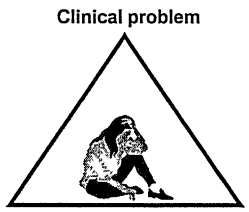
IAEA Training Course on Radiation Protection in Nuclear Medicine

Part 0

Introduction to Nuclear Medicine

NUCLEAR MEDICINE

Diagnosis and therapy with unsealed sources



Radiopharmaceuticals

Radionuclide	Pharmaceutical	Organ	Parameter
Tc-99m	+ colloid	Liver	RES
	+ MAA	Lungs	Regional perfusion
	+ DTPA	Kidneys	Kidney function

HISTORY-RADIONUCLIDES

1896	Natural radioactivity	Becquerel
1898	Radium	Curie
1911	Atomic nucleus	Rutherford
1913	Model of the atom	Bohr
1930	Cyclotron	Lawrence
1932	Neutron	Chadwick
1934	Artificial radionuclide	Joliot-Curie
1938	Production and identification of I-131	Fermi et al
1942	Nuclear reactor	Fermi et al
1946	Radionuclides commercially available	Harwell
1962	Tc99m in nuclear medicine	Harper

PIONEERS



Henri Becquerel



Ernest Rutherford

Maria Curie

Fredrique Joliot-Irene Curie

CURRENT METHODS-THERAPY

Radiopharmaceutical		For treatment of	Route of administration	Maximum activity
I-131	iodide	Thyrotoxicosis	Oral	1 GBq
I-131	iodide	Carcinoma of thyroid	Oral	20 GBq
I-131	MIBG	Malignancy	IV	10 GBq
P-32	phosphate	Polycythaemia vera	IV or oral	200 MBq
Sr-89	chloride	Bone metastases	IV	150 MBq
Y-90	colloid	Arthritic conditions	Intra-articular	250 MBq
		malignant effusions	Intra-cavitary	5 GBq
Er-169	colloid	Arthritic conditions	Intra-articular	50 MBq
Re-186	colloid	Arthritic conditions	Intra-articular	150 MBq

HISTORY-THERAPY

1936	Therapeutic use of Na-24 (leukemia)	Hamilton et al
1936	Therapeutic use of P-32 (leukemia and polycythemia vera)	Lawrence
1941	Therapeutic use of iodine in hyperthyroidism	Hertz et al
1942	Therapeutic use of iodine in treatment of metastasis from thyroid cancer	
1945	Therapeutic use of Au-198 in treatment of malignant effusion	Muller
1958	Treatment of bone metastasis with P-32	Maxfield
1963	Medical synovectomy using Au-198	Ansell

I-131 therapy

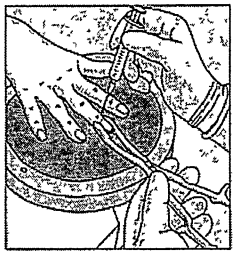
The absorbed dose to be delivered should be determined from uptake measurements, effective half-life of the radio-pharmaceutical and the size of the thyroid.

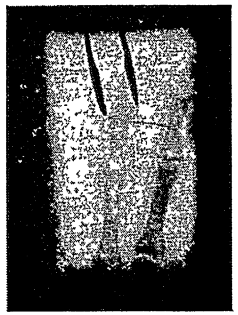
The radiopharmaceutical is administered p.os.

Hyperthyroidism

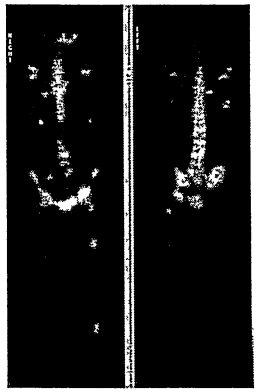
Cured after		Hypothyroidism	
3-4 months	1 year	after <7 years	after >7 years
85%	98%	14.8%	27.9%

Radiosynovectomy





PAIN PALLIATION



Intravenous injection of a radiopharmaceutical which includes e.g. Sr-89 or Sm-153

ANNUAL FREQUENCY-THERAPY (Sweden 1995)

Number of patients per 1000 population

Thyroid (tumours & hyperthyroidism)	0.39
Polycythemia vera	0.034
Other tumours	0.003
Others	0.001
Total	0.428

about 3% of all nuclear medicine

Current diagnostic methods

Imaging

Bone, Brain, Lungs , Thyroid, Kidneys, Liver/spleen, Cardiovascular, Stomach/GI-tract, Tumours, Abscesses .....

Non-imaging (probes)

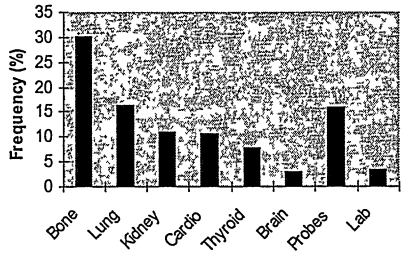
Thyroid uptake, Renography, Cardiac output, Bile acid resorption.....

Laboratory tests

GFR, ERPF, Red cell volume/survival, Absorption studies (B12, iron, fat), Blood volume, Exchange-able electrolytes, body water, bone metabolism.....

RadioImmunoassays (RIA)

Annual frequencies-diagnosis (Sweden, 1998)



15 examinations/1000 population

Health-care level I

Country	1970-79	1980-84	1985-90	Country	1970-79	1980-84	1985-90
Argentina			11.5	Kuwait			13.1
Australia	3.8	8.9	8.3	Luxembourg			23.5
Austria	18.0			Netherlands			11.6
Belgium			36.8	NewZeeland	5.6	7.3	7.5
Bulgaria		13.0		Norway	3.9		9.3
Canada			12.6	Romania		3.0	3.5
Czechoslovakia	13.6	18.3	22.9	Sweden	9.8		12.6
Denmark	14.0	14.2	13.4	Switzerland	44.9		
Finland	12.6	17.7		USSR		3.9	
France		9.0	6.9	UnitedKingdom		6.8	
Germany	31.1	39.7	39.8	United States			25.7
Italy	6.0		7.3	Yuoslavia			6.1
Japan			8.3				
				Average	11	6.9	16

Total annual number of nuclear medicine examinations per 1000 population (UNSCEAR)

Health-care level II

Country	1970-79	1980-84	1985-90	Country	1970-79	1980-84	1985-90
Barbaidos			1.0	Iraq			1.2
Brazil			1.7	Jamaica	2.8		2.0
China			0.6	Peru			0.2
Cuba	0.8			Tunisia			1.0
Equador	0.5		0.8	Turkey			2.5
India		0.1	0.2				
				Average	0.9	0.1	0.5

Health-care level III

Country	1970-79	1980-84	1985-90	Country	1970-79	1980-84	1985-90
Egypt	0.07	0.21	0.48	Sudan	0.12	0.28	0.28
Myanmar	0.54	0.36	0.11	Thailand	0.25	0.18	0.26
				Average	0.25	0.25	0.30

Health-care level IV

Country	1970-79	1980-84	1985-90		1970-79	1980-84	1985-90
Ethiopia		0.014	0.10				
				Average		0.014	0.10

Total annual number of nuclear medicine examinations per 1000 population (UNSCEAR)

HISTORY-DIAGNOSTICS

1927	Blood flow studies (Bi-214)	Blumgart-Weiss
1935	Bone metabolism (P-32)	Chiewitz-de Hevesy
1939	Thyroid studies (I-131)	Hamilton et al
1948	Radiocardiography (Na-24)	Prinzmetal et al
1956	Renography (I-131)	Taplin, Winter
1957	Liver scan (Au-198 colloid)	Friedell et al
1961	Bone scan (Sr-85)	Fleming et al
1962	Myocardium (Rb-86, Cs-131)	Carr et al
1964	Lung scan	Taplin et al
1965	Brain scan (Tc99m-pertechnetate)	Bollinger et al
1971	Bone scan (Tc99m-complex)	Subramanian et al



George de Hevesy
1885-1966

de Hevesy G & Paneth F. Die Lösligkeit des Bleisulfids und Bleichromats.
Z. Anorg Chem 82, 323, 1913.

de Hevesy G. III. The absorption and translocation of lead by plants.
Biochem J, 17, 439, 1923.

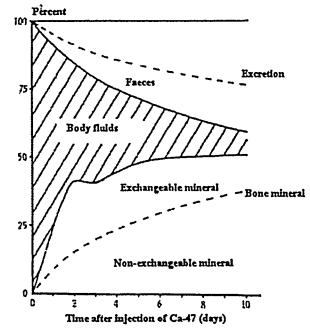
Chiewitz O. & de Hevesy G.
Radioactive indicators in the study of phosphorous metabolism in rats.
Nature 136, 754, 1935.

MINERAL METABOLISM

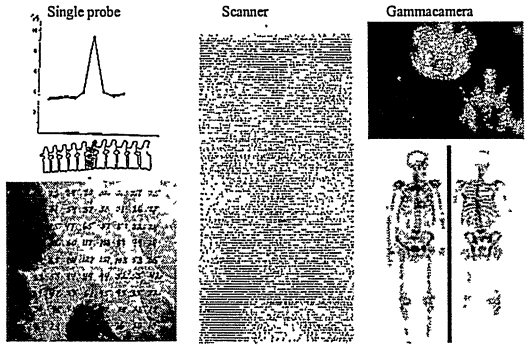
Göran C. H. Bauer
Arvid Carlsson
Bertil Lindquist

MINERAL METABOLISM
(1961)

..studies of bone by isotope techniques have now reached beyond the stage of methodology to give data of immediate physiological and clinical importance.



BONE SCAN



Instrumentation in nuclear medicine

- Activity meter
- Sample counters
- Single- and multi-probe systems
- Gammacamera
- Positron camera (PET)

Kidney clearance

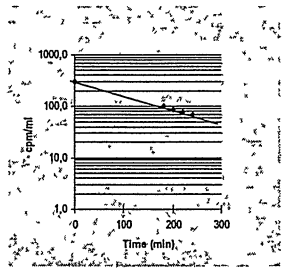
(plasma samples)

Cr51-EDTA, 300 kBq
Plasma samples at 180-240 min

Clearance (Cl) is calculated:

$$Cl = A \,/\, \int_0^{\infty} C_p(t) * dt$$

A is injected activity
C_p is activity concentration in plasma



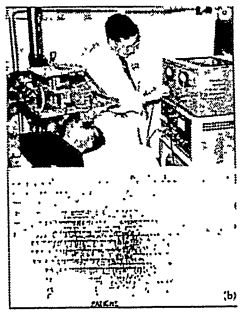
Thyroid uptake measurement



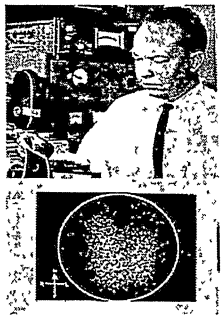
HISTORY-INSTRUMENTS

1908	Visual scintillation (ZnS)	Crookes
1927	Geiger-counter	Geiger
1944	Scintillation detector (ZnS+PM)	Curran
1948	Sodium iodide crystal	Hofstadter
1950	Scanner	Cassen
1957	Gammacamera	Anger
1963	Tomography	Kuhl

PIONEERS

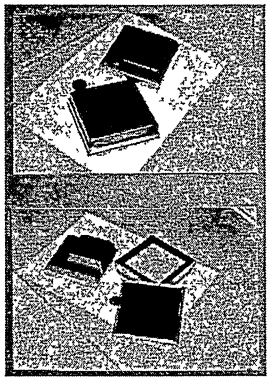


B. Cassen

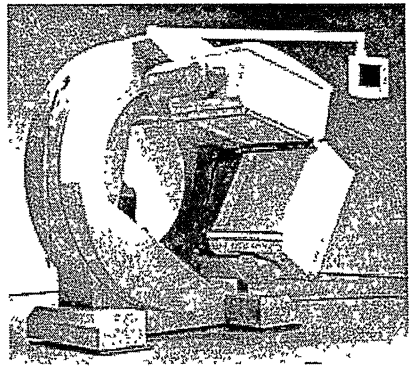


H.O. Anger

GAMMACAMERA?

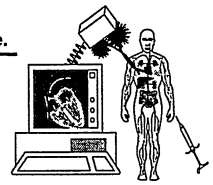


GAMMACAMERA



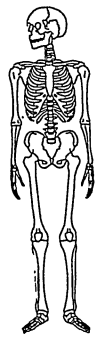
Nuclear medicine images

- Nuclear imaging detects (functional vs. anatomical) properties of the human tissue.
- The imaging is done by tracing the distribution of radiopharmaceuticals within the body with a gammacamera

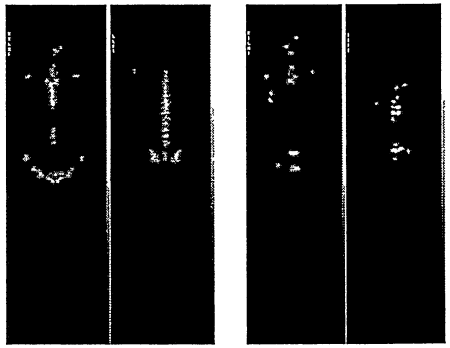


BONE SCAN

- Bone uptake of ^{99m}Tc MDP reflects bone metabolism and blood flow, and allows functional analysis of bone turnover.
- The ability to image bone metabolism alterations enables detection of lesions such as :
  - Bone metasasis
  - Benign or malignant bone tumors
  - Bone trauma.
- A three-phase acquisition procedure is required in order to detect osteomelitis.
- Bone scans also facilitate follow-up of other bone disorders, such as Paget's disease.
- Intravenous injection of 400-600 MBq ^{99m}Tc MDP . Imaging 3h after injection.



BONE SCAN



normal

pathologic

LUNG SCAN

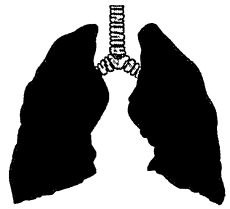
A proportionately spread embolization of the pulmonary capillary bed yields an image reflecting the lung blood perfusion (Tc^{99m} MAA). This image enhances the diagnosis of pulmonary emboli.

Intravenous injection of 100 MBq Tc^{99m} MAA. Immediate scanning.

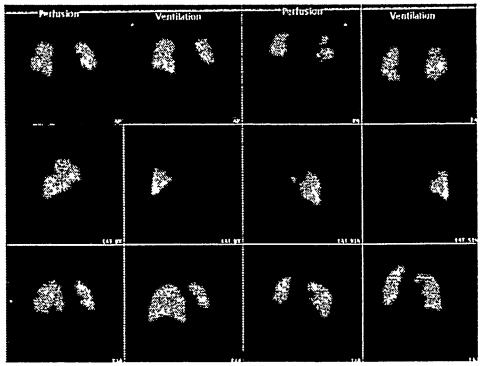
Ventilation studies (Tc^{99m} -aerosols) reflect the regional and segmental ventilation. Study interpretation is performed in conjunction with perfusion findings, supporting the differential diagnosis of pulmonary emboli.

Inhalation of 100 MBq Tc^{99m} -aerosols.

Immediate scanning.



LUNG SCAN



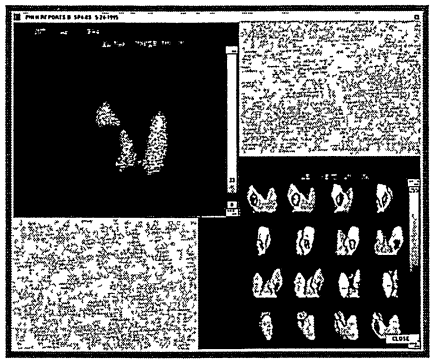
THYROID



Thyroid scintigraphy (I^{123}, I^{131} or Tc^{99m} pertechnetate) offers structural and functional information by displaying the thyroid image and calculating uptake, organ volume etc. Pinhole SPECT studies offer superior contrast resolution image over the planar image, enhancing thyroid nodules detection and evaluation.

Intravenous injection of 100 MBq Tc^{99m} pertechnetate. Scanning 15 min later.

THYROID SCAN

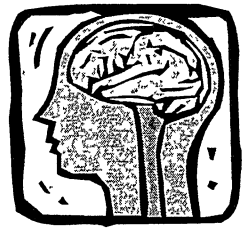


CEREBRAL BLOODFLOW

- ^{99m}Tc HMPAO or similar compound - retained in the brain in proportion to regional cerebral blood flow.
- Localizes predominately in the gray matter and does not show redistribution.
- Enhances detection of :

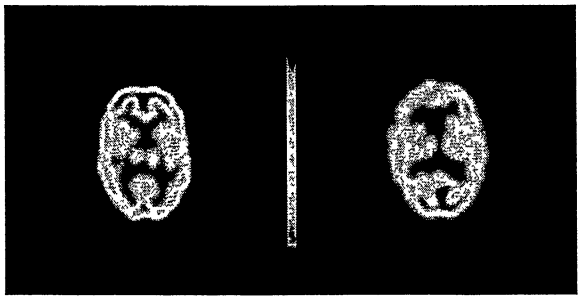
Brain dementia such as Alzheimers disease, seizure localization Foci,

Cerebral vascular problems such as cerebral ischemia, trauma and brain death



Intravenous injection of 800 MBq ^{99m}Tc HMPAO. Tomography 30 min later

Cerebral bloodflow

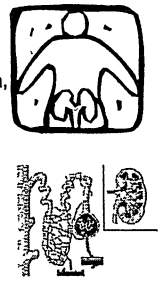


normal Alzheimers disease

KIDNEY FUNCTION

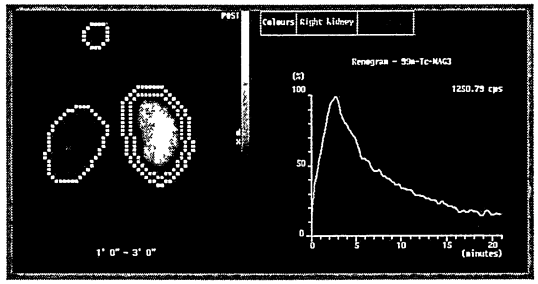
•Determination of kidney clearance of Cr51-EDTA or Tc-99m DTPA.

•Dynamic renal scintigraphy reflects renal blood perfusion, uptake and excretion. The acquisition yields a series of images. By calculating count rate in a defined ROI, a renogram is created, providing quantitative data. Different radiopharmaceuticals, such as Tc99m-MAG3, Tc99m-DTPA and I123-Hippuran, are used for renal clearance and function assessment.

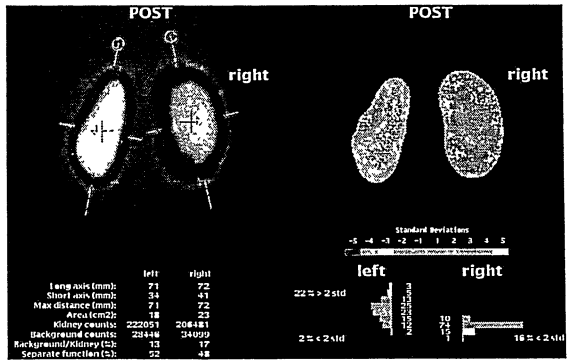


•Renal scan for parenchymal anatomy and function evaluation uses Tc99m-DMSA

Kidney function (Tc99m-DTPA)



KIDNEY FUNCTION (Tc99m-DMSA)

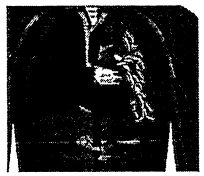


FIRST PASS STUDIES

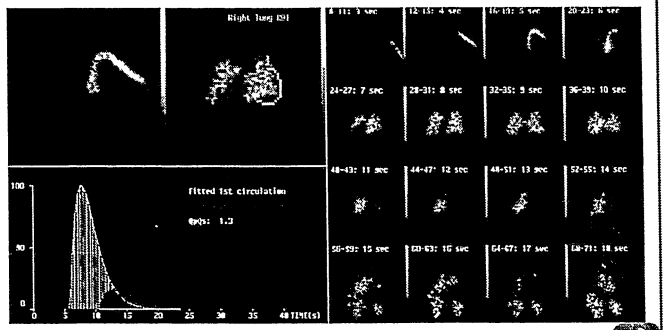
•Intravenous high activity (400-800 MBq) Tc-99m bolus tracer injection, followed by a short acquisition (4-20 frames per second during 1 minute) demonstrates Myocardial function eliminating background activity bias.

•First pass procedures facilitates:

- •Wall motion imaging
- •LV and RV ejection fraction calculations
- •Detection of left to right intracardial shunts
- •Cardiac output calculations
- •Ventricle volume calculations
- •Transit times calculations

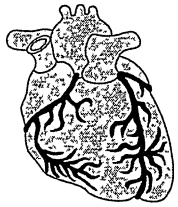


SHUNT QUANTIFICATION

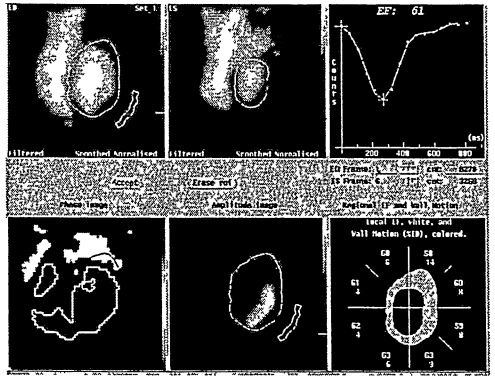


ECG-gated bloodpool scanning

- Red blood cell labeling (Tc^{99m}), followed by gated acquisition and measurement of the corresponding dynamic blood volume count rate changes, enables LV and RV blood volume quantification. The analysis of ventricular wall motion, systolic/diastolic functions, and Ejection Fraction, has application for CAD evaluation, risk stratification, and monitoring of cardiotoxicity in chemotherapy treatments.
- Intravenous injection of 600-800 MBq Tc^{99m}, scanning 10-15 min later.



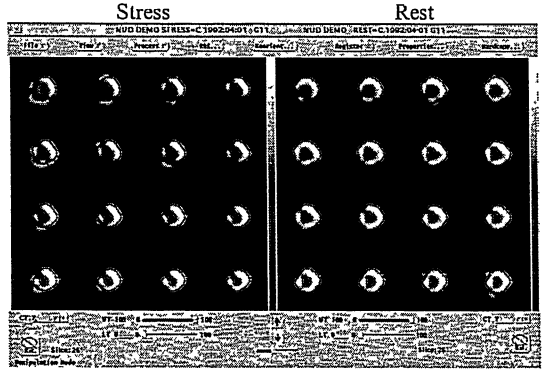
ECG-gated blodpool scanning



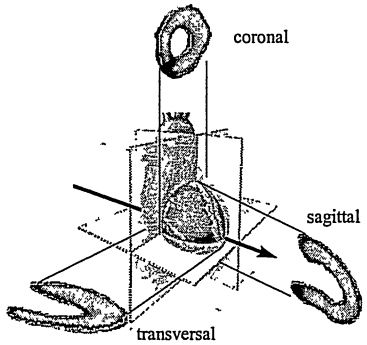
MYOCARDIAL PERFUSION

- ^{201}Tl accumulation in the myocard depends on blood flow and cellular metabolism, hence, reflects regional perfusion and viability of the cardiac muscle.
- The evaluation of a patient suspected or known for C.A.D. is based on image interpretation or quantitative analysis from reconstructed tomographic slices, which also yields regional perfusion information.
- The examination is performed under maximum stress condition and after rest.
- Injected activity 70-100 MBq ^{201}Tl. Tomographic study.

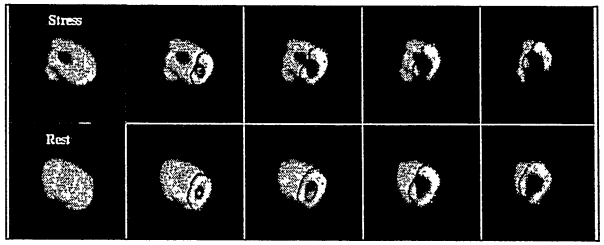
Myocardial perfusion



TOMOGRAPHIC SLICES



Myocardial perfusion

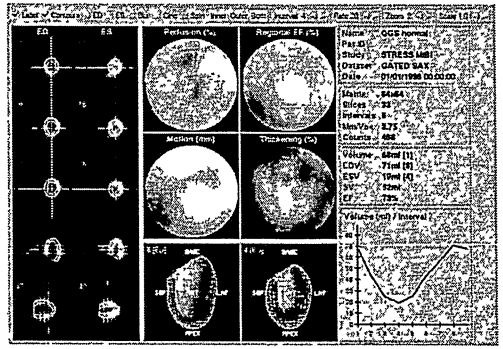


MYOCARDIAL PERFUSION

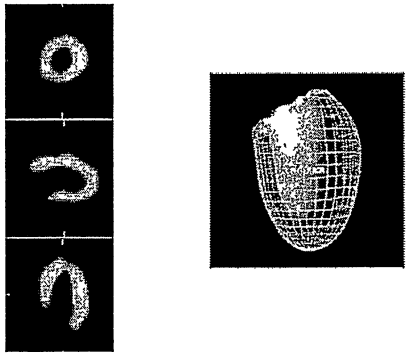
- The physical properties offered by ^{99m}Tc MIBI or Tetrofosmin facilitate evaluation of myocardial perfusion and function by enabling performance of gated SPECT perfusion studies initiated with first pass acquisition. The assessment of a patient with known or suspected C.A.D. is based on quantitative analysis and coronary artery regional perfusion evaluation, drawn from a set of reconstructed tomographic slices.
- Injected activity 800-1000 MBq. Gated tomographic acquisition



ECG-gated myocardial perfusion



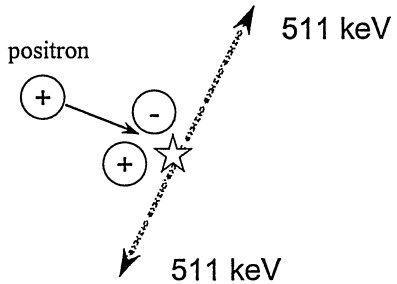
GATED SPECT



PET

Positron Emission Tomography

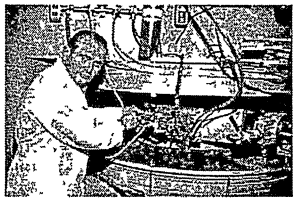
ANNIHILATION

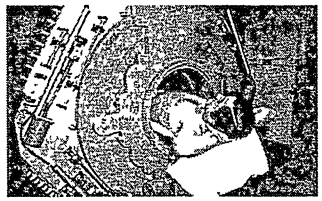


Radionuclides

Radionuclide	*Halflife*	*Particle energy (mean)*
C-11	20.4 min	0.39 MeV
N-13	10 min	0.50 MeV
O-15	2.2 min	0.72 MeV
F-18	110 min	0.25 MeV
Cu-62	9.2 min	1.3 MeV
Ga-68	68.3 min	0.83 MeV
Rb-82	1.25 min	1.5 MeV

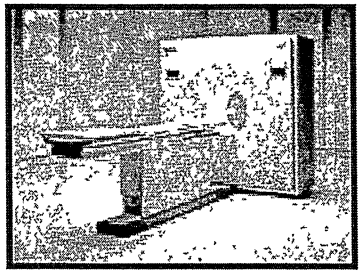
PIONEERS



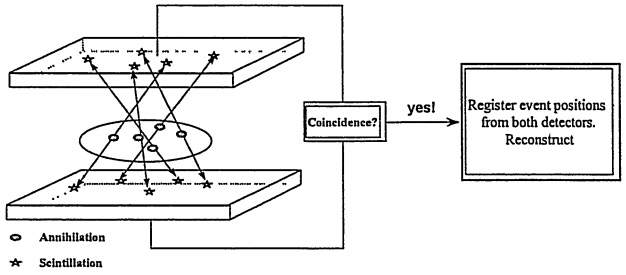


Michel Ter-Pogossian prepares a radiopharmaceutical for an examination of Henry Wagner Jr with one of the first PET-scanners (1975).

PET-SCANNER

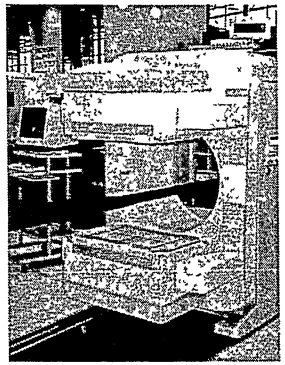


PET with gammacamera

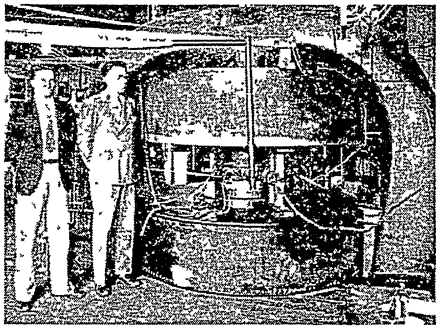


(Gerd Muehllehner et al 1994)

PET with gammacamera

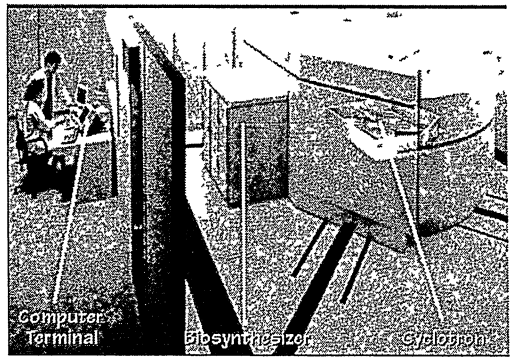


CYCLOTRON

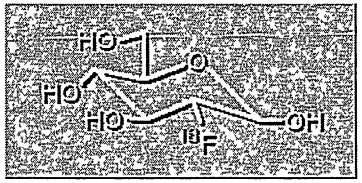


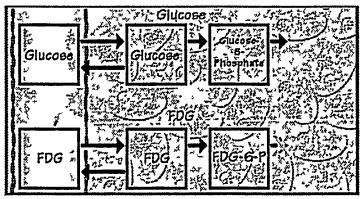
Stanley Livingstone and Ernest Lawrence with their 8 MeV cyclotron (1935)

CYCLOTRON IN HOSPITALS

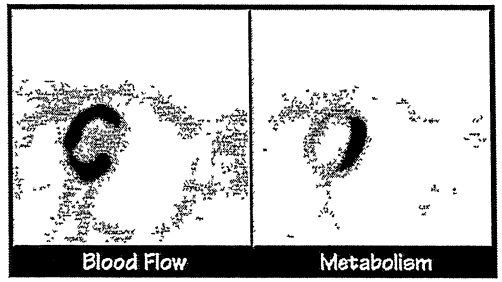


F18-FDG





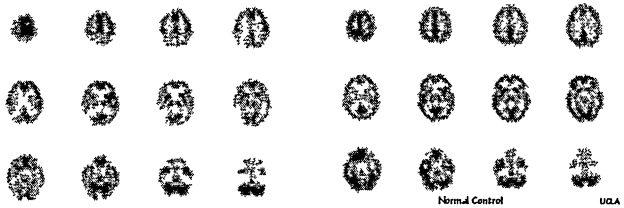
FDG in cardiology



FDG in oncology



FDG in neurology

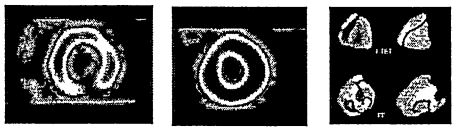


Alzheimers disease

Normal

The Future
Diagnostic methods

- New radiopharmaceuticals based on positron emitters.
- Radiopharmaceuticals with high specificity.
- More advanced application programs which improve both sensitivity and specificity of the examination.





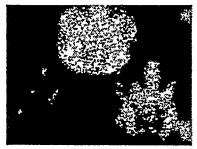
The Future
Instrumentation



- Improved performance of the gammacamera
- Improved detection of positron emitters
- More sophisticated methods for reconstruction and correction of tomographic examinations
- Advanced electronic reporting systems.



Nuclear medicine - unclear medicine?



No! Nuclear medicine is an efficient diagnostic and therapeutic tool and is justified from a medical point of view.

