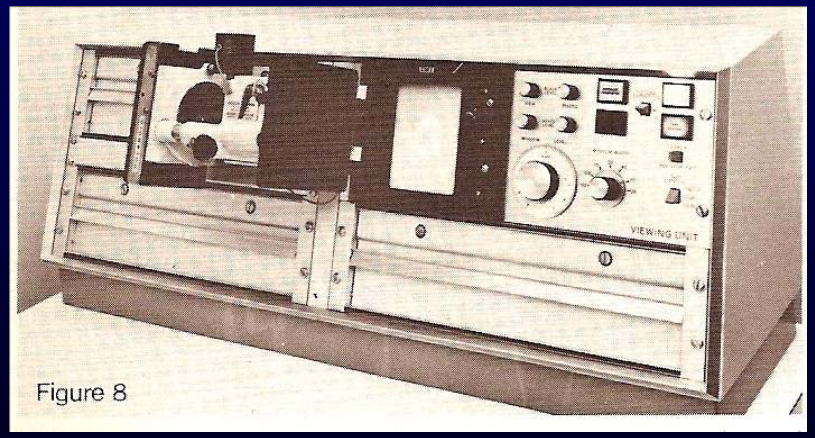
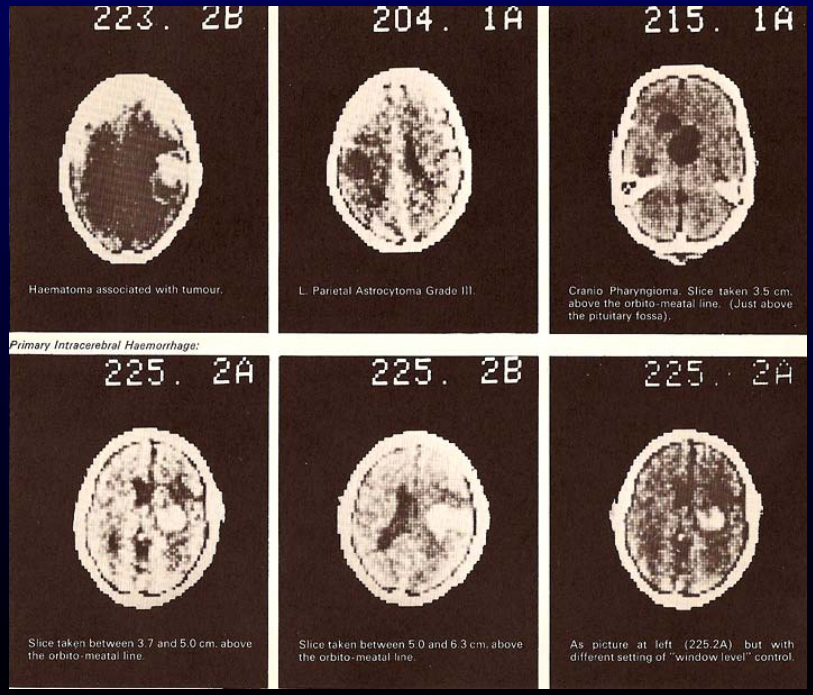


Figure 8



1972 sales brochure

EMI: Rise and Fall

1971: Prototype head scanner installed at Atkinson Morley Hospital

1972: First clinical results presented by James Ambrose, MD on 70 patients

1973: Clinical production, two units installed in the US at Mayo Clinic and at MGH

1974: ACTA whole body scanner installed

1975: 3rd generation machines installed

1975: 10 companies now make CT scanners including all of the major equipment manufacturers

1978: EMI loses $56 million

1979: EMI introduces the 7070 nutating ring scanner

1979: EMI sells business to Thorn Electrical Industries

1980: GE buys scanner business from Thorn for $37.5 million

EMI: Rise and Fall

The saga of EMI's CT scanner business became a case study at the Harvard Business School:

- Although CT represented a conceptual breakthrough, the technologies it harnessed were quite well known and understood
- Supposedly well protected by a wall of patents
  - Once the product was on the market it could be reverse engineered and its essential features copies

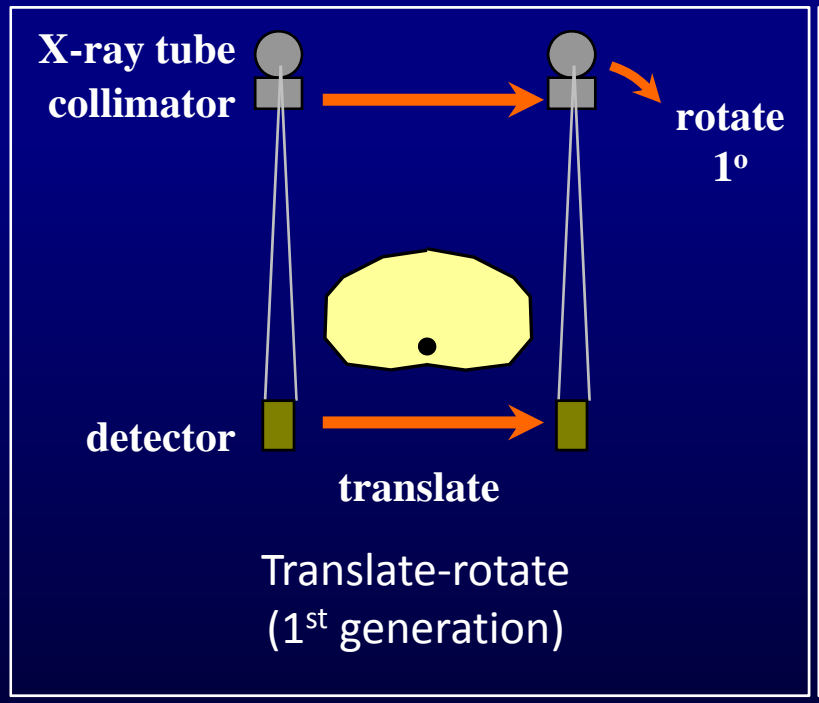
Whole Body Scanner

- ACTA Scanner
  - Installed in Georgetown University Medical Center in February 1974
  - Ist generation geometry-very similar to EMI head scanner
  - 5 minute data acquisition time
- Developed by Robert Ledley
- Sold by Pfizer
- Sold for under $300,000
- Currently in the Smithsonian National Museum of American History

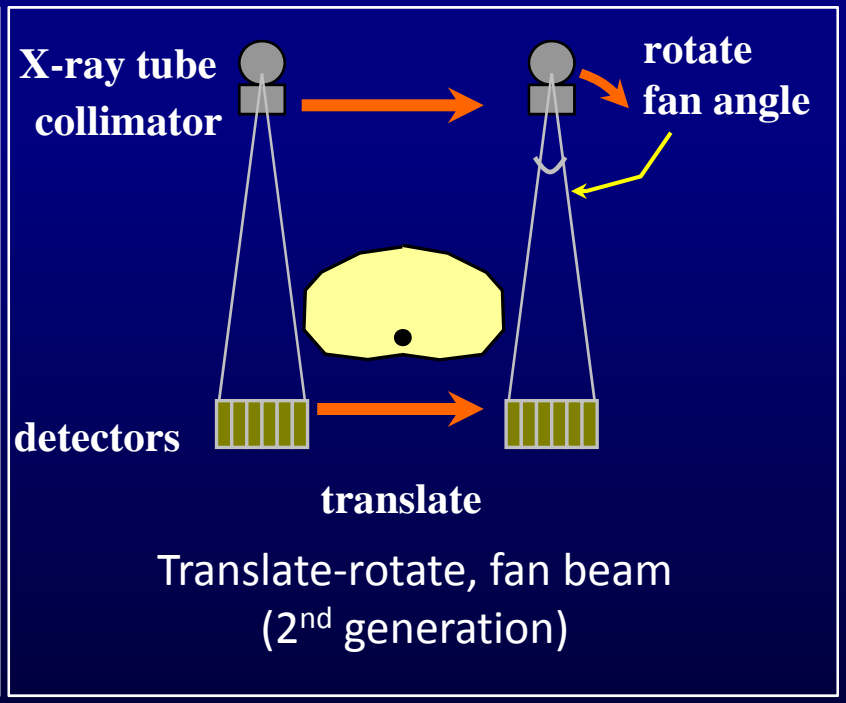
Delta Scanner (Ohio Nuclear)

- 1st installed November 1974 in the Cleveland Clinic
  - Whole body scanner with translate-rotate geometry with ~ 2 minute acquisition
- Produced one of the first 2nd generation scanners
  - 3 detector configuration
- Subsequently produced 3rd and 4th generation scanners
- Relatively long-lived (1974-1985)
  - Bought by Johnson and Johnson
- Intellectual property sold to GE in 1986

CT Data Acquisition



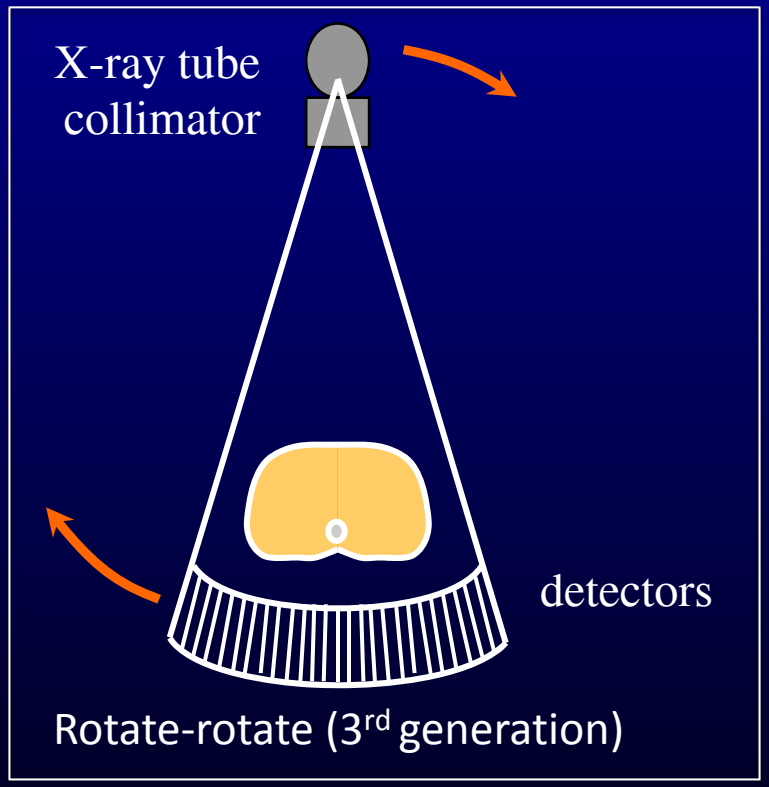
Translate-rotate
(1st generation)

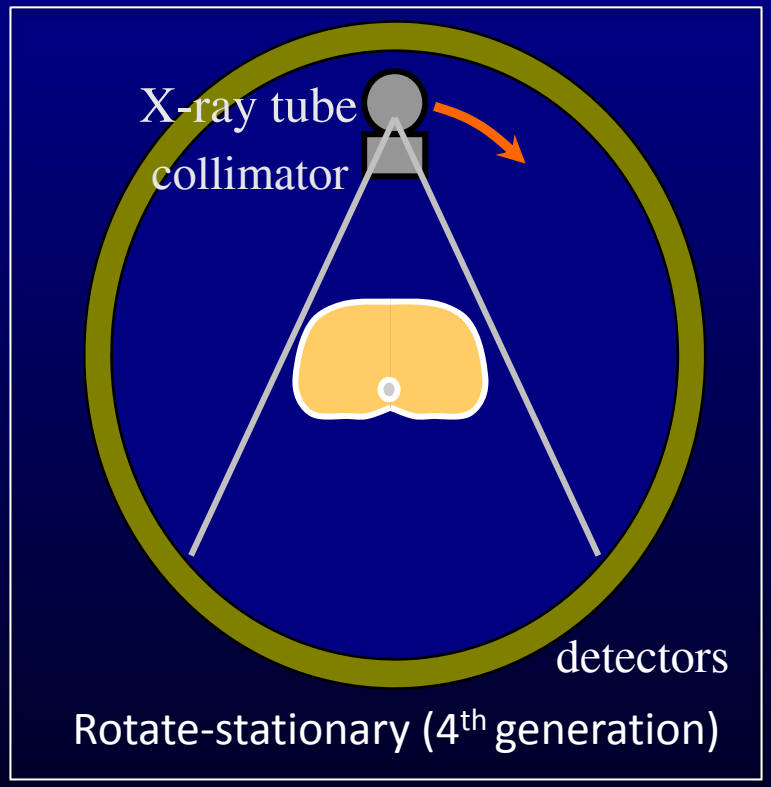


Translate-rotate, fan beam
(2nd generation)

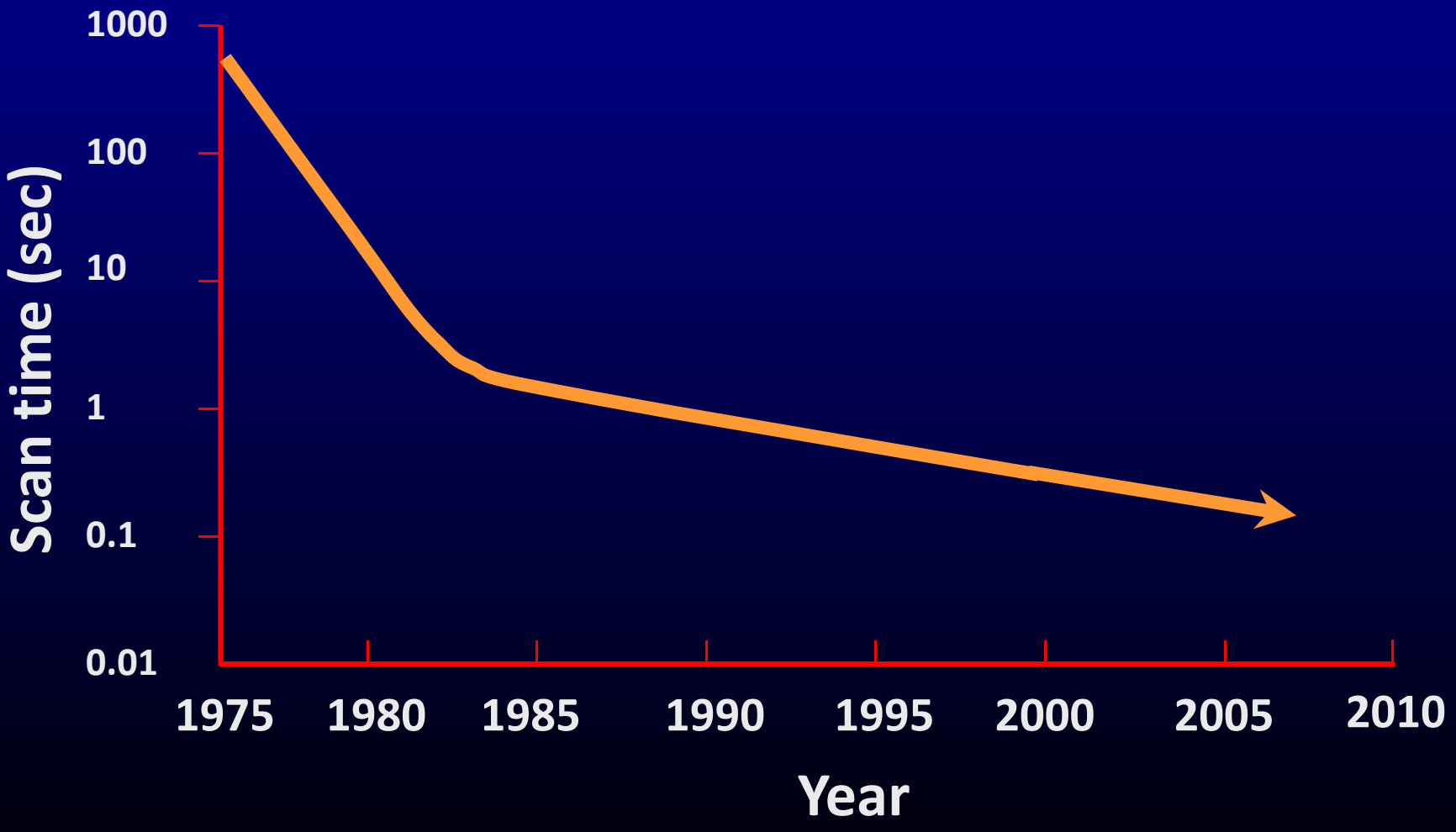
- Calibrate detectors prior to acquiring each view

CT Geometries





Quest for Scan Speed



Typical Performance Circa 1976

SEARLE

SPECIFICATIONS

Searle CT Systems
Division of Searle Diagnostics, Inc.
4233 No. United Parkway, Schiller Park, IL 60176. Telephone (312) 678-8650

November 1, 1976

Pho/Trax, an x-ray CT imager, can perform a 360° scan in 5 seconds. Pho/Trax is capable of head and torso scanning.

Scan Speed: There are four scan speeds - 5 sec., 10 sec., 20 sec., or 40 sec.

Slice Thickness: 3mm to 12mm in 1mm increments selectable from the operator's console.

Reconstruction Speed: The scan is available for analysis 40 seconds post scan.

Display Matrix: 256 X 256

Field-of-View: Selectable from 5 inches to 20 inches in 1 inch increments.

Pixel Element: Nominally 0.5mm to 2.0mm depending upon the Field-of-View.

Accuracy of Measurements: Absorption coefficients measured to less than ½% standard deviation with respect to water.

Detector Array: Xenon gas, multiple detector array.

X-Ray Tube: Fixed anode continuous beam 140 KV maximum, 4 KW oil cooled.

X-Ray Beam: 40° fan shaped beam.

Scan Gantry: 25° range of tilt capability.

Aperture Diameter: 23.5 inches

Diagnostic Viewing Console: The console has joy stick, region-of-interest selection and dual floppy discs.

Image Display: A black and white display screen and Polaroid attachment is standard. Optional equipment includes: multi-format 8 X 10 x-ray film readout, and color display.

Line Printer: Optional line printer available with print capabilities of 125 LPM or 200 LPM.

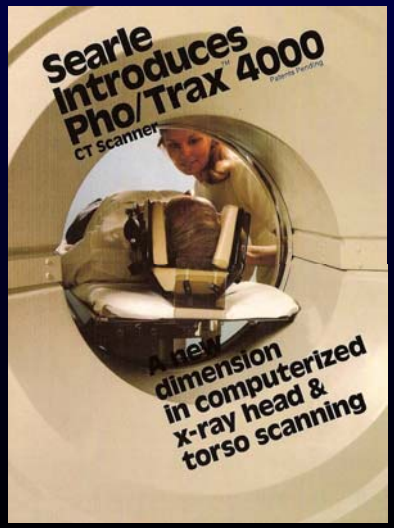
Reference Code: Annotation page includes hospital name, patient's I.D. and other information. Also a comments section is provided. The displayed image includes patient I.D. and pertinent scan information. The R-O-I image also provides the same data.

Computer: Interdata 8/32 computer is provided with the Pho/Trax. Each computer includes 256K Bytes of high speed main frame memory and 10M Bytes disc drive. A mag tape option is available.

Dosimetry: Dose at 1.0cm slice thickness for a 5 second scan on a head phantom...

Dose	Single Slice	10 Contiguous Slices
Central	0.10 rad	0.40 rad
Max Skin	0.54 rad	0.67 rad

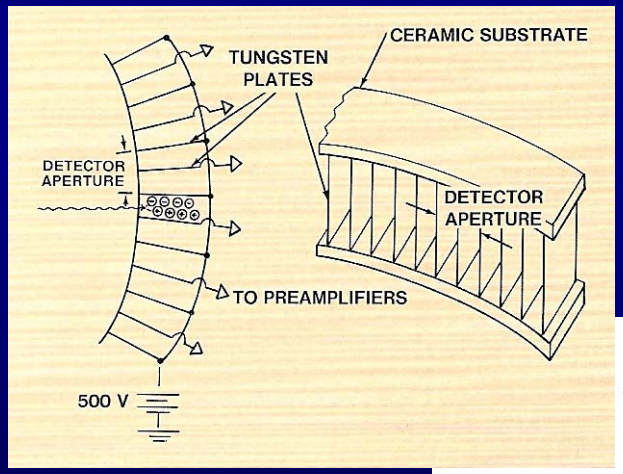
- Searle Pho/Trax
  - Head scanner
  - 3rd generation
  - Gas detectors
  - 5-40 sec scan time
  - 40 sec recon
  - Also had a body scanner (Pho/Trax 4000

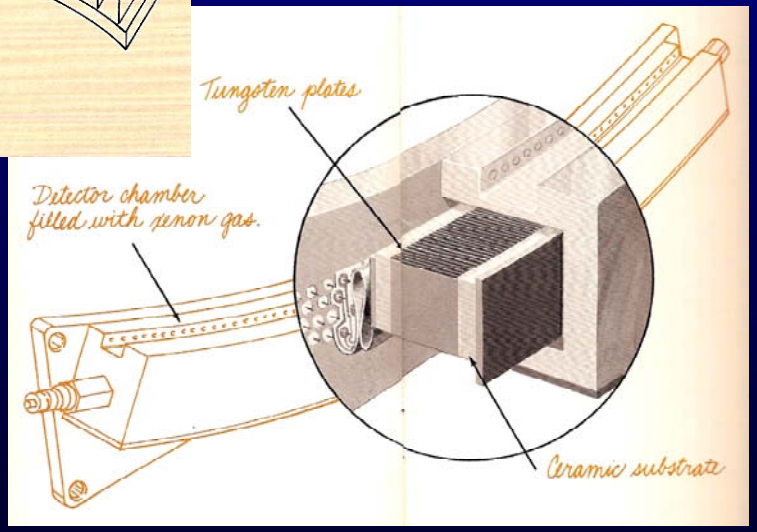


Innovations in 3rd Generation Geometries

- Challenge was to have stable detectors
  - No ability to calibrate during acquisition
  - Some machine required calibration between patients
- Samples per view determined by detector geometry

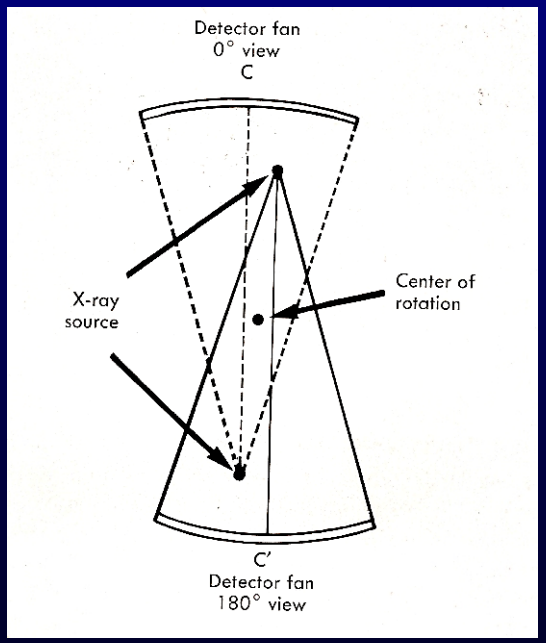
Gas Detectors



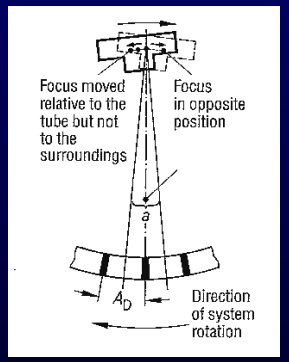


- High pressure Xe
  - ~ 20 atm
  - ~10-20 cm thick
- Used only in 3rd generation machines
- GE, Varian, Artronix, Searle

Sampling Innovations: 3rd Generation



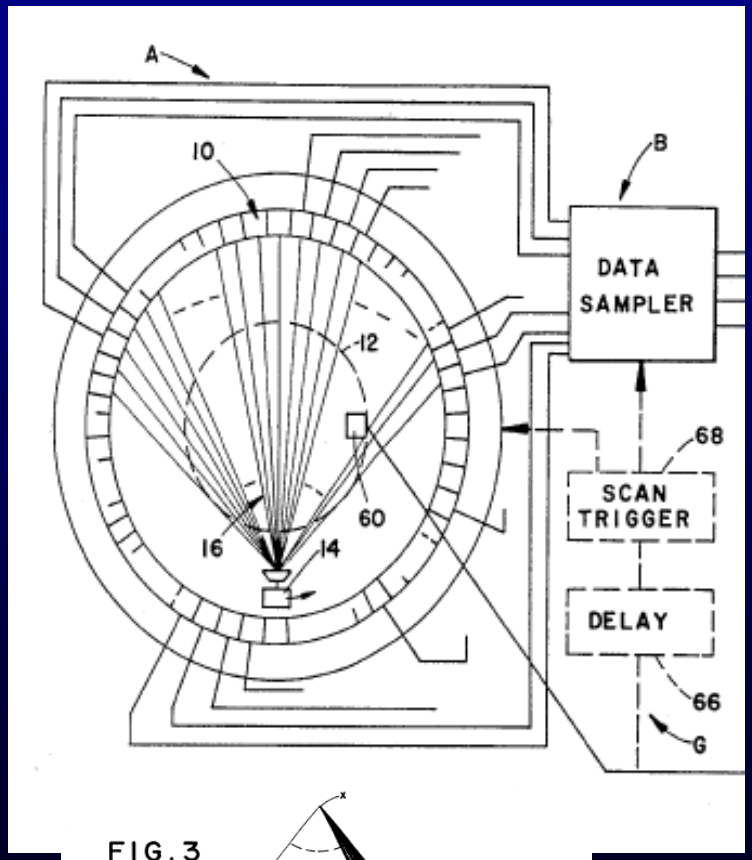
Quarter off-set (1979)

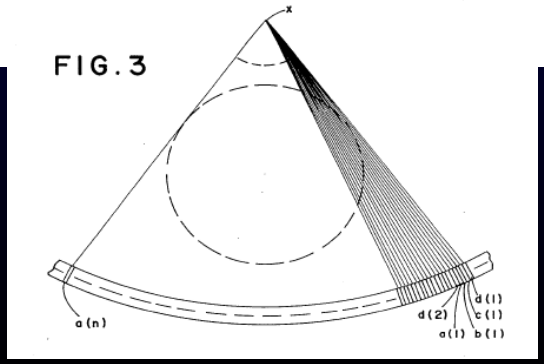


Flying Spot (1981)

RA Brooks, et al J Comput Assist Tomo 3 (1979)511-518

American Science and Engineering

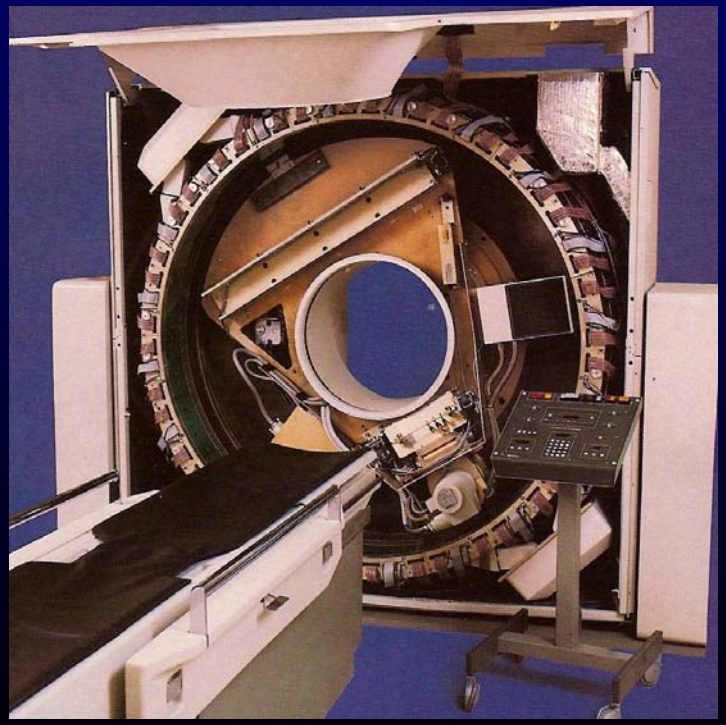




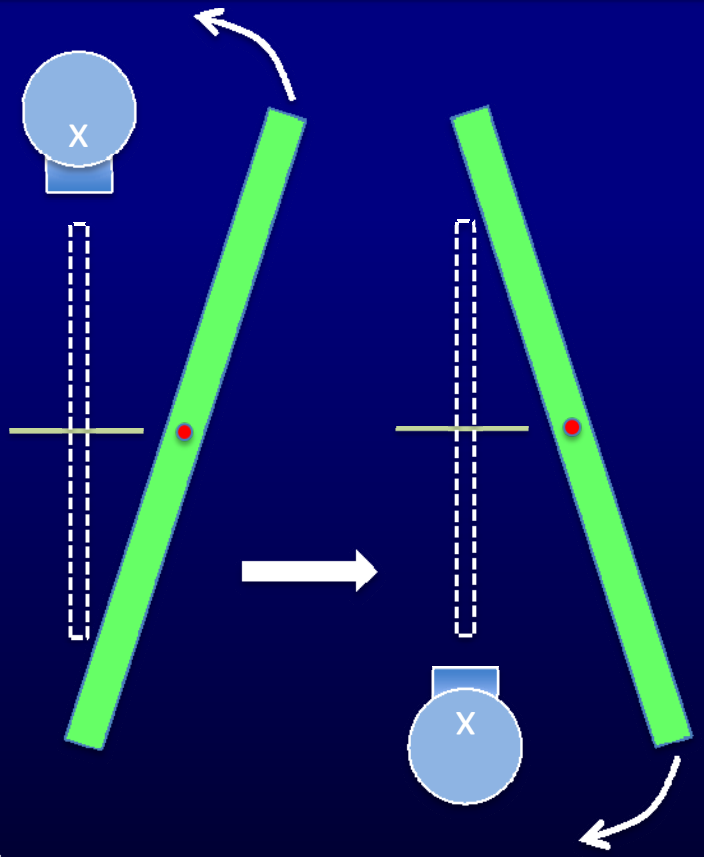
- First 4th generation CT (1976)
  - Rights later sold to Picker
- Used BGO
- Developed to overcome stability requirements of 3rd generation geometry
- Shown at 1976 RSNA

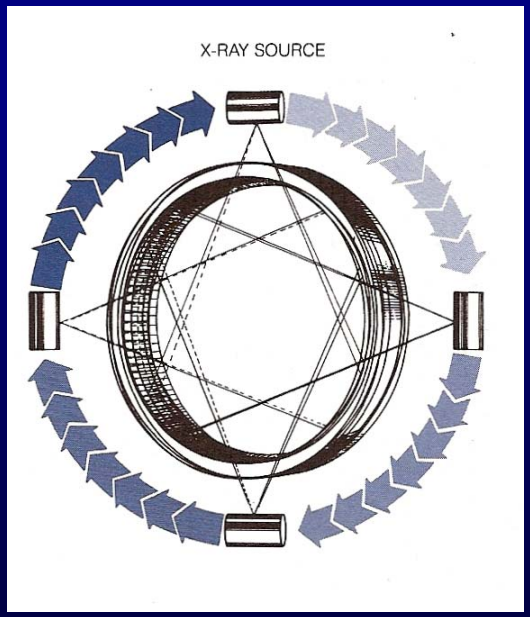
Innovations in 4th Generation Geometries

- Challenge is to have sufficient views
  - Samples per view not an issue



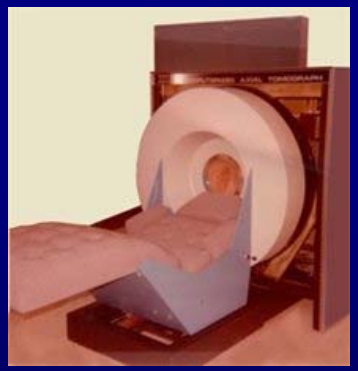
EMI 7070





- 4th generation, nutating ring
- Reduces ring diameter
  - For a given number of detectors, improves spatial resolution
  - 1088 CsI detectors
- Circa late 1970s

Artronix: A Typical Case



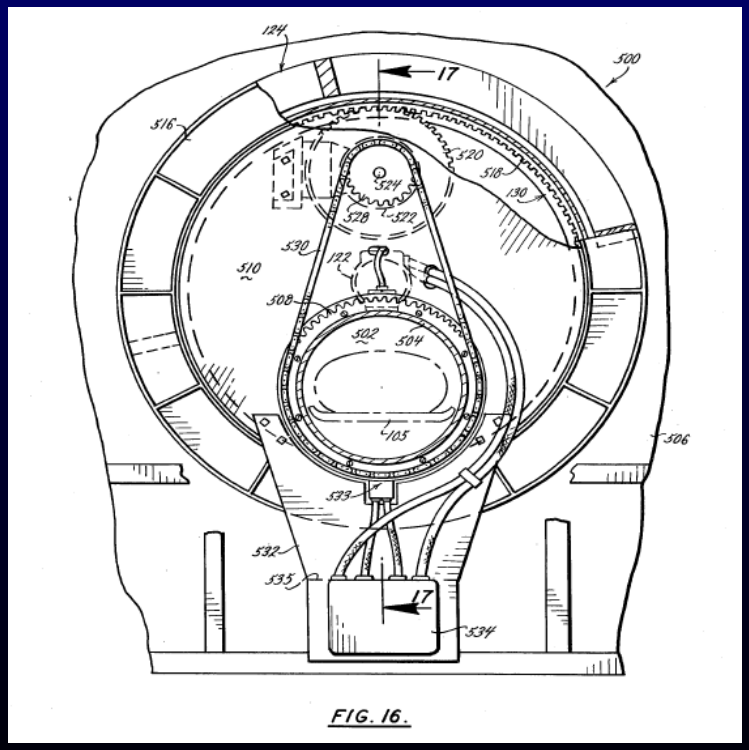


FIG. 16.

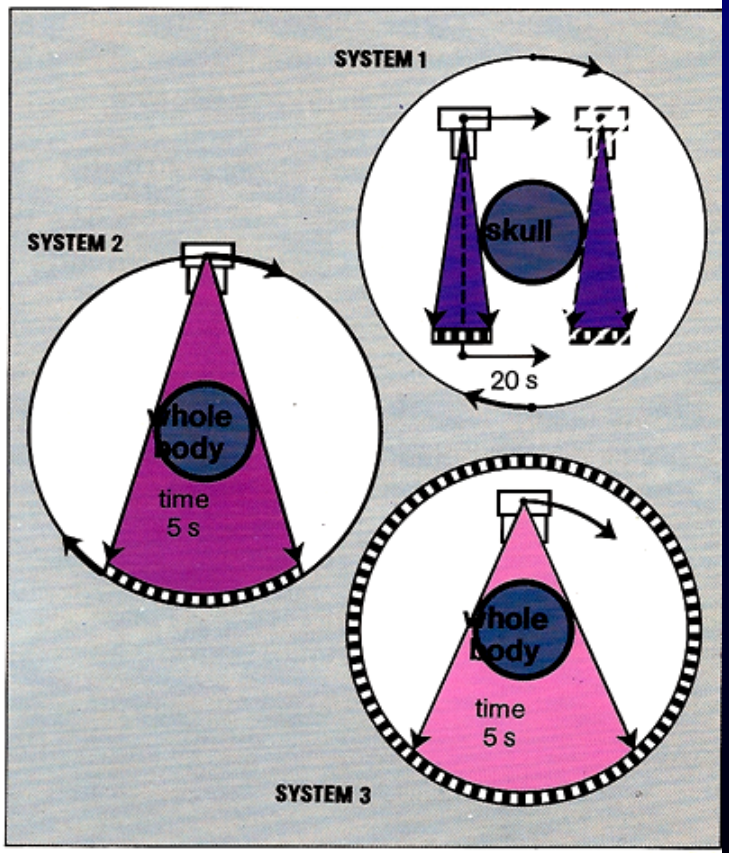
- Entered the CT market ~1974
  - 3rd generation
- Made both head and body scanners
- One of the first systems using Xe gas detectors
- Produced a 4th generation variant
- Went out of business in 1978

Decisions

conclusion

Principles 2 and 3 are suitable for systems designed for whole-body examinations : mainly because of the short examination time required by the involuntary movement of organs.
Maximum utilization of the X-ray beam is also an important element.
Principle 1 is most suitable for neuroradiology as it provides definitely superior spatial resolution.
Plus, the data obtained by multiple beams (from 30 to 60 detectors at a divergence angles of 10° to 20°) allows excellent utilization of the dose.
And, acquisition time is in the order of of 20 seconds, quite acceptable for the skull where voluntary movements can be controlled and/or the patient's movements can be calculated and compensated mathematically.

These considerations illustrate the reason for CGR's choice.



Miscellaneous Innovations

Company	Innovation
AS&E	4^{th} generation geometry, BGO detector
Artronix	Xe detector, 4^{th} generation variant
Elscint	Combined $2^{nd}/3^{rd}$ generation machine
Ohio Nuclear	2^{nd} generation, $CaF_2(Eu)$ solid state detector
Varian	Xe/Kr gas detector, high voltage slip rings

1978 Status

Table I—Characteristics of CT Scanners

GENERATION [a]	I	II	III
Time to Produce One Section	4-6 min.	20 sec. -2 min.	under 20 sec.
X-ray Source	single pencil beam	2 or more pencil beams or single fan beam	single fan beam
Detectors	1	2 or more (up to 60)	hundreds - contiguous
Motion of Gantry	Source and detector move together in small lateral and small rotational steps	Sources and detectors move together in larger lateral and rotational steps than Generation 1	Rotational motion only. In most models, source and detectors move together, but in some, only source moves
Operational [b] Commercial Models	EM I Brain Scanner (H)[c] Pfizer ACTA 0100 (B)[c] Siemens Siretom (H) General Electric - Neuroscan CT/N (H)	EM I CT 1010 (H) EM I CT 5005 (B) Ohio-Nuclear DELTA (H and B) Syntex System 60 (H) Syntex System 90 (B)	Artronix Neuroscanner 1100 or 1110 (H) General Electric CT/T (B) Varian (B) American Science & Engineering (B) Searle Pho/Trax (B)
Models not yet installed [b]		Phillips Tomascan (B)	Artronix Whole-Body scanner 1120 (B)

a Nomenclature of Brownell (79).
[b] As of June 1, 1978.
c H = Head, B = Body.

- 14 companies listed
- All geometries represented

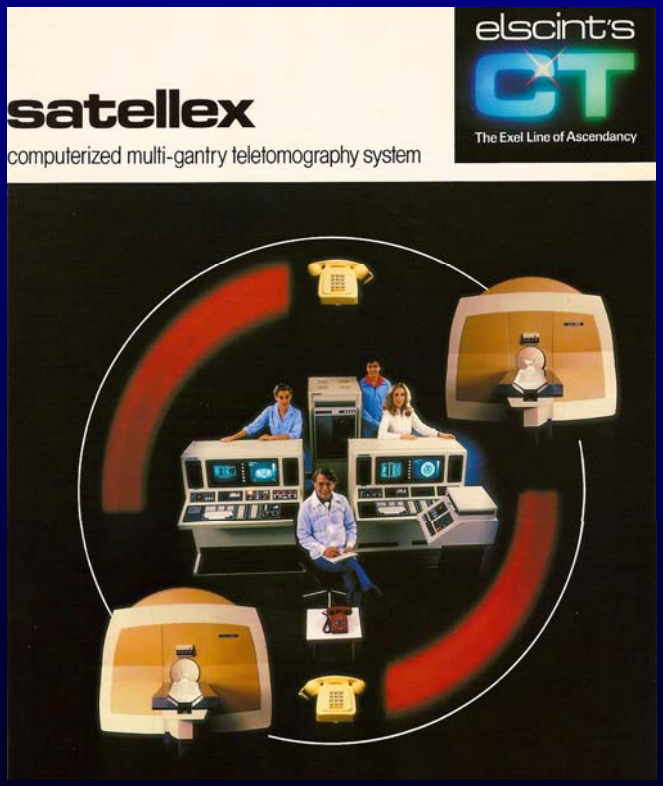
Policy Implications of Computed Tomography (CT) Scanner, NTIS #PB81-163917 (1978)

CT Industrial Applications (NDT)

1981

- Aerojet Strategic Propulsion Company
  - Principle use solid fuel rockets/missles
  - 420 KeV
  - Up to 1m diameter objects
  - Slice thickness 1-10mm

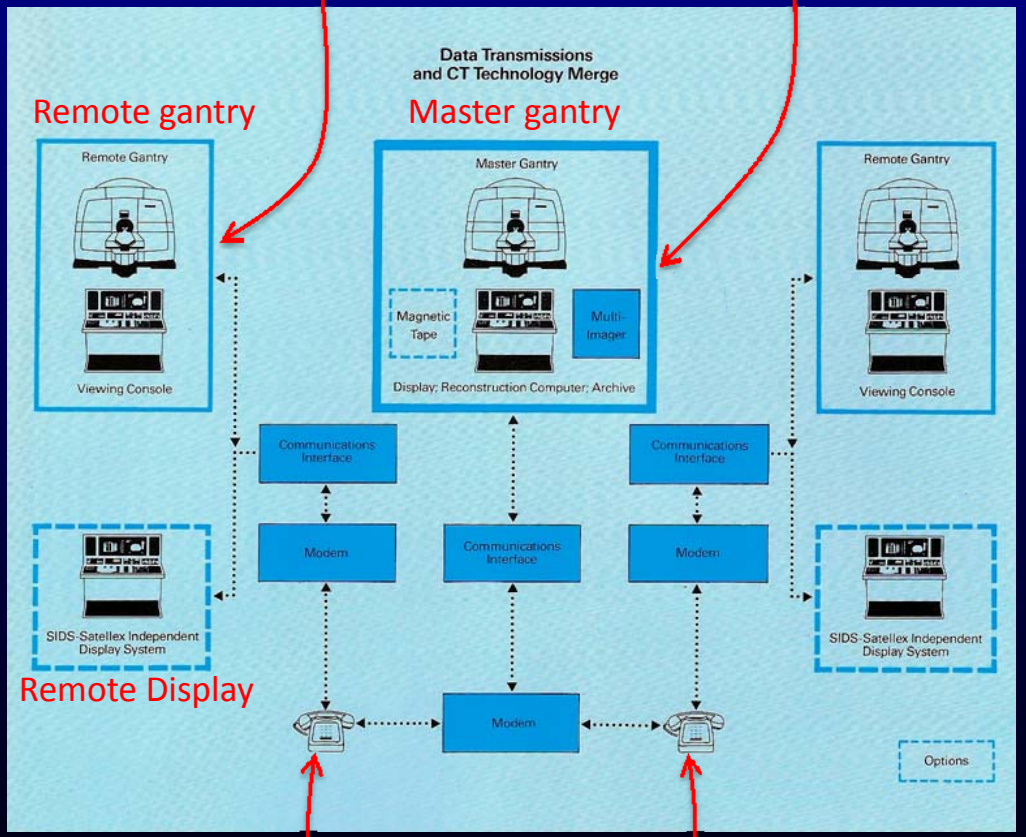
Teletomography



Circa 1985

Data acquisition and display only

Reconstruction done centrally



Modem links

Dose Measurements

- Computed Tomography Dose Index
  - formalized in 1981 by TB Shope, et al Med Phys 8 (1981)488-495.

$$CTDI_{14T} = \frac{1}{nT}\int_{-7T}^{+7T} D(z)dz$$

Socioeconomics

- Required education (re-education?) of practicing radiologists
- Cost-effectiveness questions
  - Concerns regarding the cost of medical care if CT did not replace existing procedures
- "Much work remains to be done in order to establish those areas in which CT scanning will actually affect patient management not just verify the existence of disease!"
  - McCullough and Payne: 'X-Ray Transmission Computed Tomography', Med Phys 4(1977) 85-98.

And Today

- Scan times < 0.3 sec
- No tube cooling issues
- Slice thicknesses of 0.5 mm
- Can buy a CT scanner for ~ same as an EMI head scanner
- BUT top end machines sell for > $2.5 million