Applications of (Nuclear) Radiation for Societal Welfare – emphasis on Healthcare Applications

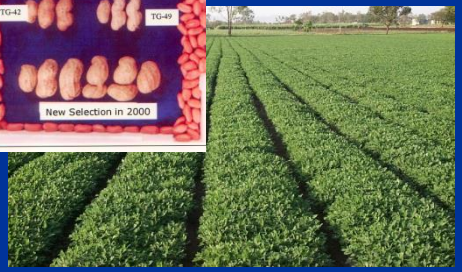
Meera Venkatesh
prof.mvenkatesh@gmail.com

IWSA Lecture; 07 May 2020

Nuclear Techniques and Applications

- Nuclear

- Radiation based technologies
  - Varied Uses; applications

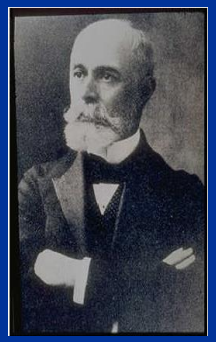


Radiation – A Glimpse at the past

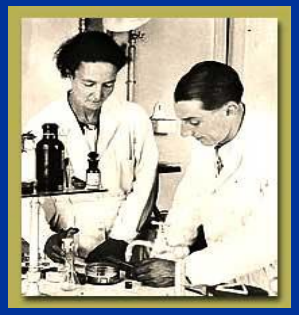
- **Radiations**
  - ❖ Radioactive nuclides – natural; artificial
  - ❖ *Machine produced : X-rays; e-beams*
  - ✓ Foundation laid more than a century ago!
  - ✓ First Half of last century – ‘Golden’ era
  - ✓ Numerous Nobel Prize Winning inventions and discoveries

W.H. Rontgen (1901-Phy)

George Hevesy (1943)

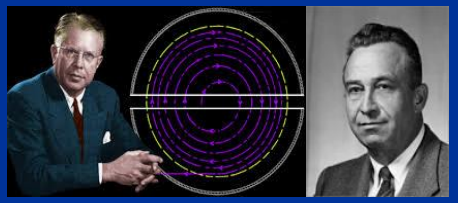


Henry Becquerel ; Marie & Pierre Curie (1903)

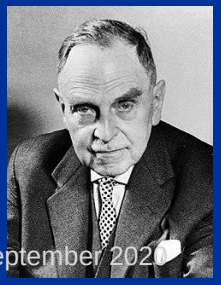


Frederick & Irene Joliot Curie (1935)

Enrico Fermi (1938)

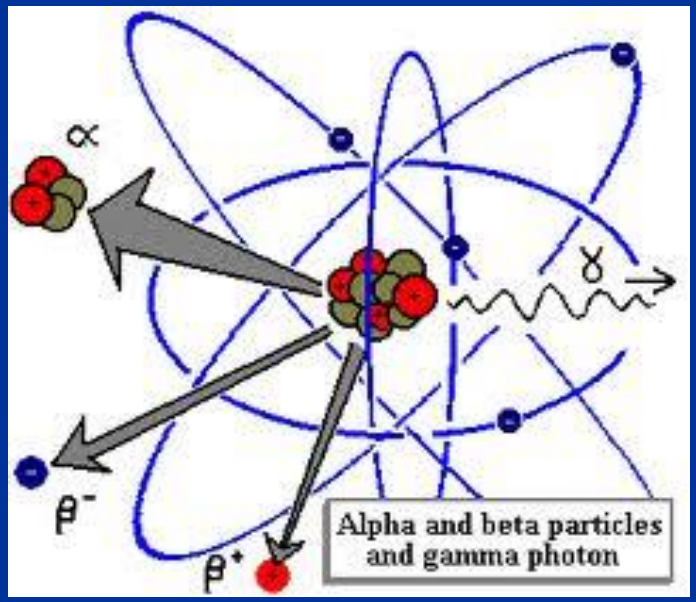


Lawrence & Livingston (1939)



Otto Hahn (1944)

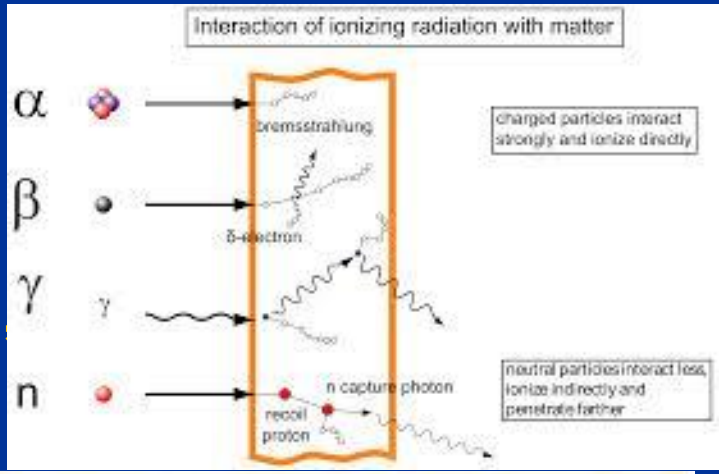
Nuclear Radiations

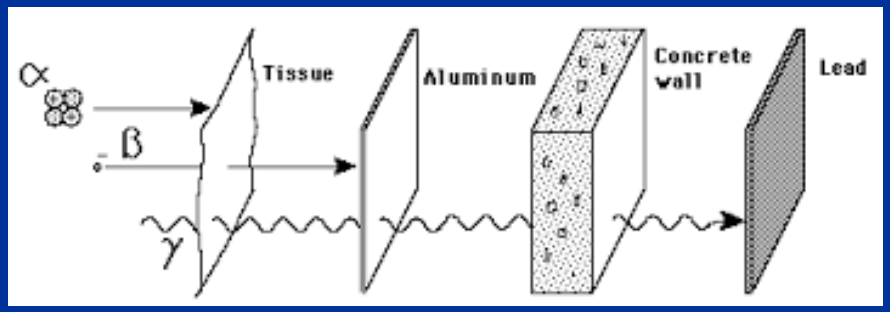


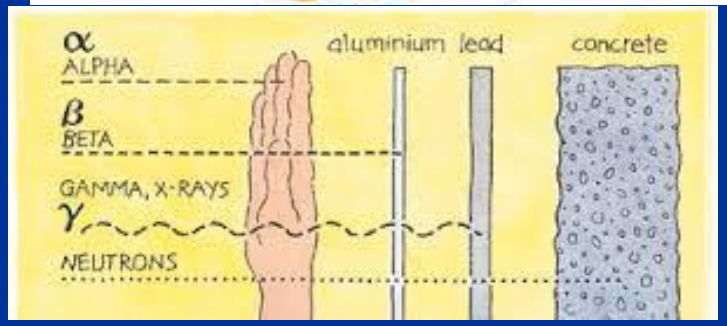
- **'Nuclear': Atomic nucleus**
  - Isotopes
    - Radioactive isotopes
    - Stable isotopes
  - **Radiations :**
    - alpha (α), beta (β) : particulates;
    - gamma (γ) : non-particulate
    - energetic; ***varying energies***
    - Transient - non-permanent; Concept of half life ($T_{1/2}$)
  - **Nuclear techniques**
    - **Related to isotopic measurements**
    - **Based on Radiation induced processes**

Radiations : why are they useful

- Being **energetic**, radiations are '**powerful**' and can cause changes when they come across material; And, they also undergo '**attenuation**'



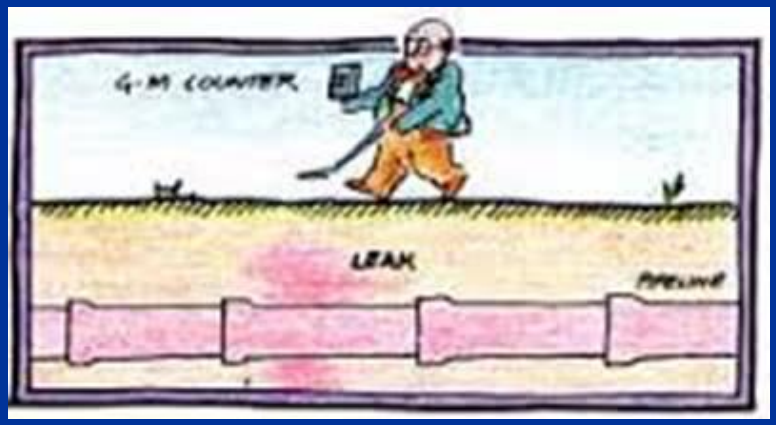




- These **changes** and **attenuation** are the basis of their enormous uses in a variety of areas – many of which touch our daily life!

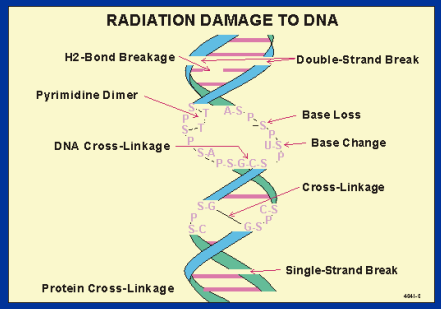
Radiations : How are they useful -1

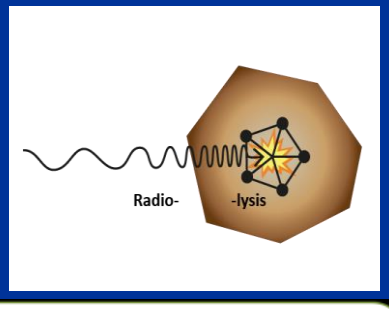
- **Radiation & Radionuclides**
  - Energetic
    - Can be easily detected at very low levels and can provide information, wherever they are (like spies!)
    - Basis for use of radioisotopes as ***tracers***

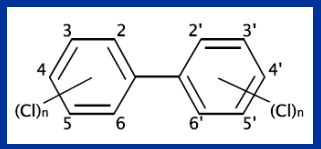


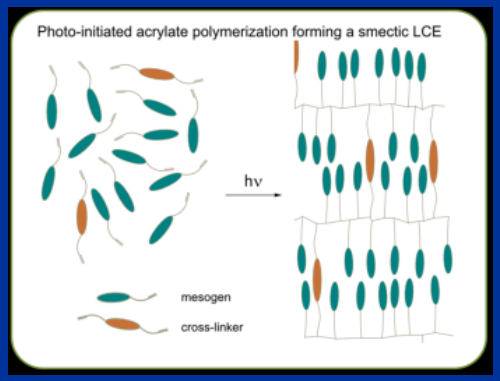
Radiations : How are they useful -2

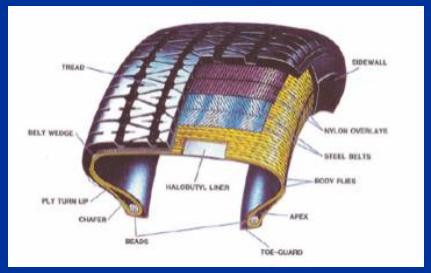
- **Radiation & Radionuclides**
  - Energetic
    - Powerful to cause changes in living as well as inanimate things
      - Can **damage/kill** germs/bacteria/virus/cancer cells
      - Can **alter materials**
        - Can **cross-link** molecules
        - Can **break** tough chemicals
        - Can **create defects** in crystal





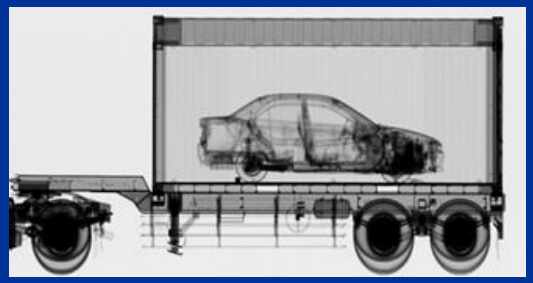


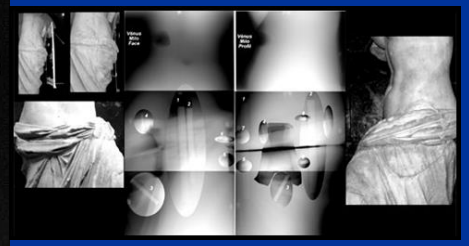




Radiations : How are they useful - 3

- Radiation & Radionuclides
  - Energetic
    - Lose energy on passing through matter
    - The ‘attenuation’ behavior is dependent on the matter they interact with and hence can provide information about the material they pass through

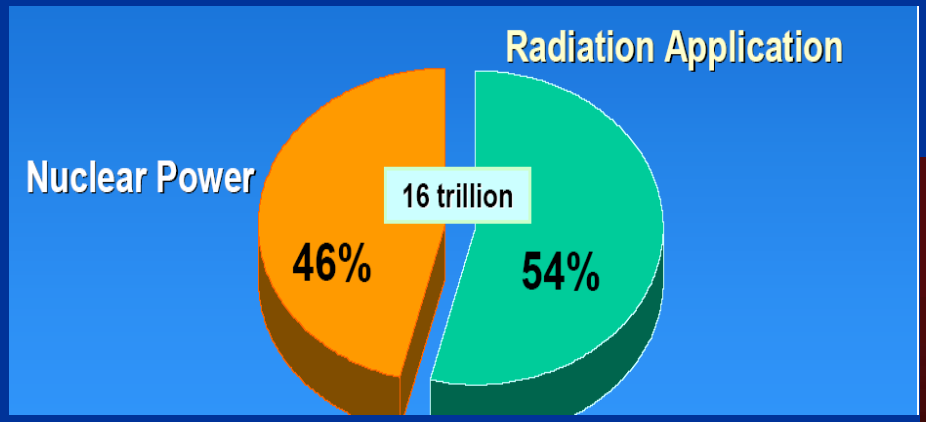




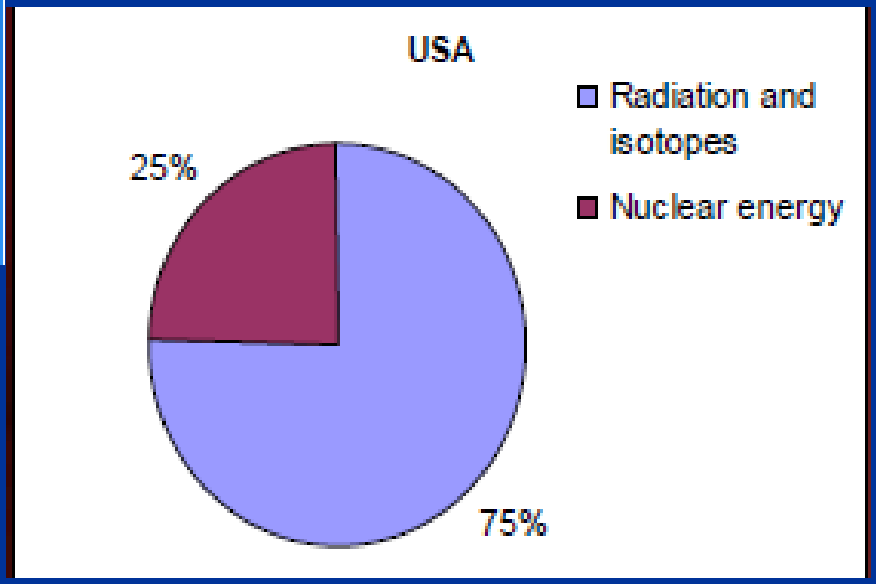
Some Areas of Impact

- **Healthcare**
- **Food & Agriculture**
- **Industry**
- **Water Resources Management**
- **Environment**
- **Art/Artefacts/Cultural Heritage**
- **Research**

Impact of non-power applications of radiation based technologies



Japan (1997):
3.2% of the GDP 494 T¥



J.Nucl.Sci.Tech. 39(2002)1020-1124

Food and Agriculture

- **Radiotracers** in Agriculture; research
  - process understanding; optimization of manure/pesticide; tracking the fate of the used manure/pesticide etc.
- **Radiation induced mutation breeding** – Food security
- **Food Irradiation -** Food security, safety, hygiene
- **Sterile Insect Technology** – Crop/animal protection

Food and Agriculture - Food Irradiation

- Damage to living cells
- Death of living organisms - bacteria, canc
  - Disease causing organisms
    - **Food preservation by irradiation**

Quarantine

Fruits

One Process

Multiple Uses

Sprout Inhibition

Onion, Potato, Ginger,Garlic

Disinfestation

Cereals, Pulses, Dry Fruits

Shelf-life Extension

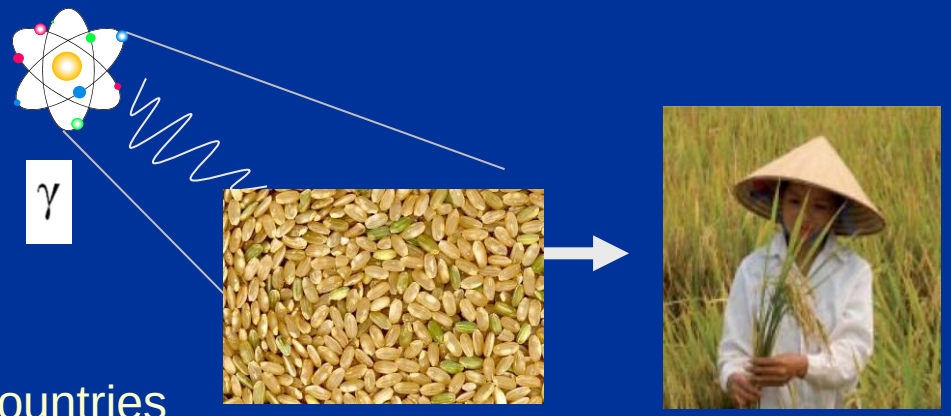
Cut flowers, fruits, Meat, Fish ..

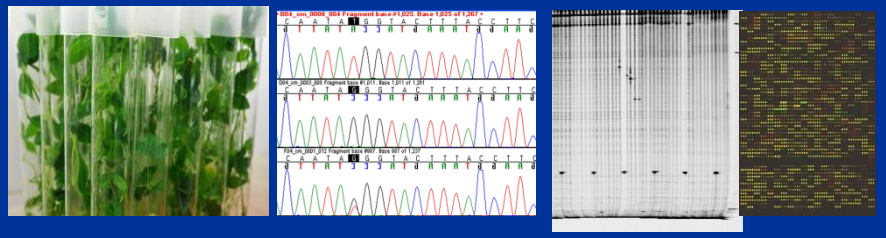
Hygienization

Spices, Flesh Foods

Food and Agriculture – Crop Mutation

- Damage to living cells
- Mutation of crops - Random
- Crop improvement - Selection
- Climate and disease resistance
- Improved yield and nutrition
- >3000 reg. mutant varieties in >70 countries

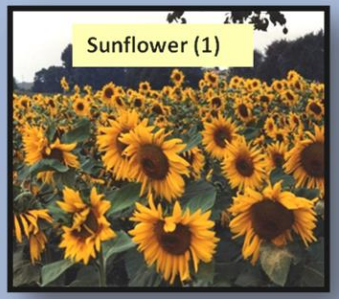




Mutagenesis; Tissue Culture; Genomics;
Phenomics; Transcriptomics; Reverse Genetics

TROMBAY (BARC) CROP VARIETIES RLEASED FOR COMMERCIAL CULTIVATIO

40 crop varieties developed and released commercial cultivation agro-climatic zones in th



Trombay Crop Varieties Released and Notified for Commercial Cultivation by Ministry of Agriculture, Government of India

Crop	Variety	Year of Release	Released for	Salient features
Groundnut	TG-47 (RARS T1)	1983	Maharashtra	Tolerant to rust and late leaf spot
	TDG-39	1995	Maharashtra	Resistant to rust and late leaf spot
	TBG-39	2004	Maharashtra	Resistant to rust and late leaf spot
	TG-51	2007	Maharashtra	Resistant to rust and late leaf spot
	TLG-45	2007	Maharashtra	Resistant to rust and late leaf spot
	TG-38	2007	Maharashtra	Resistant to rust and late leaf spot
	TG-37A	2007	Maharashtra	Resistant to rust and late leaf spot
	TPG-41	2007	Maharashtra	Resistant to rust and late leaf spot
	TG-26	2007	Maharashtra	Resistant to rust and late leaf spot
	TKG-19A	2007	Maharashtra	Resistant to rust and late leaf spot
	TG-22	2007	Maharashtra	Resistant to rust and late leaf spot
	TAG-24	2007	Maharashtra	Resistant to rust and late leaf spot
	Somnath (TGS-1)	2007	Maharashtra	Resistant to rust and late leaf spot
	TG-3	2007	Maharashtra	Resistant to rust and late leaf spot
	TG-17	2007	Maharashtra	Resistant to rust and late leaf spot
	TG-1	2007	Maharashtra	Resistant to rust and late leaf spot
Soybean	TAMS 98-2	1995	Maharashtra	Resistant to yellow mosaic virus
	TAMS-38	2004	Maharashtra	Resistant to yellow mosaic virus
Mustard	TPM-1	1995	Maharashtra	Resistant to powdery mildew
	TM-2	2004	Maharashtra	Resistant to powdery mildew
	TM-4	2007	Maharashtra	Resistant to powdery mildew
Sunflower	TAS-82	2004	Maharashtra	Resistant to powdery mildew
Mungbean	TM-2000-2 Pairy mung	2010	Chhattisgarh	Suitable for rice fallow and resistant to powdery mildew
	TM-96-2 (*Trombay Pesara*)	2007	Andhra Pradesh	Resistant to powdery mildew and *Corynespora* leaf spot
	TJM-3	2007	Madhya Pradesh	Resistant to powdery mildew, Yellow mosaic virus and *Rhizoctonia* root –rot diseases
	TMB-37	2005	Uttar Pradesh, Bihar, Jharkhand, Assam, WB	Tolerant to yellow mosaic virus
	TARM-18	1995	Maharashtra	Resistant to powdery mildew
	TARM-1	1995	Maharashtra, Gujarat, MP, AP, Kerala, Orissa, Karnataka, Tamil Nadu	Resistant to powdery mildew
	TARM-2	1992	Maharashtra	Resistant to powdery mildew
	TAP-7	1983	Maharashtra, Karnataka	Tolerant to powdery mildew
Blackgram	TU 94-2	1999	Andhra Pradesh, Kerala, Karnataka, Tamil Nadu	Resistant to yellow mosaic virus
	TAU-2	1992	Maharashtra	High yielding
	TPU-4	1992	Maharashtra, Madhya Pradesh	Large seed
	TAU-1	1985	Maharashtra	Large seed, most popular variety in Maharashtra
Pigeonpea	TJT-501	2009	Madhya Pradesh, Gujarat, Maharashtra, Chhattisgarh	High yielding, tolerant to *Phytophthora* blight, early maturing
	TT-401	2007	Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh	High yielding, tolerant to pod borer and pod fly damage
	TAT-10	1985	Maharashtra	Early maturing
	TT-6	1983	Madhya Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Karnataka, Kerala	Large seed
Cowpea	TRC-77-4 (*Khalleshwari*)	2007	Chhattisgarh	Suitable for rice based cropping system
Paddy	Hari	1988	Andhra Pradesh	Slender grain type
Jute	TKJ-40 (*Mahadev*)	1983	Orissa	High yielding

Food and Agriculture – Sterile Insect Technique

- Damage to living cells – Genetic Modification
- **Sterile Insect Technique (SIT)** for area-wide **integrated pest management** of major insect pests causing enormous damage to crops or humans
- Selective sterilization of male insects using gamma radiation (EB; X rays)
- Release in large numbers in fields

- Fruit flies; Tse-tse fly;

Industry

- **Radiotracers** – Industrial processes; water resource management
- **Non-destructive testing (NDT) and Nucleonic gauges**
- **Radiation processing**
- **Miscellaneous**
  - **Energy**
  - **Low strength radioactive sources in niche areas**

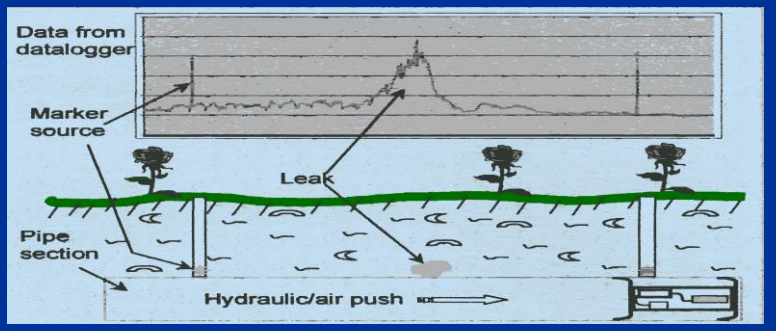
RN Thermoelectric Generator

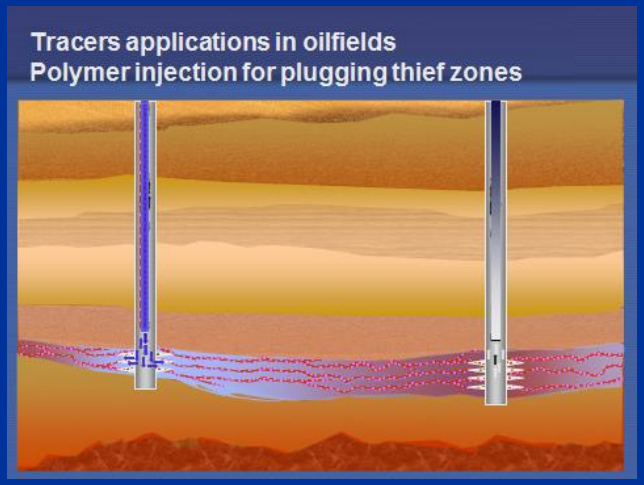
Smoke detector – Am-241

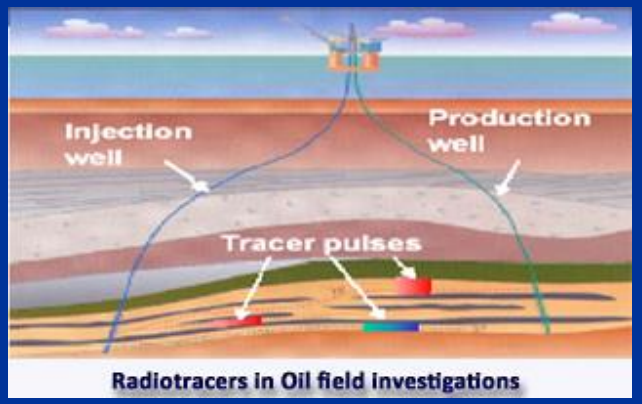
- **Low activity sources for use in instruments, space crafts etc.**

Industry - Radiotracers

- Trouble shooting
- Chemical process development/optimization
- Monitoring industrial reactions
- Tracking movement of fluids
- Tracking silt movement in ports/ shores
- Identifying leakages – dams; pipelines



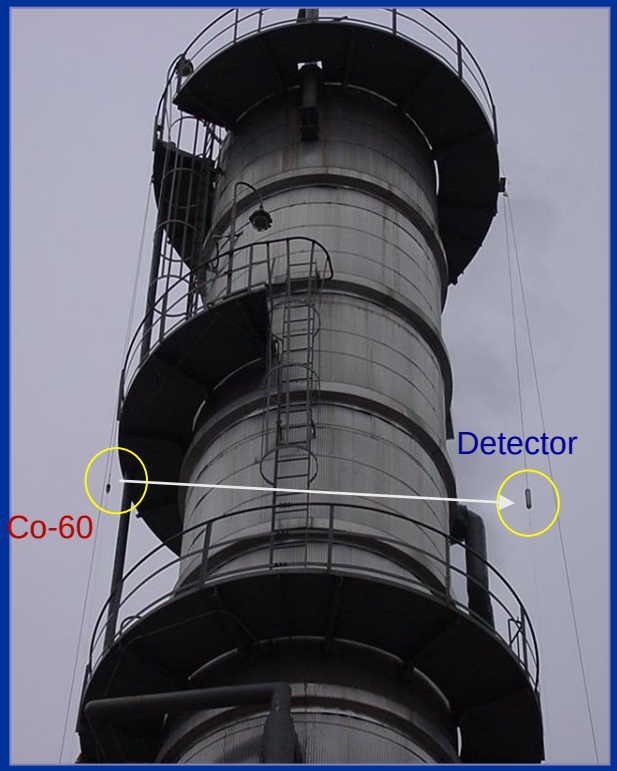


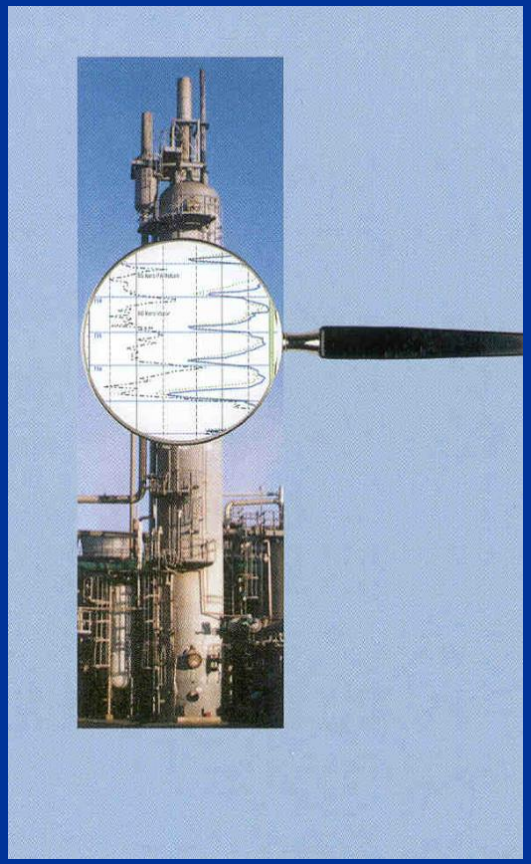


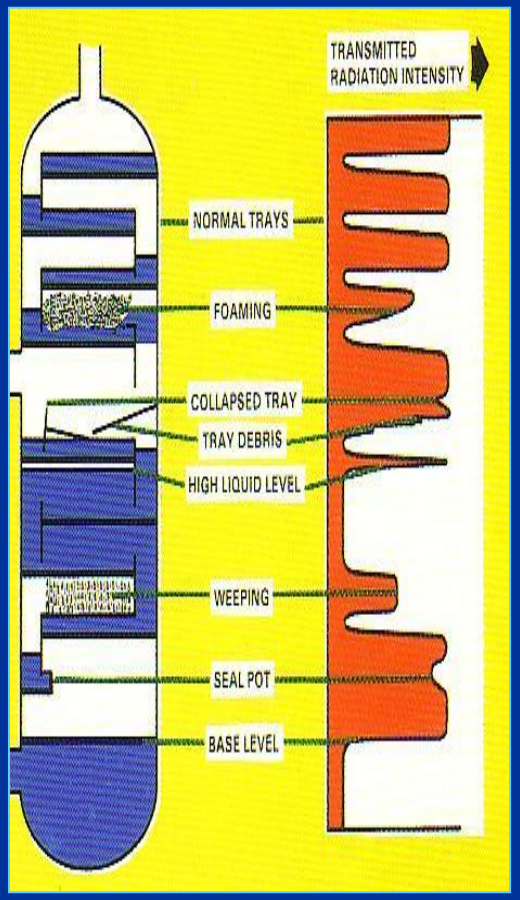
Industry– NDT and nucleonic gauges

- **Attenuation of radiation**
- **Intensity decrease** : information about the material - uniformity, thickness, defects etc.
  - **Gamma radiography** : imaging internals of machine components – just like human radiography!
    - QA; QC; analysis of status of/defects in materials
  - **Nucleonic Control Systems**: thickness, level measurements – process automation; QC;
- **Increased production efficiency**

Gamma scanning - industrial columns - troubleshooting







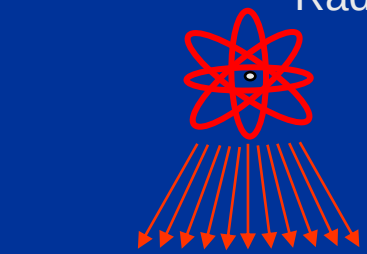
Use of NDT for Trouble shooting to solve a problem in a petrochemical industry saves time as well as money – months and millions!!

Non Destructive Testing – Radiography

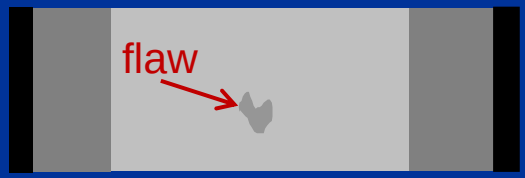
Inspection of objects to detect flaws

Welds pipelines

Radiography

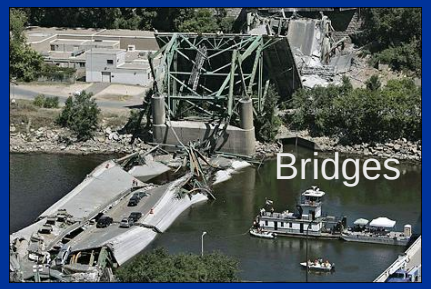


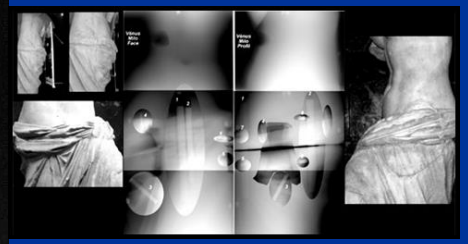
X-ray film



Top view of developed film

Air Plane inspection



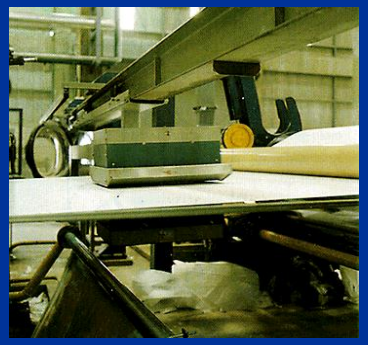


Pressure vessel

Nucleonic Control System (NCS)

Improving product quality, saving energy and materials
NCSs : part of modern industrial machinery

- Thickness, density, moisture, filling level in paper, plastic, steel and several other industries
- For component analysis in cement and coal industry
- Process control; Quality Control
- High productivity; automation of production processes
- Safety



Thickness gauge for paper production

Online Coal ash monitor

coal face analyser

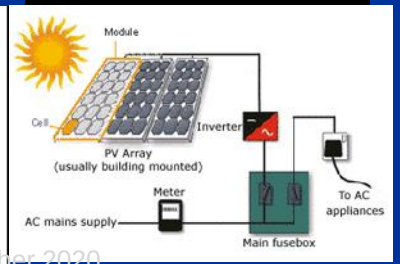
On-line measurement in Cement plant

Industry : Radiation Processing -1

- **Deposition of energy in the matter**
  - **Cross-linking molecules**
    - Strengthening materials; high performance
      - wires, cables, ‘O’ rings, surfaces etc.

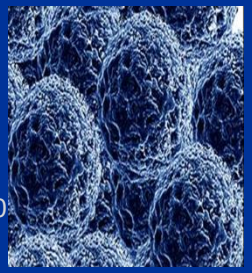
  - ***Irradiated wires and cables***

Automobiles; Railways; Aerospace; Power Industry; Photovoltaic systems;
Electronic Appliances



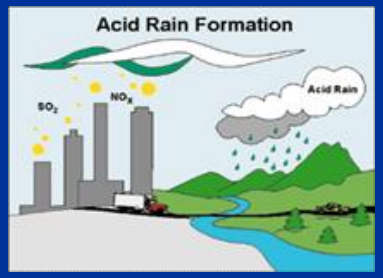
Industry : Radiation Processing - 2

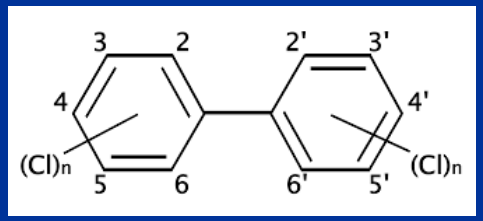
- **Deposition of energy in the matter**
  - **Cross-linking molecules**
    - Polymerization; Novel polymers
      - Reinforcement – wood; art objects
      - Heat shrinkable polymers
        - Several applications –wires; food package;
      - Surface modification – toys (safe); tires (tough) etc.
      - Bio-degradable polymers
        - *Healthcare applications (Hydrogel etc.)*
        - Value addition of biowaste (‘wealth from waste’) - crab shells to produce nutraceuticals;
      - Nanomaterials – large potential



Industry – Environment : Radiation Treatment

- **Deposition of energy in the matter**
  - **Breaking tough molecules -** Environmental remediation through treatment of
    - Flue gases - CO_2, NOx; SO_2
    - Industrial effluents – dyes; drugs; pharmaceuticals.
    - Volatile organic chemicals
    - PCBs in used transformer oils



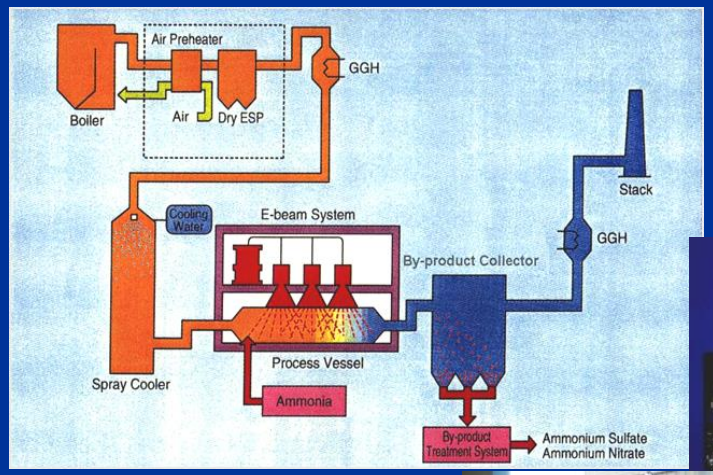


Cosmic Ray

SO_2, NO_x CO_2:

H_2SO_4
HNO_3
H_2CO_3

Acid rain



Industry – Environment : Radiation Treatment

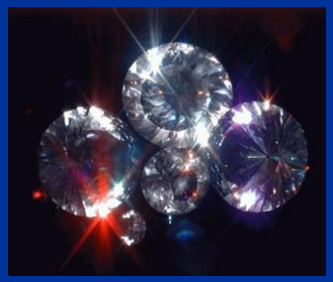
- Destruction of harmful living organisms
  - **Treatment of sewage waste** – sanitization & high quality natural manure by-product

- Treatment of materials in unforeseen situations
- Example – Anthrax through post
- Possible uses in emergencies; natural calamities etc. to treat contaminated water/food etc.

Sanitization of postal mail – Anthrax threat 2001!

Radiation Treatment – value added materials

- **Deposition of energy in the matter**
  - **Value addition**
    - Creation of ‘defects’
      - Exotic products- Gems, diamonds



Radiation Processing : Reinforcement & Preservation of heritage objects

Preservation/dis-infestation of Cultural heritage objects and old valuable documents/books using ‘Radiation treatment’

Artefact (Mexico) in poor condition (L) restored by polymeric reinforcement (c) using radiation technology to make it an ‘as good as new’ piece (R)

Baby Mammouth Khroma (>50000 year old) in special refrigerated chamber after the irradiation treatment. Exhibited at the Musée Crozatier, Le Puy-en-Velay, France

Healthcare Applications

- Diagnosis - *radiotracers*
- Therapy – *deleterious effect of radiation*
- Post treatment monitoring
- Medical Sterilization – *radiation processing*
- High performance Materials - *radiation processing*

Healthcare - Radiotracers

- **Radiotracers – in diagnosis**
  - **Radiometric Assays –** use in a lab test, in biological samples (blood serum/plasma, spinal fluid etc.) **– Radio Immuno Assay : A Nobel Prize winning technology (Yalow & Berson; 19**

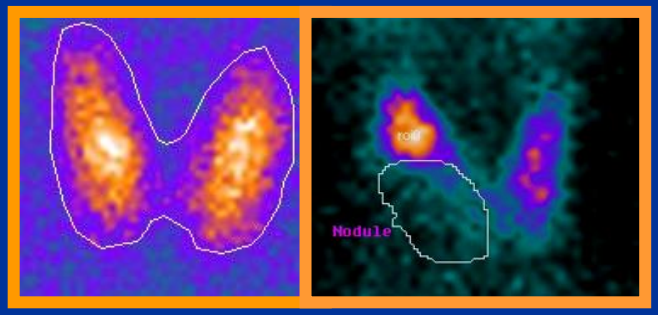
    - Quantitative measurement of biological molecules at nanomolar (nM) levels in complex matrices

    - Hormones – endocrinology (Thyroid disorders – c **(T3-T4-TSH)**)
    - Tumour markers – cancer – diagnosis; treatment monitoring; regular follow-up (Prostate-**PSA**; Breast; Uterine; Liver Cancers)
    - Drugs – personalised medicine; forensics; monitoring

❖ **Carbon-14 –Urea capsules in diagnosis of Helicobacter Pylori infection –** simple, quick test of value!

Healthcare - Radiotracers

- **Radiotracers – in diagnosis**
  - **Diagnostic Nuclear Medicine**
    - Administration of a radiolabelled molecule (**Radiopharmaceutical**) into the body and imaging
      - Organs – anatomy & function (NM scans available for nearly all the important organs and functions)

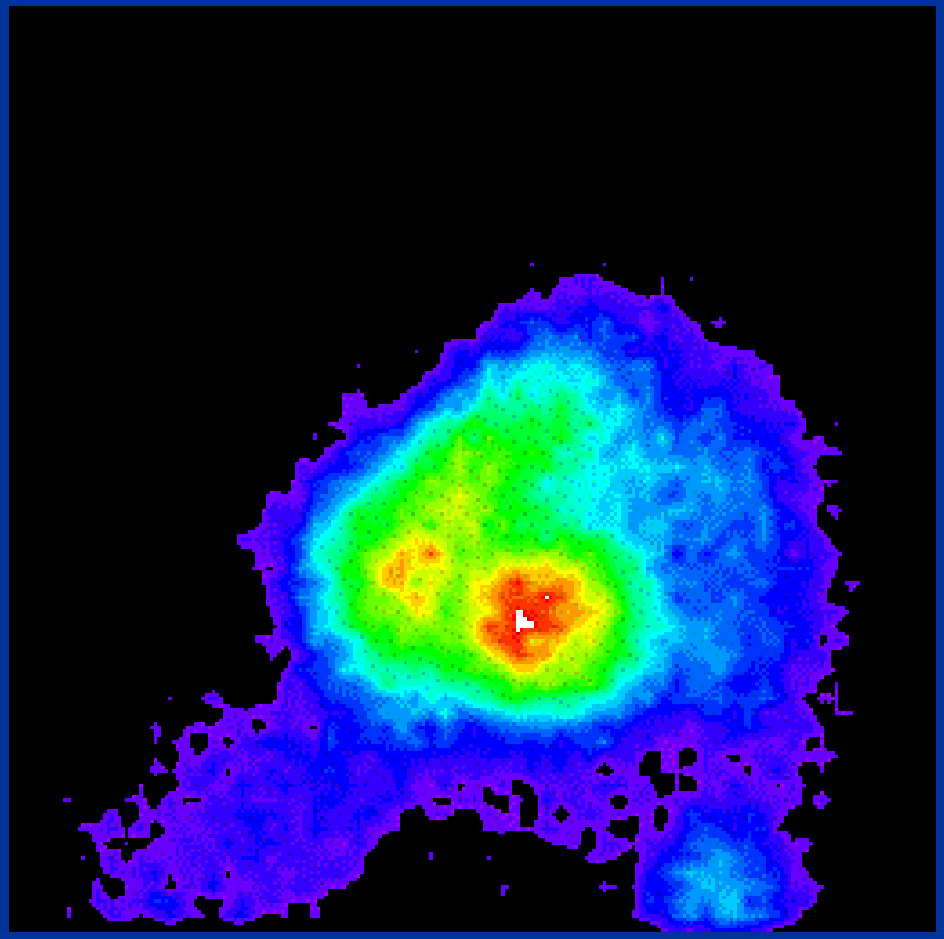


      - Tumours - shape, position
        - Cancer-diagnosis; treatment monitoring; regular follow-up

Cardiology, Oncology and neurology – most NM studies

Example: Functioning of heart muscles

Typical heart scan - dynamic showing various regions for easy diagnosis of functioning and quantification of results



Healthcare – Nuclear Medicine

- NM - Specialty – use of radiolabelled molecules (**Radiopharmaceuticals**) inside the body (*in-vivo*)
- 'Molecular' imaging; 'Functional' as well as 'anatomical' information
- Phenomenal growth over past decades ; Innovations
  - **Imaging technology** *(detectors; image processing; computation; fusion)*
    - Gamma Camera; Single Photon Emission Tomography (SPECT); Positron Emission Tomography (PET)
    - Fusion imaging – PET-CT; SPECT-CT; PET-MRI; SPECT-MRI
  - **Molecular Biology –Innovations ;** cancer biology, monoclonal antibody, tumor specific targeting molecules
  - **Radioisotopes production and availability; radiolabeling techniques**

Nuclear Medicine - Growth

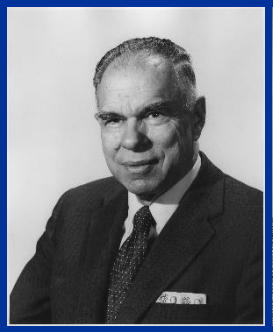
Continued spectacular inventions through 20th century

Rectilinear Scanner

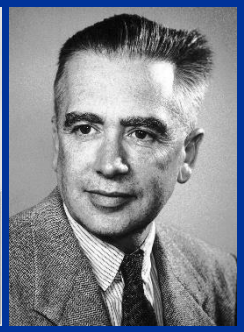
Gamma camera

Hal Anger

SPECT

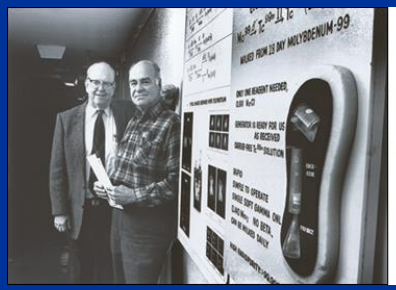


Glenn Seaborg



Emilio Segre

Tc-99m



Tucker and Powell

Tc-99m Generator

PET

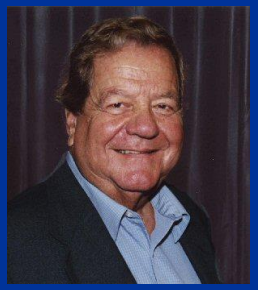
Positron emitter F-18 for imaging

Monoclonal antibodies

Kohler & Milstein – 1984 N

Tumor specific peptides

Tc-99m Work-horse; ~40 M studies/y; F-18-FDG – PET ~ 4 M /y



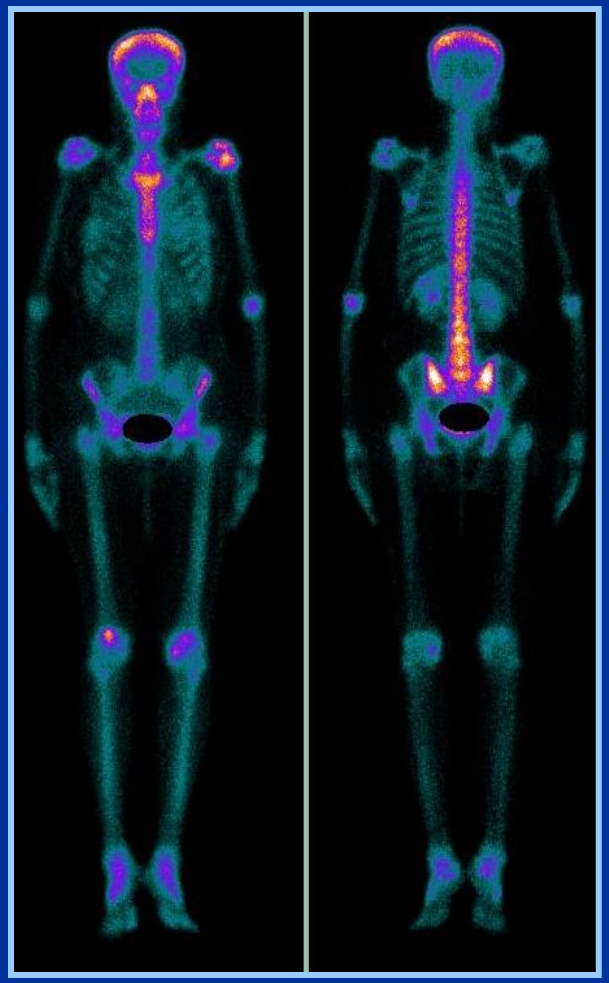
Dr. Henry N. Wagner Jr.

Advances in practice of radiopharmacy & radioisotope transportations

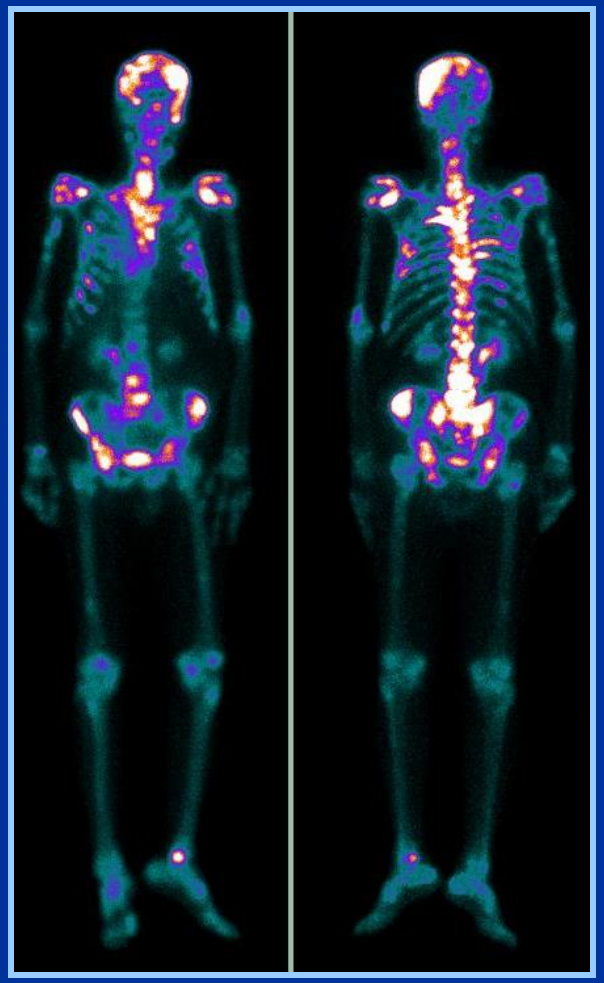
WHOLE BODY BONE SCAN

for skeletal metastases in patients with known or suspected cancer.

^{99m}Tc Methylene Di Phosphonate Bone Scan

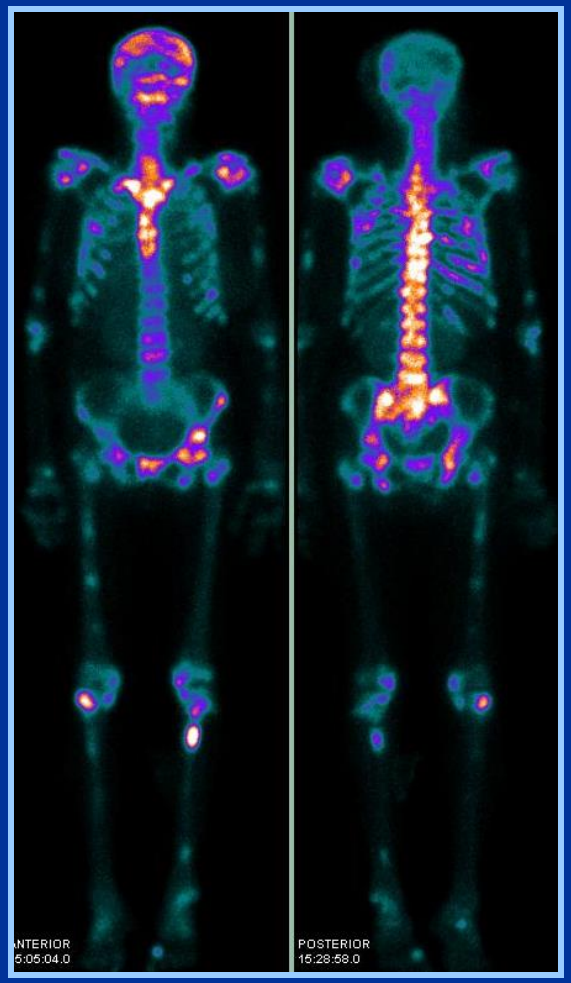


Normal



Multiple Metastases

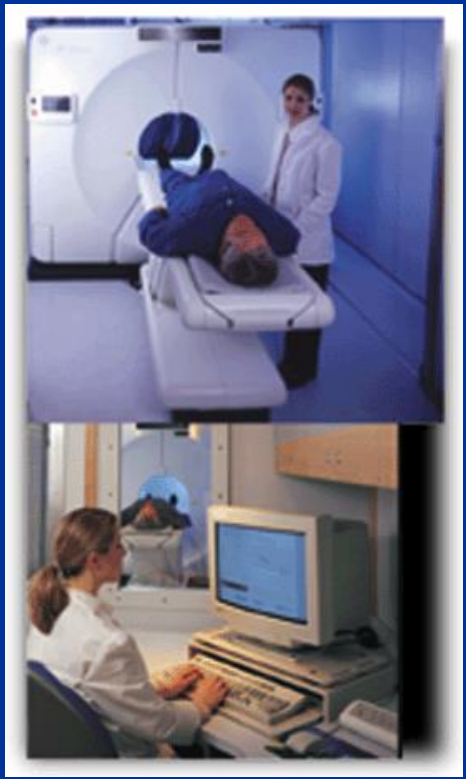
Ca Prostate

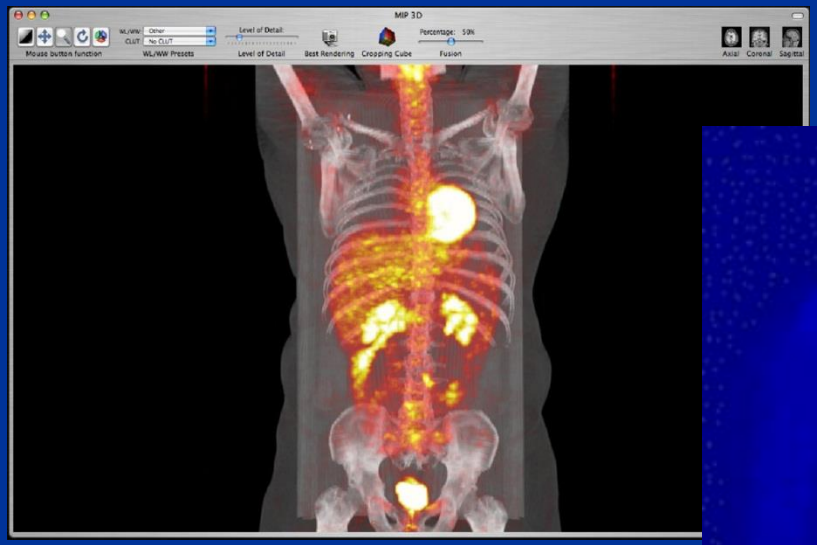


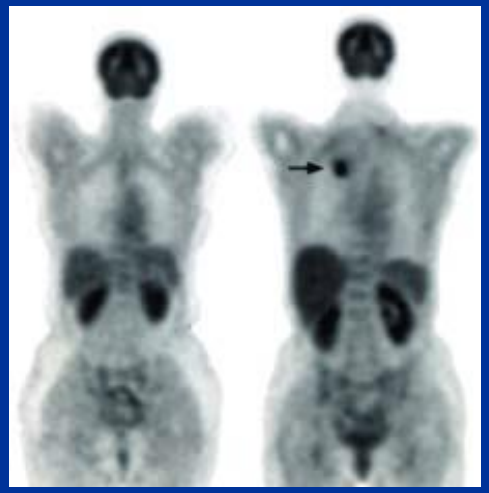
Multiple Metastases

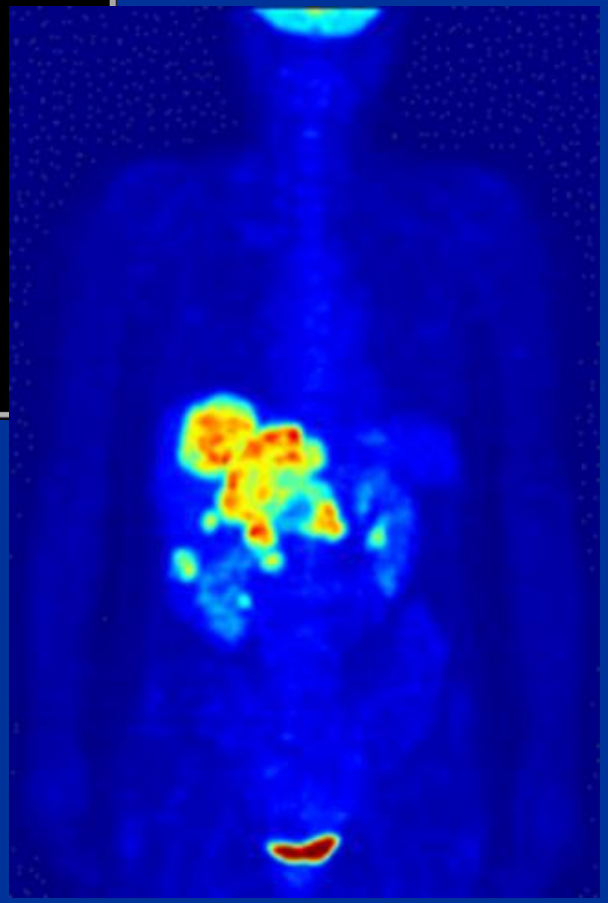
Ca Lt Breast

Example : PET machine & PET image



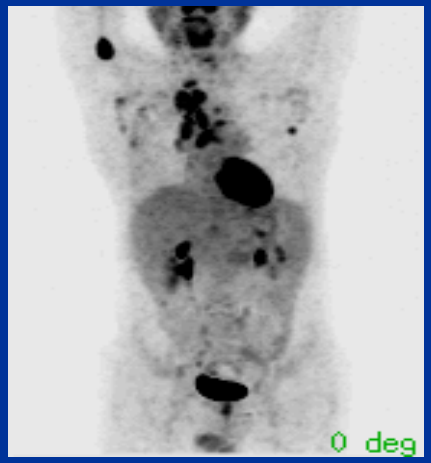


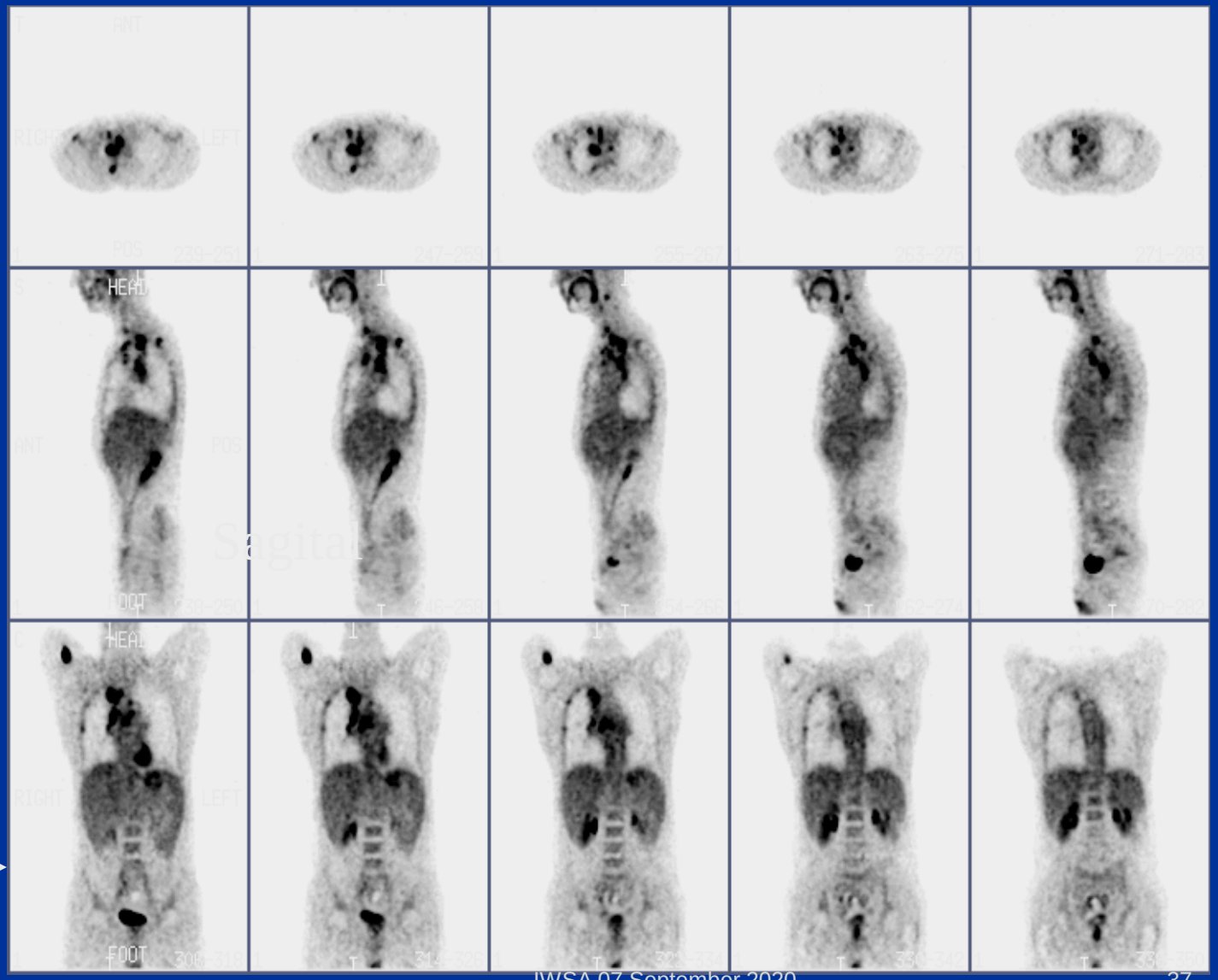




Lung Cancer

Transaxial →

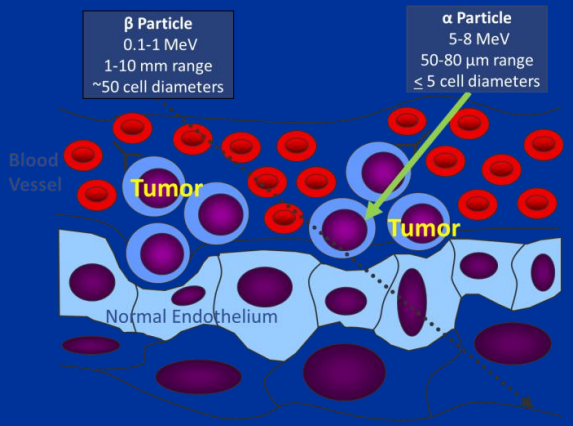




Coronal →

Healthcare – Nuclear Medicine - Therapy

- Well established; Very old (1943 onwards) Radio Iodine-131 used in therapy of thyroid cancer and hyperthyroidism
- Particulate radiations - β- ; α; Auger/conversion electrons



- Cancers - therapy and pain palliation
- Non-cancerous ailments – hyperthyroidism, radiation synoviorthesis etc;

Healthcare – Nuclear Medicine - Therapy

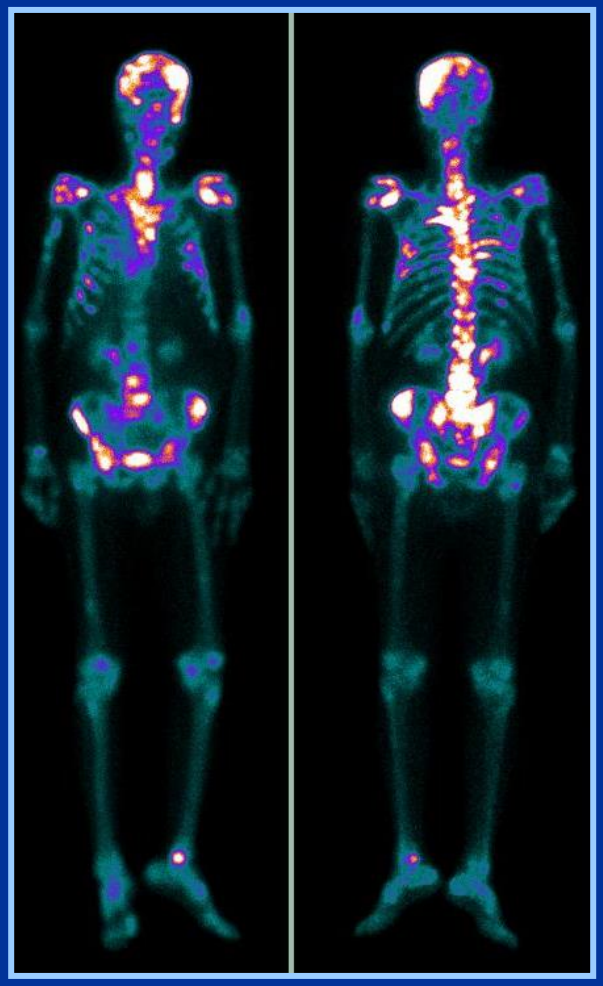
- Growing ambit/variety
  - Targeting molecules - Radiolabelled antibodies/Peptides

    Prostate, colon, breast, ovary, non-Hodg.Lymp. Neuroendocrine tumours
  - Several radioisotopes explored with success
    - Lutetium-177; Yttrium-90; Actinium-225 + many more

- Personalised therapy
  - Diagnosis and therapy closely linked
  - ‘Theranostics’ - increasing focus to use the same bio-molecule to carry out diagnostic studies and later for therapy – for better efficiency and dose calculations

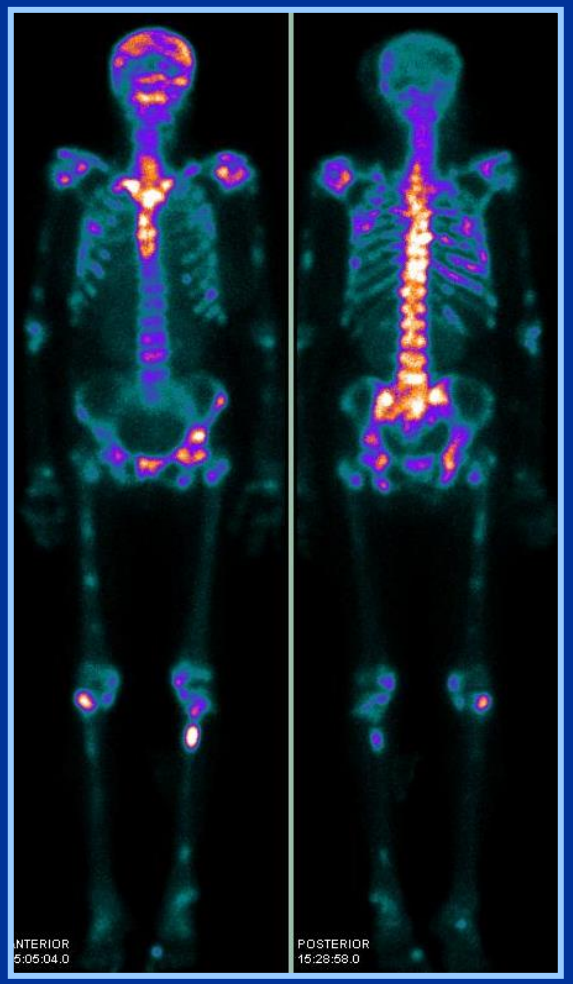
Skeletal metastases in patients with known or suspected cancer.

^{99m}Tc MDP Bone Scan – Diagnosis; ^{153}Sm EDTMP palliative therapy



Multiple Metastases

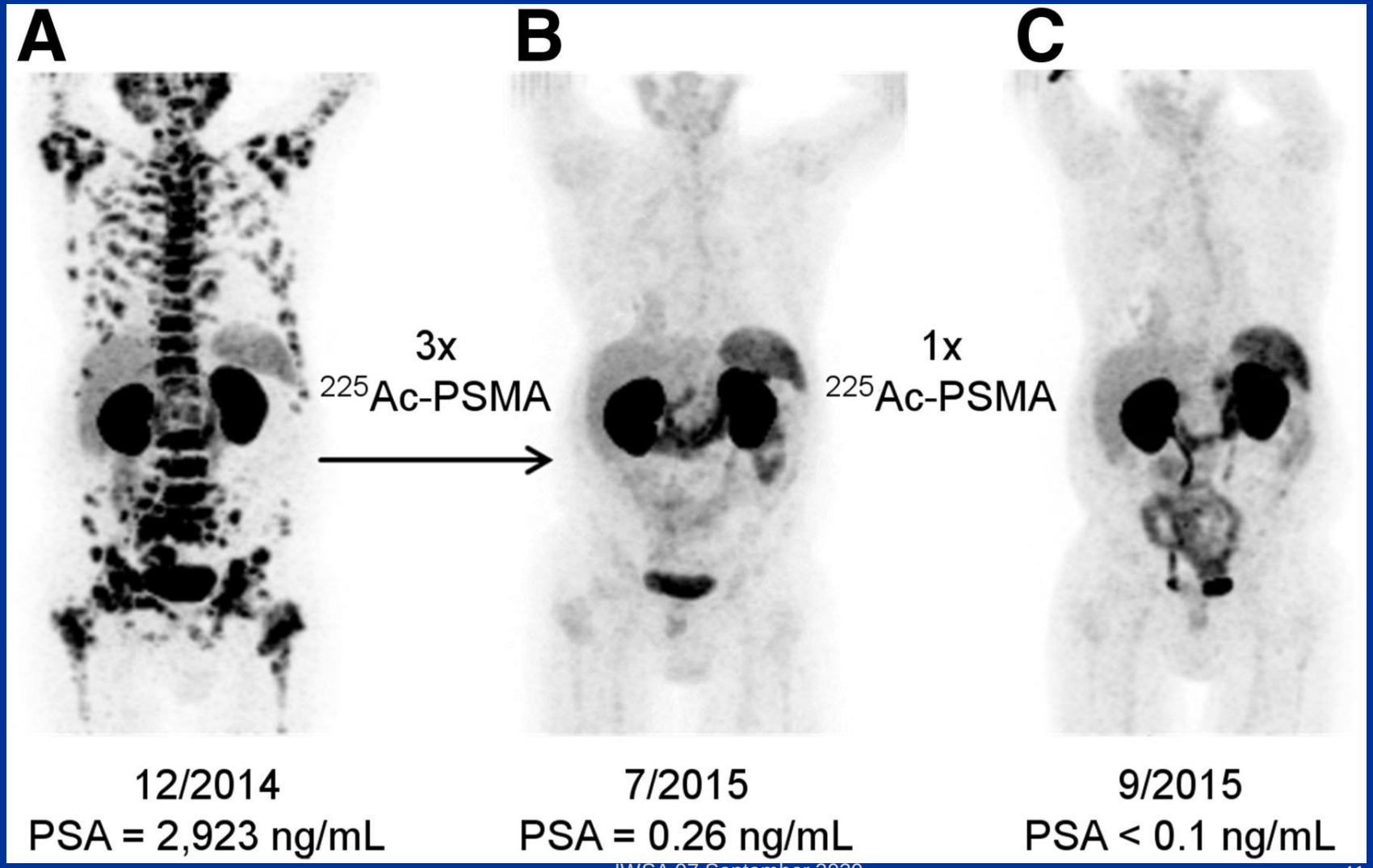
Ca Prostate



Multiple Metastases

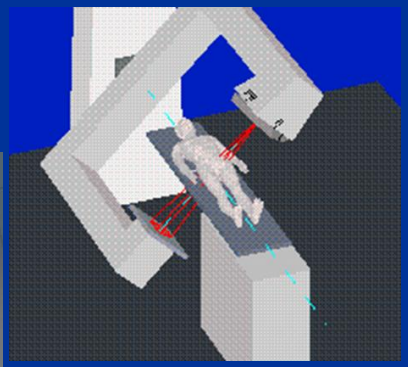
Ca Lt Breast

Scans of patient – prostate cancer : Pretherapeutic tumor spread (A), restaging 2 mo after third cycle of ^{225}Ac-PSMA-617 (B), and restaging 2 mo after one additional consolidation therapy (C).



Healthcare – Therapy

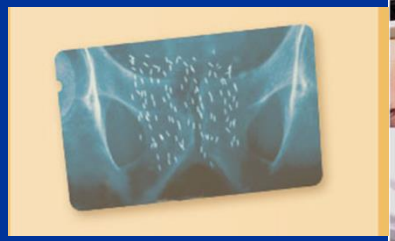
- **Teletherapy – External radiation**
  - Cobalt-60 γ rays
    - Gamma Knife - Brain tumors



  - Linear Accelerators – LINAC
    - Electrons/X ray photons

Healthcare – Therapy

- **Brachytherapy – In contact with the body**
  - Radioactive implants- wires, patches, particles, solution …
    - Interstitial – breast; neck; prostate cancers



    - Mould – skin; ocular ..

    - Intercavitory – cervix; brain
    - Intravascular – Cardiac vessels; Liver

Healthcare – Radiation processing

- **Sterilization of medical products by gamma irradiation**
  - Use of radiation to kill disease causing organisms - bacteria, cancer cell, fungi

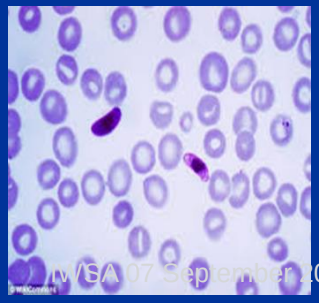
200 Cobalt-60 γ medical sterilization plants

- **Blood/tissue Irradiation**
- **Vaccine irradiation**
- **Radiation polymers – varied applications**

Emerging Uses:

Nanomaterials for use in medicine

Scaffolding for tissue growth



Gamma-irradiated vaccine shows potential in the battle against malaria

Clinical trials – 3rd stage

In a nutshell

- Radioisotopes and radiation have numerous applications in diverse fields that touch our daily lives.

- Healthcare applications are extremely gratifying and provide unique contribution towards patient care and management.

- Radiation based applications are safe when followed in a proper manner following safety guidelines and regulations; and the benefits are immense!!

My sincere thanks to

- *My teachers and mentors who helped pave the professional path of my life*
- *Department of Atomic Energy (BARC; BRIT) and all my colleagues who helped me progress in my professional journey*
- *International Atomic Energy Agency which provided me the opportunity to get a closer glance at global scenarios and colleagues who broadened my vision*
- *My family, friends and colleagues for the encouragement, unstinted support and warmth*
- *And, to all of you audience!*