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Present and Future (non-power) Nuclear applications

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PRESENT AND FUTURE (NON-POWER) NUCLEAR APPLICATIONS: an overview and some examples

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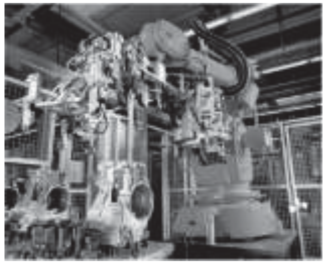
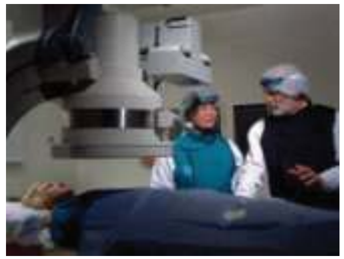
Non-Power Nuclear Applications

Applications of Radioisotopes and Ionizing Radiations to:



- Industry
- Space Exploration

- Environmental Protection
- Archaeometry



- Human Health
- Food and Agriculture

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Many radioisotopes are used in non-power nuclear applications.

They are produced either in nuclear reactors or by using particle accelerators.

After their production they have to be separated from the matrix and purified utilizing chemical procedures.

In the next figures many of these radionulcides are reported. Their half-life and the major fields of utilization are also indicated.

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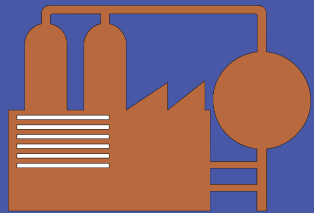
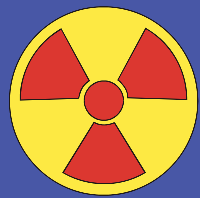
IMPORTANT RADIOISOTOPES, THEIR SOURCE OF PRODUCTION AND DIFFERENT APPLICATIONS





INDUSTRY	Reactor	Accelerator
1. Radiation processing	Co-60	
2. Nucleonic instrumentation	Cs-137, Co-60, Am-241, Kr-85, Pm-147, Sr-90, Tl-204, C-14, Cf-252, Ni-63, Fe-55, Cd-109, Po-210	Co-57
3. Non-destructive testing	Ir-192, Se-57, Yb-169	
4. Tracer studies	Sc-47, In-113m, Xe-133	

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IMPORTANT RADIOISOTOPES, THEIR SOURCE OF PRODUCTION AND DIFFERENT APPLICATIONS

MEDICINE	Reactor	Accelerator
1. Gamma imaging	Tc-99m, I-131, Xe-133	Ga-67, In-111, Kr-81m I-123, Tl-201
2. PET imaging	F-18	F-18, Ga-68, I-124, Cu 64 C-11, N-13, O-15
3. Radioimmunoassay	I-125, H-3	
4. Radiopharmaceutical for therapy	I-131, P-32, Y-90, Er-169, Sm-153 Sn-117m, Ho-166, Re-186, re-188	At-211
5. Teletherapy	Co-60	
6. Brachytherapy	Ir-192, I-125, Cs-137,, Au-198, Ru-106	Pd-103

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Reactor Radioisotopes (half-life indicated)

Lutetium-177 (6.7 d): Lu-177 is increasingly important as it emits just enough gamma for imaging while the beta radiation does the therapy on small (eg endocrine) tumours. Its haif-fife is long enough to allow sophisticated preparation for use.
Palladium-103 (17 d): Used to make brachytherapy permanent implant seeds for early stage prostate cancer.
Phosphorus-32 (14 d): Used in the treatment of polycythemia vera (excess red blood cells).
Potassium-42 (12 h): Used for the determination of exchangeable potassium in coronary blood flow.
Rhenium-186 (3.8 d): Used for pain relief in bone cancer.
Rhenium-188 (17 h): Used to beta irradiate coronary arteries from an angioplasty balloon.
Samarium-153 (47 h): Sm-153 is very effective in relieving the pain of secondary cancers lodged in the bone; also very effective for prostate and breast cancer.
Selenium-75 (120 d): Used in the form of seleno-methionine to study the production of digestive enzymes.
Strontium-89 (50 d): Very effective in reducing the pain of prostate and bone cancer
Xenon-133 (5 d): Used for pulmonary (lung) ventilation studies.
Ytterbium-169 (32 d): Used for cerebrospinal fluid studies in the brain.
Ytterbium-177 (1.9 h): Progenitor of Lu-177.
Yttrium-90 (64 h): Used for cancer brachytherapy and as silicate colloid for the relieving the pain of arthritis in larger synovial joints.
Radioisotopes of **caesium, gold and ruthenium** are also used in brachytherapy.

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Reactor Radioisotopes (half-life indicated)

Molybdenum-99 (66 h): Used as the 'parent' in a generator to produce technetium-99m.
Technetium-99m (6 h): Used in to image the skeleton and heart muscle in particular, but also for brain, thyroid, lungs (perfusion and ventilation), liver, spleen, kidney (structure and filtration rate), gall bladder, bone marrow, salivary and lacrimal glands, heart blood pool, infection and numerous specialised medical studies.
Bismuth-213 (46 m): Used for targeted alpha therapy JAI), especially cancers.
Chromium-51 (28 d): Used to label red blood cells and quantify gastro-intestinal protein loss.
Cobatt-60 (10.5 months): Formerly used for external beam radiotherapy.
Copper-64 (13 h): Used to study genetic diseases affecting copper metabolism, such as Wilson's and Menke's diseases.
Dysprosium-165 (2 h): Used as an aggregated hydroxide for synovectomy treatment of arthritis.
Erbium-169 (9.4 d): Use for relieving arthritis pain in synovial joirfts.
Holmium-166 (26 h): Being developed for diagnosis and treatment of liver tumours.
Iodine-125 (60 d): Used in cancer brachytherapy (prostate and brain), also diagnostically to evaluate the filtration rate of kidneys and to diagnose deep vein thrombosis in the leg. It is also widely used in radioimmuno-assays to show the presence of hormones in tiny quantities.
Iodine-131 (8 d): Widely used in treating thyroid cancer and in imaging the thyroid; also in diagnosis of abnormal liver function, renal (kidney) blood flow and urinary tract obstruction.
Iridium-192 (74 d): Supplied in wire form for use as an internal radiotherapy source for cancer treatment (used then removed).
Iron-59 (46 d): Used in studies of iron metabolism in the spleen.

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Cyclotron Radioisotopes (half-life indicated)

Carbon-11 (20.38 m), **Nitrogen-13** (9.96 m), **Oxygen-15** (2.03 m), **Fluorine-18** (190.7 m): These are positron emitters used in PET for studying brain physiology and pathology, in particular for localising epileptic focus, and in dementia, psychiatry and neuropharmacology studies. They also have a significant role in cardiology. F-18 in FDG has become very important in detection of cancers and the monitoring of progress in their treatment, using PET

Cobalt-57 (272 d): Used as a marker to estimate organ size and for in-vitro diagnostic kits

Gallium-67 (78 h): Used for tumour imaging and localisation of inflammatory lesions (infections)

Indium-111 (2.8 d): Used for specialist diagnostic studies, eg brain studies, infection and colon transit studies

Iodine-123 (13 h): Increasingly used for diagnosis of thyroid function, it is a gamma emitter without the beta radiation of **I-131**

Krypton-81 m (13 sec) from Rubidium-81 (4.6 h): Kr-81 m gas can yield functional images of pulmonary ventilation, e.g. in asthmatic patients, and for the early diagnosis of lung diseases and function

Rubidium-82 (65 h): Convenient PET agent in myocardial perfusion imaging

Strontium-92 (25 d): Used as the 'parent' in a generator to produce Rb-82

Thallium-201 (73 h): Used for diagnosis of coronary artery disease other heart conditions such as heart muscle death and for location *of* low-grade lymphomas

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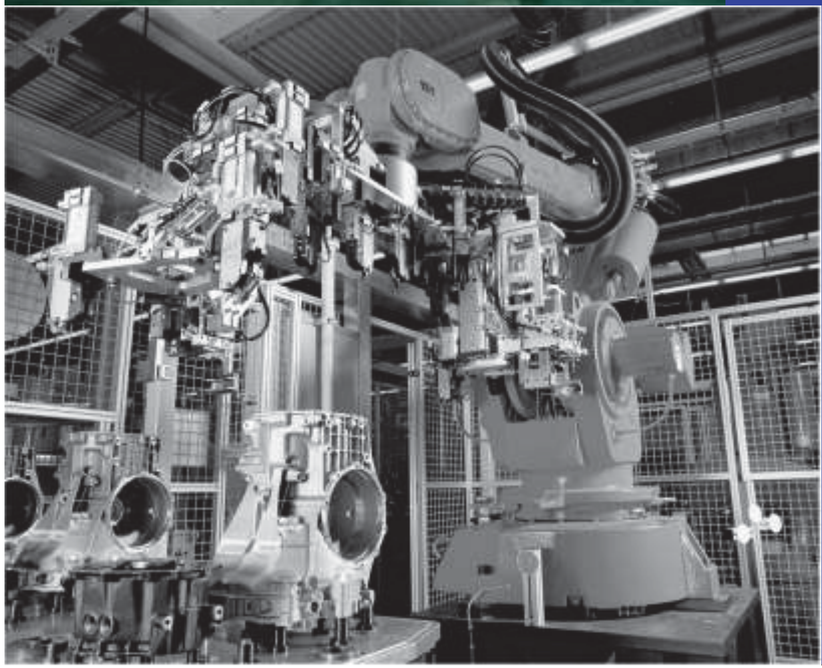
INDUSTRIAL APPLICATIONS



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The next two figures show examples of the many industrial sectors and consumer products where radiation and radioisotope -based technologies are utilized.

The third figures shows some applications of radiation technology utilizing accelerators and how different acceleration voltages can be used for different processess.

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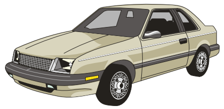
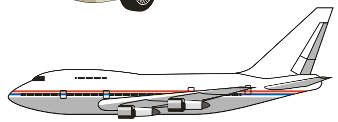
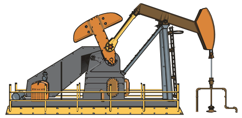
Examples of industrial use of radioactive materials



- The automobile industry uses radioactive materials to test the quality of steel in cars.



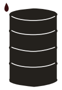
- Aircraft manufacturers use radiation to check for flaws in jet engines.



- Mining and petroleum companies use radionuclides to locate and quantify mineral deposits.

- Can manufacturers use radioactive materials to obtain the proper thickness of tin and aluminum.

- Pipeline companies use radioactive materials to look for defects in welds.



- Oil, gas and mining companies use them to map geological contours, using test wells and mine bores and to determine the presence of hydrocarbons.

- Construction crews use radioactive materials to gauge the density of road surfaces and subsurfaces, and determine the moisture content.

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Examples of consumer products using radiation

- Many smoke detectors—installed in nearly 90 percent of U.S. homes—rely on a tiny radioactive source to sound the alarm when it senses smoke from a fire.
- Computer disks "remember" data better when they are treated with radioactive materials.
- Non stick pans are treated with radiation to ensure that the coating will stick to the surface.
- Photocopiers use small amounts of radiation to eliminate static and prevent paper from sticking together and jamming the machine.
- Cosmetics, hair products and contact lens solutions are sterilized with radiation to remove irritants and allergens.
- Natural amethysts are now often given their distinctive color by irradiating the raw stones in a reactor or by exposure to accelerator radiation sources.
- Nuclear batteries power buoys as well as remote Arctic radio transmitters.







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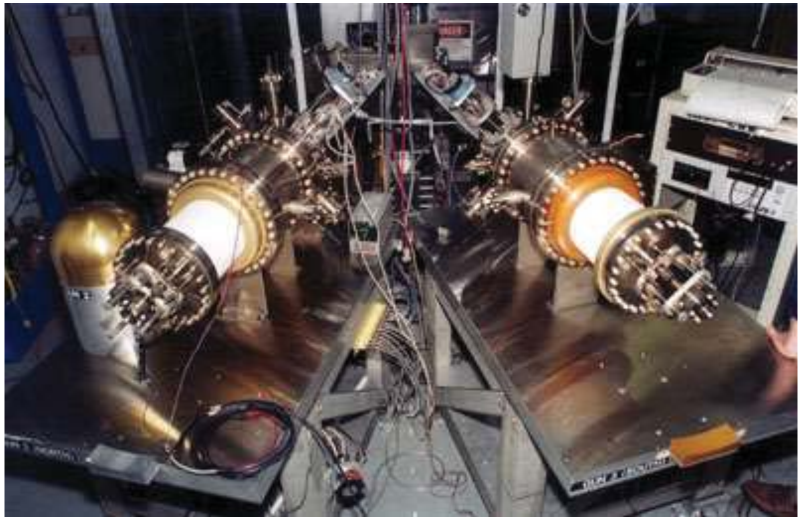
ELECTRON BEAM ACCELERATORS

Accelerators produce elelctron beams with high energy used for applications in different fields

Example of specifications:

Energy: 1.5 MeV | **Beam current: 25 mA**

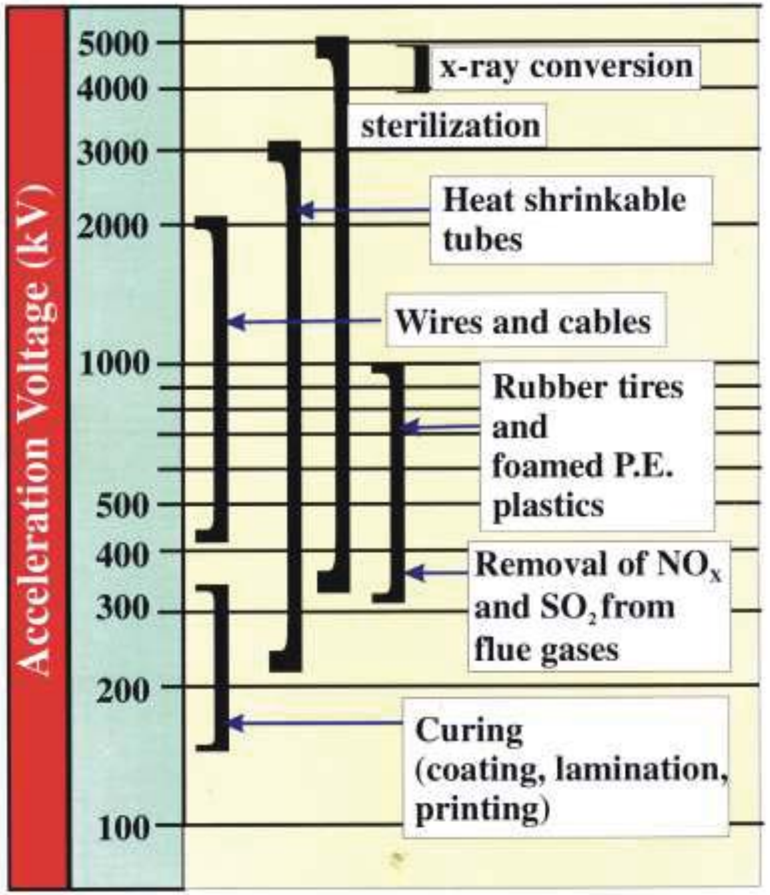
Power: 37.5 kW | **Scan width: variable up to 90 cm**



Fast electrons produce chemical reactions in a variety of materials with high efficiency, uniformity and good control

Pavia4.cdr

Different applications use different acceleration voltage



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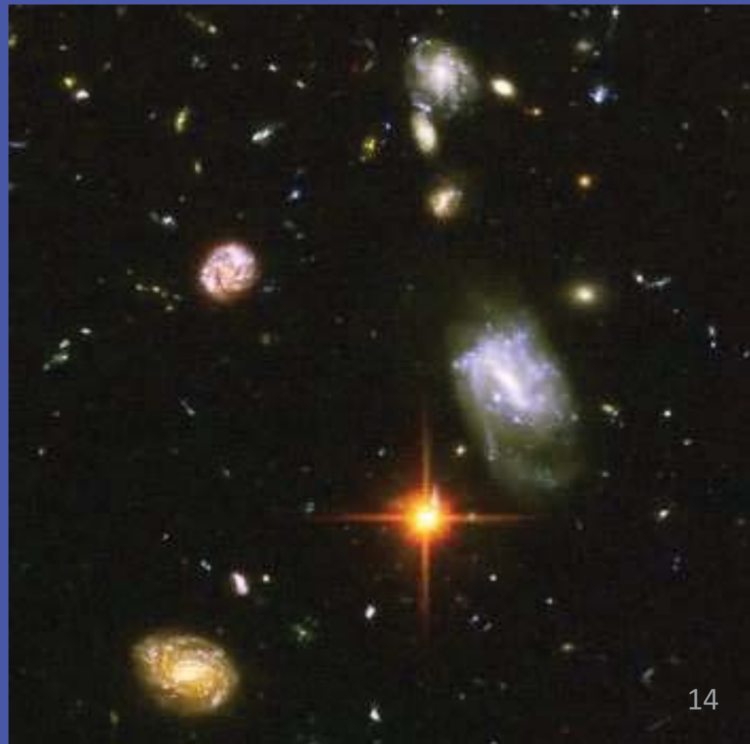
APPLICATIONS TO SPACE EXPLORATION



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Space exploration would not be possible without the use of radiation techniques. These are used in a variety of essential ways by NASA and other space programmes and include the production of heat, electricity and propulsion

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Radioisotope applications for space exploration

A major requirement of any satellite or spacecraft launched in **the deep space** is to have a mechanism to produce sufficient heat to protect the instruments and crews from the cold (about 400 F below zero) for a long period of time (several years).

All spacecrafts also need reliable electrical power supplies for instruments, computers, flight control, collection and transmission of data back to Earth.

Solar energy cannot be used (it drops inversely proportional to the square of the distance from the sun). Batteries or fuel cells have life-time and weight limitations.

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RADIOISOTOPE HEATER UNITS (RHU)

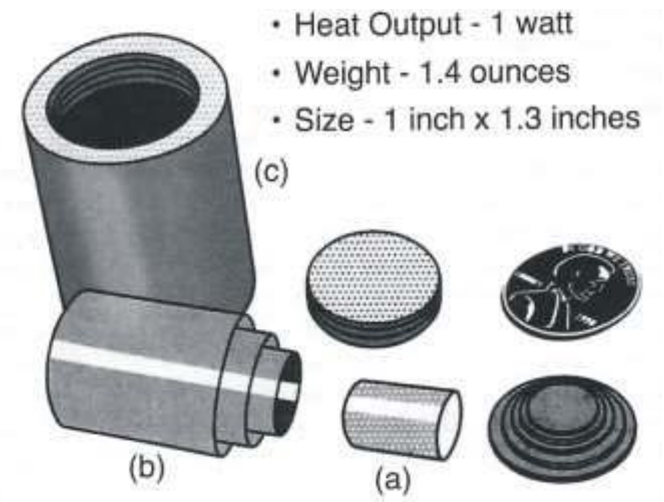
Use Pu-238 (half-life=87 y; alpha decay; no gamma rays)

Alpha particles are stopped by a ceramic matrix that heats up

The delivered power is small (about 1 Watt)

A typical RHU cluster contains 84 units

The design make difficult to generate dust, should an accident occur



Radioisotope Heater Hunit (RHU)

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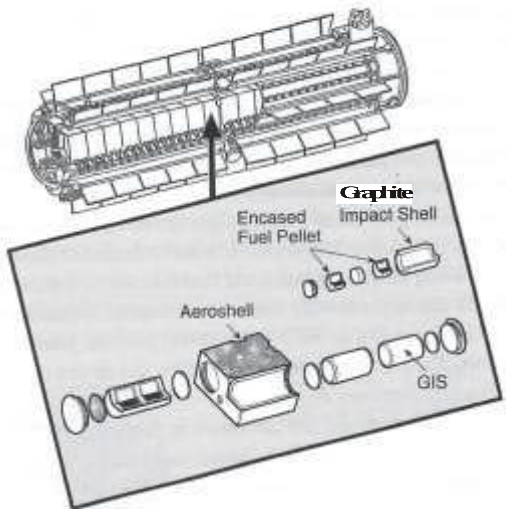
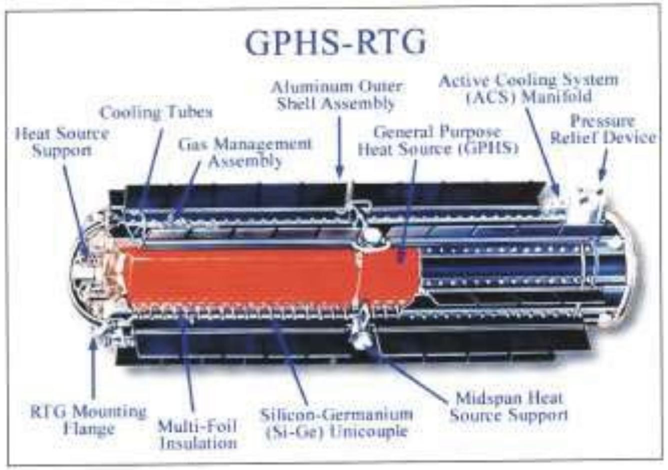
RADIOISOTOPE THERMOELECTRIC GENERATORS (RTG)

- Use Pu-238 (half-life=87 y; alpha decay; no gamma rays)
- Convert heat into electricity by the Seebeck effect
- No moving parts
- Contain 18 units (72 pellets) encapsulated in iridium
- Can provide up to several tens of kW

Have been used in the *Apollo Lunar Missions* and the *Pioneer, Voyager, Galileo and Ulysses* missions





Radioisotope Thermoelectric Generators (RTGs) used for space flights

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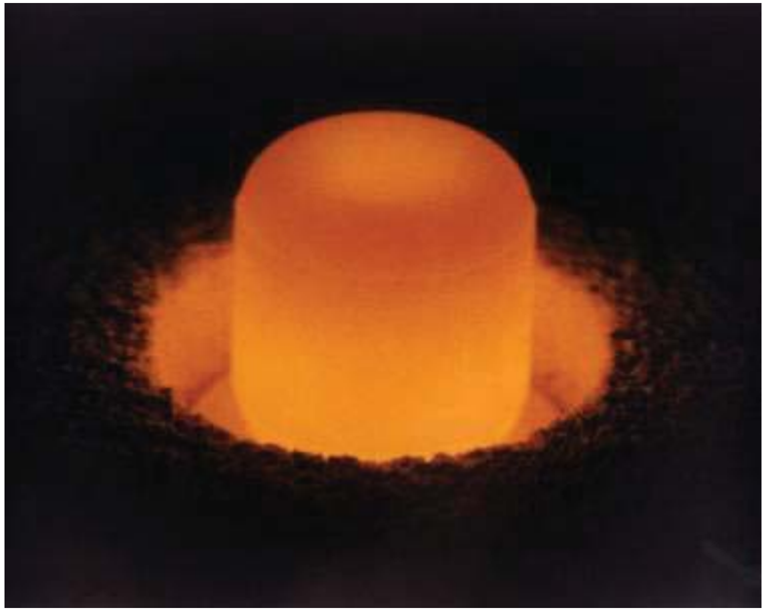
Pure plutonium-238 is prepared by irradiation of neptunium-237 that can be recovered from spent nuclear fuel during reprocessing, or by the irradiation of americium-237 in a reactor.

In both cases, the targets are subjected to a chemical treatment, including dissolution in nitric acid to extract the plutonium-238.

A 100 kg sample of light water reactor fuel that has been irradiated for three years contains only about 700 grams of neptunium-237, and the neptunium must be extracted selectively.

Plutonium-238	
General	
Name, symbol	Plutonium-238, ^{238}Pu
Neutrons	144
Protons	94
Nuclide data	
Half-life	87.7 years
Parent isotopes	^{242}Cm (α) ^{238}Np (β^-) ^{238}Am (β^+)
Decay products	^{234}U
Decay mode	**Decay energy**
Alpha decay	5.593 MeV



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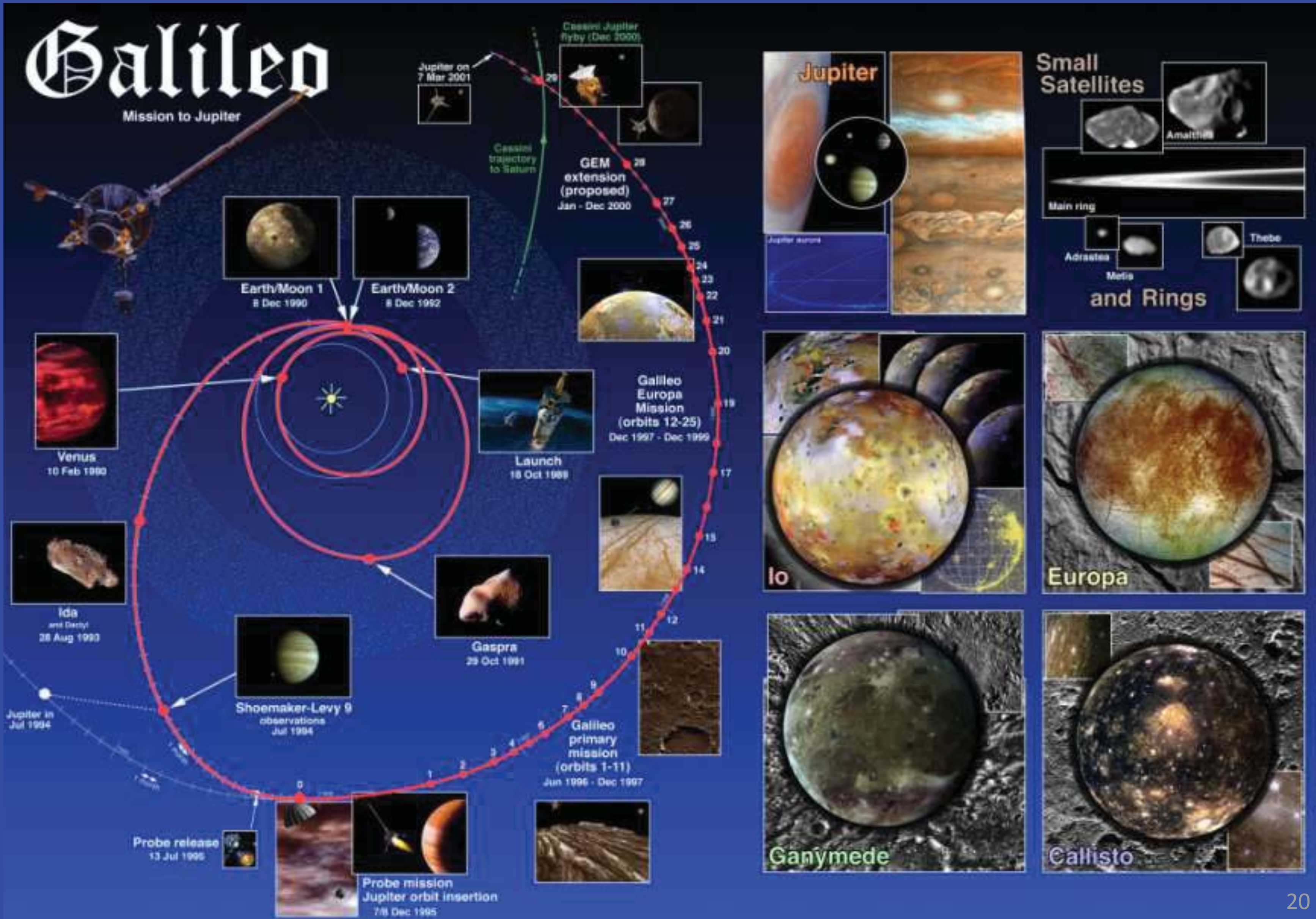
The Galileo mission



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The Galileo mission

Galileo conducted an eight years mission to Juppiter (1996-2004) and its four moons: Io, Europa, Ganymede,Callisto. _Galileo_ had 120 RHU and 2 RTG.

Lunch vehicles were not powerful enough to send _Galileo_ directly to Jupiter. Therefore a complex route was chosen that first took advantage of the gravitational pull of Venus and then the Earth.

This required two orbits around the sun.

_Galile_o consisted of two spacecrafts: an orbiter and an atmospheric probe called Huygens.

The orbiter made ten orbits around Jupiter

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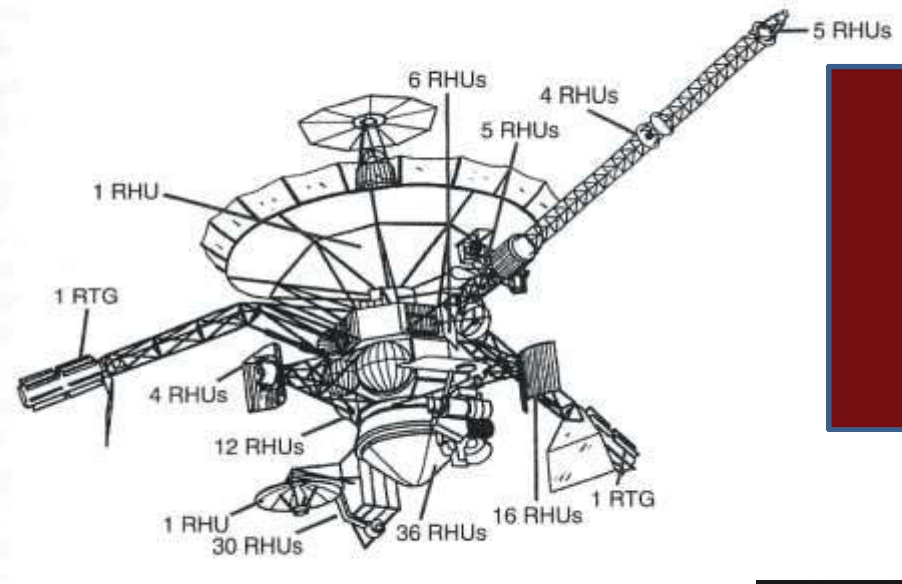

Radioisotopes heating and power units aboard the Galileo spacecraft

The space mission could have not been accomplished without RHU and RTG power sources.

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APPLICATIONS OF NUCLEAR TECHNIQUES TO THE PROTECTION OF THE ENVIRONMENT

Monitoring **Prevention** **Remediation**

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The next figure shows a list of different nuclear analytical techniques (NAT).

The first group includes the NAT based on the direct measurement of the radiation emitted by radioisotopes. They are applied when the analyte is radioactive.

The second group of NAT can be applied to the analysis of non radioactive materials. The sample can be made radioactive by an external neutron flux (neutron activation analysis -NAA) or stimulated to emit X-rays (X-Ray Fluorescence analysis -XRF- and and proton induced X-Ray emission - PIXE) or gamma rays (Proton induced gamma emission-PIGE) by a particle accelerator.

The third group consists of analytical techniques based on the measurement of the mass of an atom using a mass spectrometer (the atomic mass depends on the properties of the atomic nucleus).

Ion dilution analysis is based on the addition to the sample to be analyzed of a known quantity of an isotope of the same element to be analyzed. This added isotope can be either non-radioactive or radioactive. In the first case a mass spectrometer has to be used. In the second case instruments for measuring the alpha, beta or gamma radiation are utilized.

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NUCLEAR ANALYTICAL TECHNIQUES (NATs)

- **ALPHA (α) SPECTROSCOPY**
- **GAMMA (γ) SPECTROMETRY**
- **BETA (β) SCINTILLATION COUNTING**

- **NEUTRON ACTIVATION ANALYSIS (NAA)**
- **X-RAY FLUORESCENCE (XRF)**
- **PIXE**
- **PIGE**

← *Ion Beam Analysis (IBA)*

- **INDUCTIVELY COUPLED PLASMA-MASS SPECTROMETY (ICP-MS)**
- **THERMAL IONIZATION MASS SPECTROMETRY (TIMS)**
- **ACCELERATOR MASS SPECTROMETRY (AMS)**

- **ISOTOPE DILUTION ANALYSIS (IDA)**

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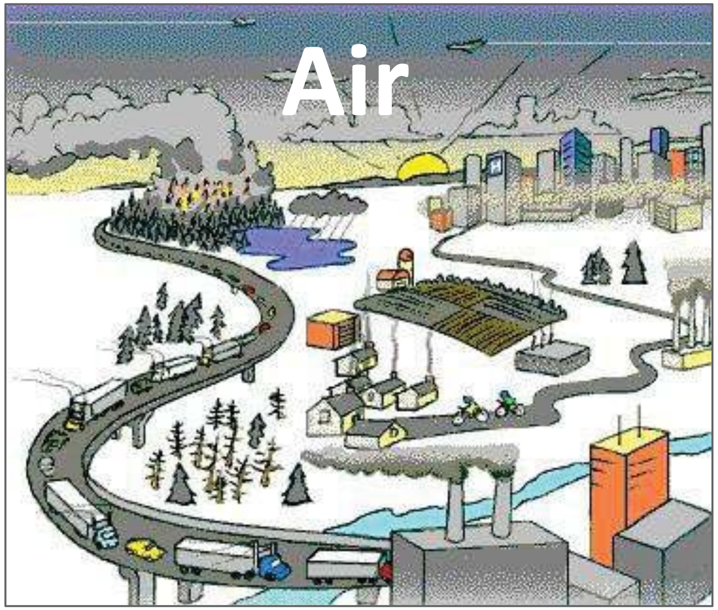
- •ALPHA (α) SPECTROSCOPY
- •GAMMA (γ) SPECTROMETRY
- •BETA (β) SCINTILLATION COUNTING

→ **Monitoring Radionuclides in the Environment**

(accidental or intentional release by Nuclear Power Plants, Low-Level nuclear waste storage sites, radioactivity in water, soil, air, vegetation, etc.)



Bottled Drinking Water

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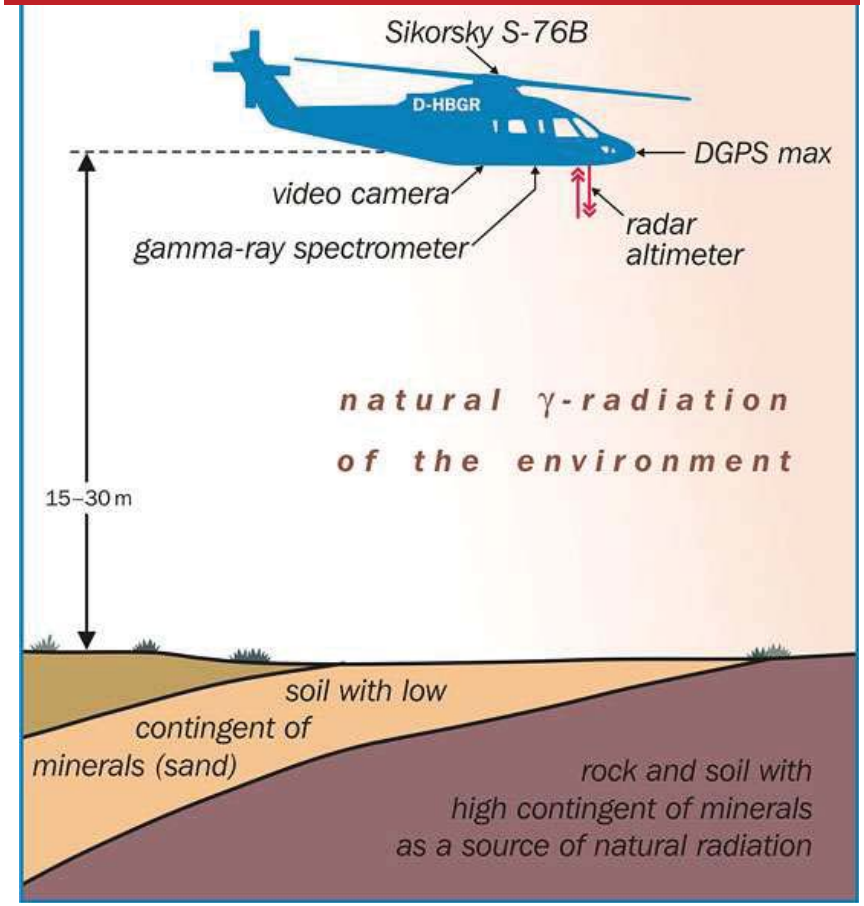
APPLICATIONS OF GAMMA RAY SPECTROMETRY

All rocks and soils are naturally radioactive, containing various proportions of a variety of radioactive elements. The natural decay of these elements produces a variety of types of radiation (alpha, beta, gamma) at specific energy levels.

AIRBORNE GAMMA RAY SPECTROMETRY



Only gamma-ray radiation has sufficient energy to be useful for geological mapping or exploration. Gamma-ray spectrometry provides a method of measuring concentrations of individual radioactive elements (in particular, K, U, Th) as the basis for mapping rocks and soils by virtue of their characteristic radioactivity signatures.

Airborne methods provide valuable, systematic coverage of large areas.

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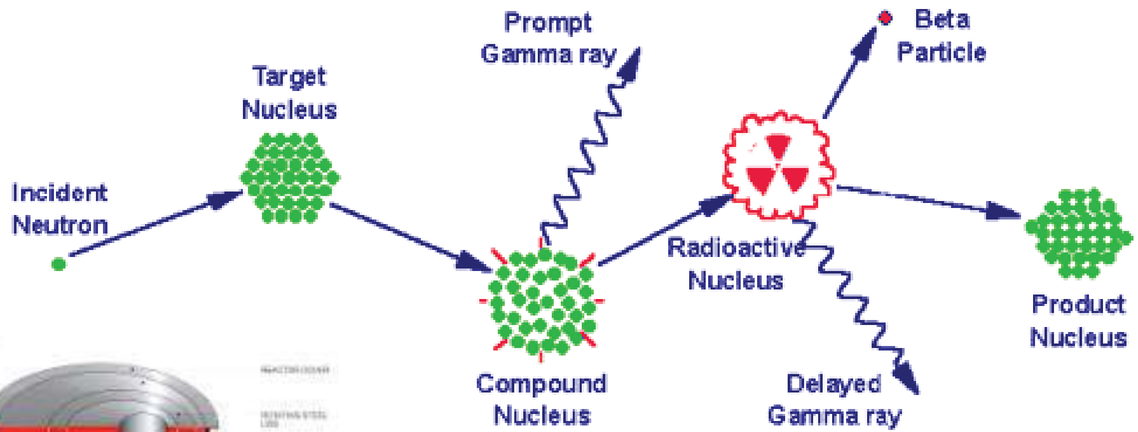
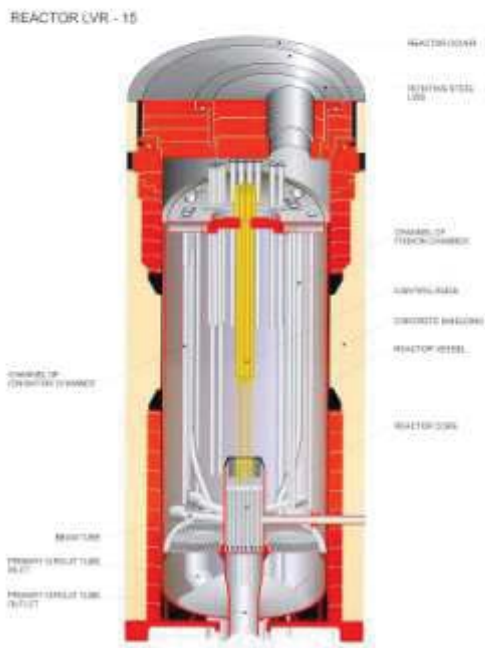
NEUTRON ACTIVATION ANALYSIS

Based upon the conversion of stable atomic nuclei into radioactive nuclei by irradiation with neutrons followed by the measurement of the radiation released (gamma radiation) by these radioactive nuclei.





A Research Reactor is needed

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EXAMPLES OF APPLICATIONS OF NAA TO ENVIRONMENTAL MONITORING

Typical elements determined by NAA in airborne particulate matter

Neutron Activation Analysis (NAA): aluminum (Al), arsenic (As), gold (Au), barium (Ba), bromine (Br), calcium (Ca), cadmium (Cd), chlorine (Cl), cobalt (Co), chromium (Cr), caesium (Cs), europium (Eu), iron (Fe), gallium (Ga), iodine (I), indium (In), potassium (K), lanthanum (La), lutetium (Lu), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), rubidium (Rb), antimony (Sb), scandium (Sc), samarium (Sa), thorium (Th), titanium (Ti), vanadium (V), tungsten (W), zinc (Zn)

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EXAMPLES OF APPLICATIONS OF NAA, XRF and PIXE

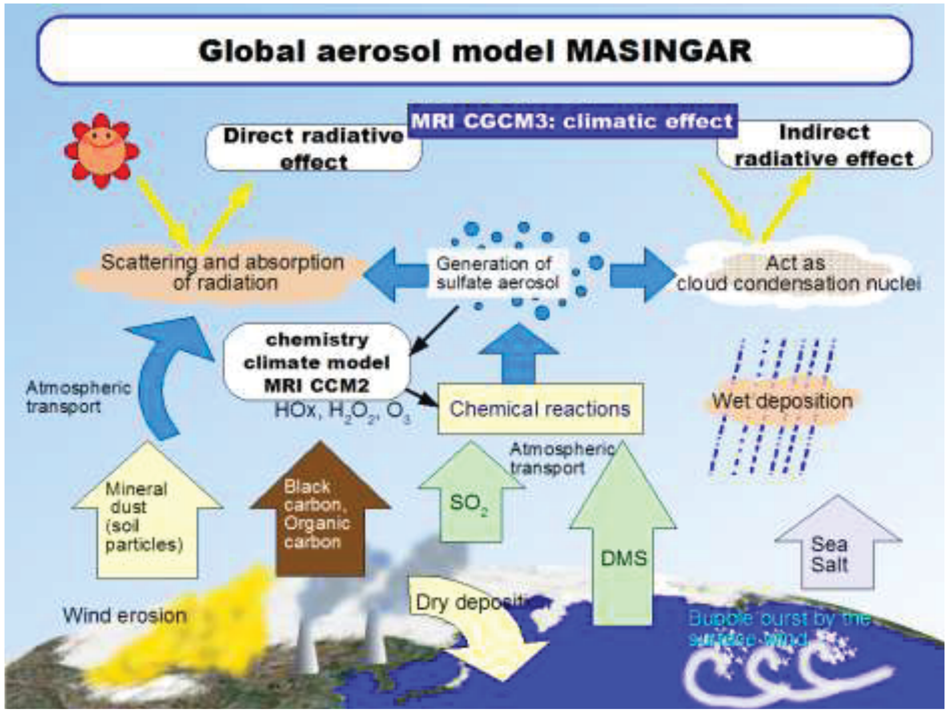
SPM [dust, smoke, aerosols]

Aerosols are collected on a thin film or filter made of light elements. These filters are afterwards analyzed.

- Analysis of e.g. S, V, Ni, Cu, Zn, As, Pb can be done in 5 minutes.

The air-pollution (mainly through the heavy metals) can be traced to the source.

Air pollution analysis is requested indoors (e.g. in working environments) and outdoor near specific pollution sources.



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SPM – SOURCE IDENTIFICATION

The presence or absence of certain chemical elements provide a unique kind of FINGERPRINT which enables individual source of pollution to be identified

Source of pollution are characterized by being composed of different mixtures of elements in different proportions.

Examples of elements associated with six fingerprint sources of fine particles

Source	Elements
Motor vehicle	H, Na, Al, Si, S, Cl, Fe, Zn, Br, Pb, (elemental carbon)
Coal combustion	H, Na, Al, Si, P, S. K, Ca, Fe, (elemental carbon)
Smoke	H, Cl, K, Ca, (elemental carbon)
Soil	Al, Si, K, Ca, Ti, Mn, Fe
Sea spray	Na, S, Cl, K, Ca
Industry	H, P, S,V, Cr, Cu,Pb (elemental carbon)

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Gamma radiation emitted by strong radioactive sources such as Co-60 or X-rays produced by powerful accelerators can be also used to:

• remove pollutants generated coal combustion such as SO_2 and NO_x ,

• remove volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAHs) from the flue gas treatment facilities of municipal waste incinerator plants,

• degrade both the toxic organic compounds and the biological contaminants that are present in waste-waters.

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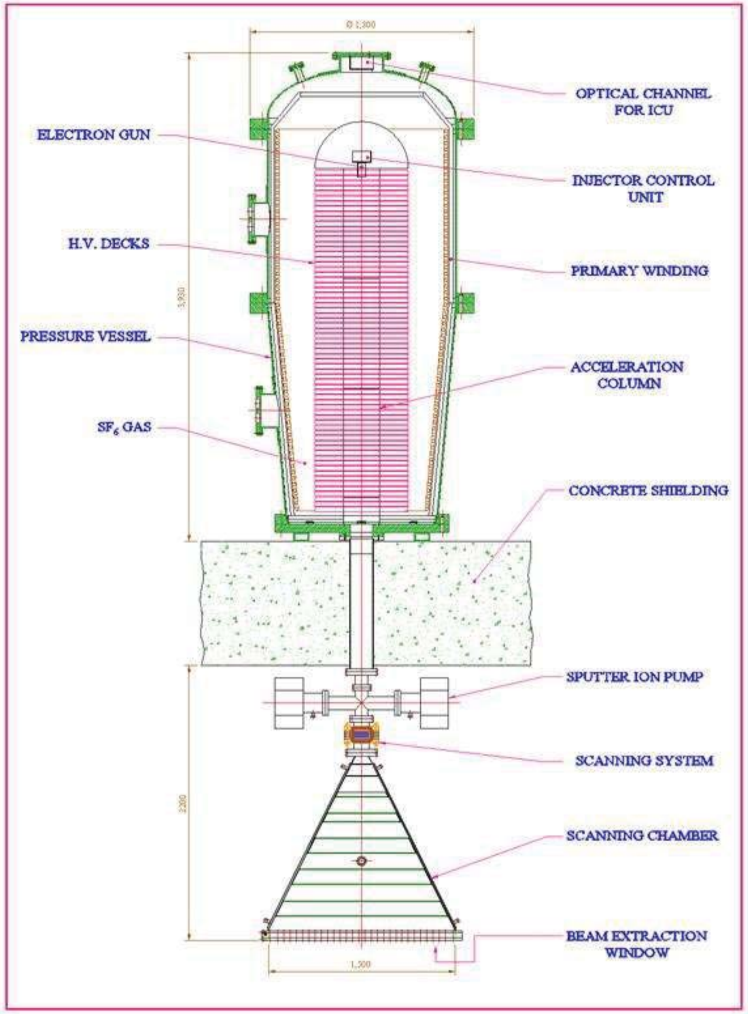
APPLICATIONS OF RADIATION SOURCES TO ENVIRONMENTAL PROTECTION: prevention and remediation

Radioisotopes sources (^{60}Co, ^{137}Cs)

Electron accelerators



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PROTECTING THE ENVIRONMENT

- **Cleaning of Flue gases from coal burning power stations**

- **Treatment of off-gases to remove toxic compounds**

- **Cleaning waters and industrial waste water**

- **Disinfection of sewage sludge to use it as organic fertilizer**

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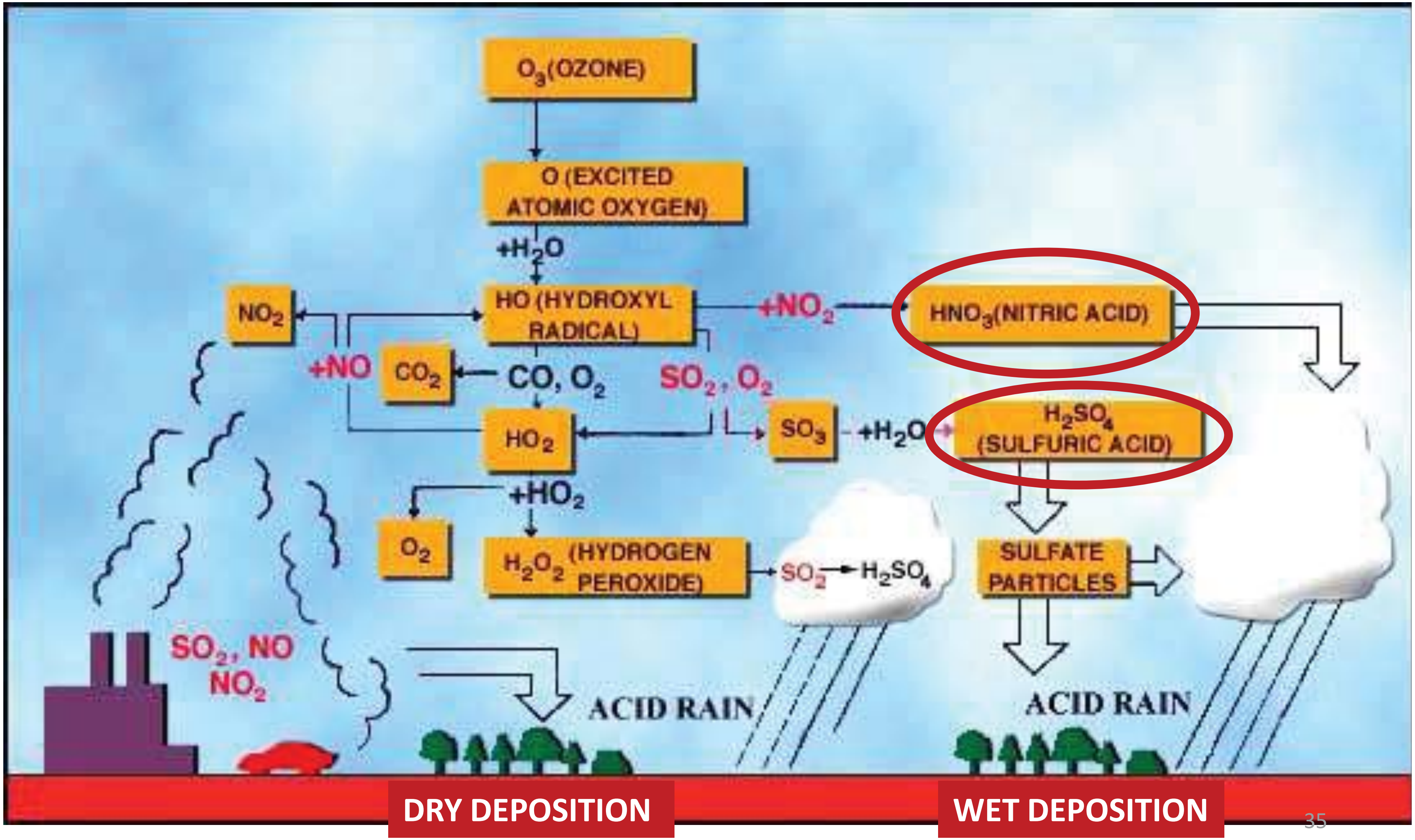
Formation of Acid Rain



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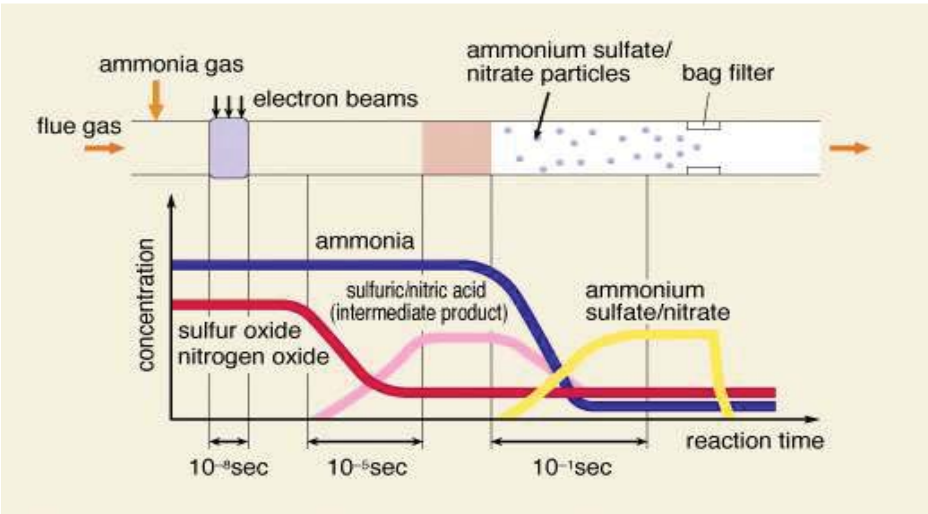
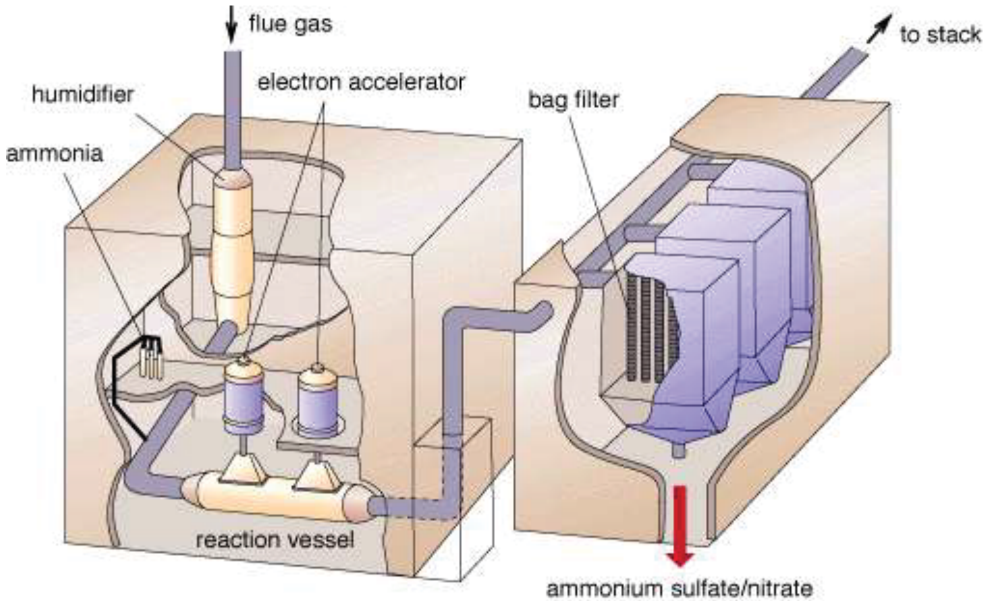
REMOVAL OF SULFUR/NITROGEN OXIDES POLLUTANTS FROM FLUE GASES BY RADIATION PROCESSING

Flue gases exhausted from thermoelectric power plants and municipal waste incinerators contain environmental pollutants such as sulfur/nitrogen oxides, which cause acid rain.

When the flue gas is irradiated by electron beams (EB) in the presence of ammonia gas, the sulfur and nitrogen oxides are converted into ammonium sulfate and nitrate respectively, which are useful as agricultural fertilizers.



Reaction of sulfur/nitrogen oxides with ammonia under the irradiation of electron beams



Schematic drawing of the pilot plant for electron beam flue gas treatment, installed at Kaweczyn thermoelectric power station (Poland)

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REMOVAL OF SULFUR/NITROGEN OXIDES POLLUTANTS FROM FLUE GASES BY RADIATION PROCESSING

Electron beam technology is a dry scrubbing process for simultaneous SO_2 and NO_X removal with no generation of waste.

The main components of flue gas are N_2, O_2, H_20 and CO_2, with much lower conc. of SO_2 and NO_X . Ammonia is present as an additive.

The efficiency of pollutant removal ranges from 87 to 97% for SO_2, and from 85 to 90% for NO_X.

Ammonium sulphate makes up 96-97% of the by-product, with ammonium nitrate accounting for another 2%. The nitrogen content is approximately 21 % or higher, which is the value recommended for use in commercial fertilizer.

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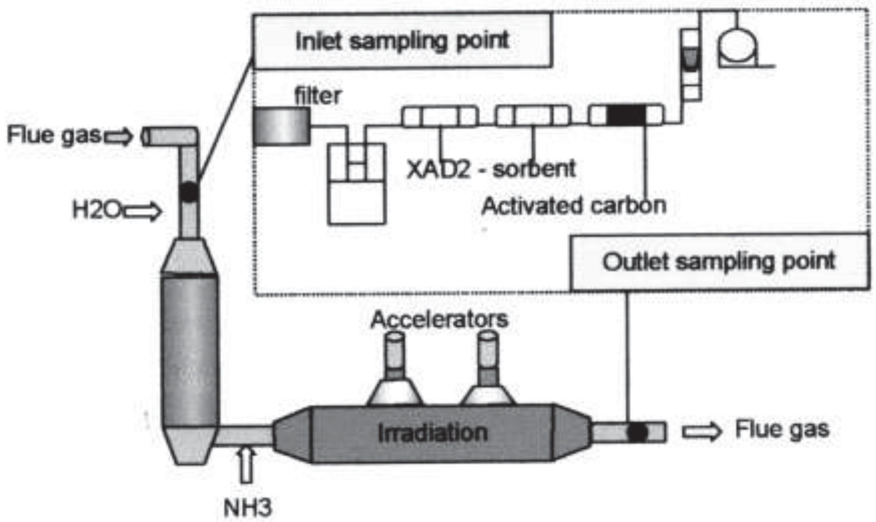
RADIATION INDUCED REMOVAL OF VOLATILE ORGANIC COMPOUNDS (VOCs) FROM EXHAUST GASES

Another possible application of the technology is for the removal of VOCs and polycyclic aromatic hydrocarbons (PAHs), for example, in flue gas treatment facilities of municipal waste incinerator plants.

The primary reactions in the decomposition of VOCs by irradiation are similar to those in SO_2



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Water pollution : the global problem

Water pollution is the leading worldwide cause of deaths and diseases, and that it accounts for the deaths of more than 14,000 people daily.

Water is referred to as polluted when it is impaired by anthropogenic contaminants and either does not support a human use, like serving as drinking water, and/or is unable to support its biotic communities, such as fish.

The contaminants include a wide spectrum of chemicals and pathogens.

Pathogens from inadequately treated sewage discharges can produce waterborne diseases in either human or animal hosts.

Older cities with aging infrastructure may have leaky sewage collection systems (pipes, pumps, valves), which can cause sanitary sewer overflows or combined sewers, which may discharge untreated sewage during rain storms.

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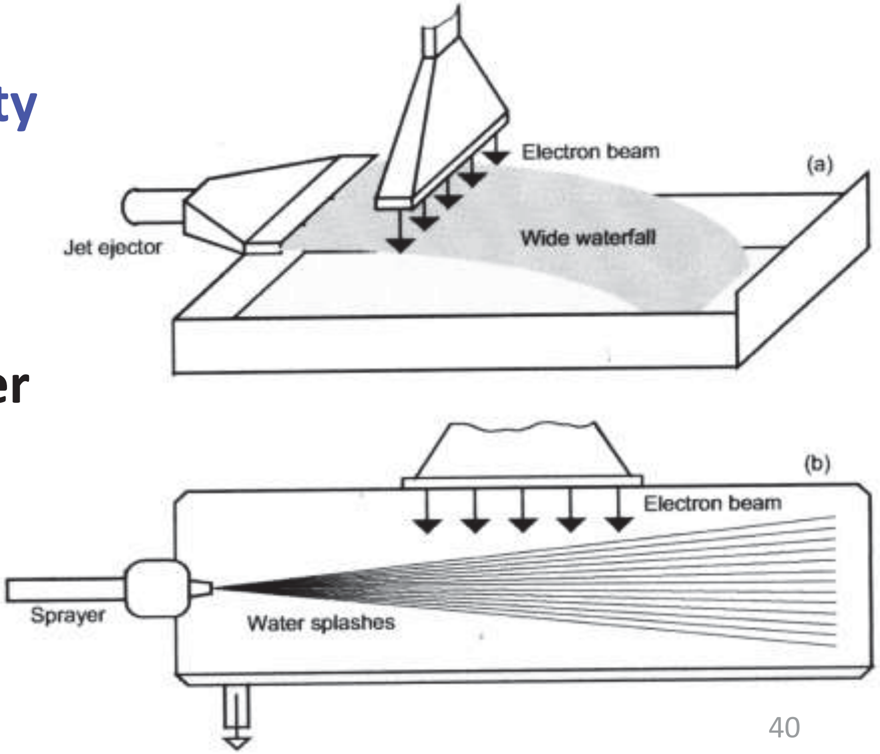
RECLAMATION OF EFFLUENT FROM MUNICIPAL WASTEWATER TREATMENT PLANTS

Radiation processing can simultaneously **degrade both the toxic organic compounds and the biological contaminants that are present.**

Radiation wastewater treatment technologies are **essential to protect public health and to meet water quality criteria** for the **aquatic environment and for water recycling and reuse.**



Moreover, when reclaimed wastewater is to be used for **human consumption**, **disinfection is absolutely crucial**, and **removal or inactivation of pathogenic organisms** is a critical step.

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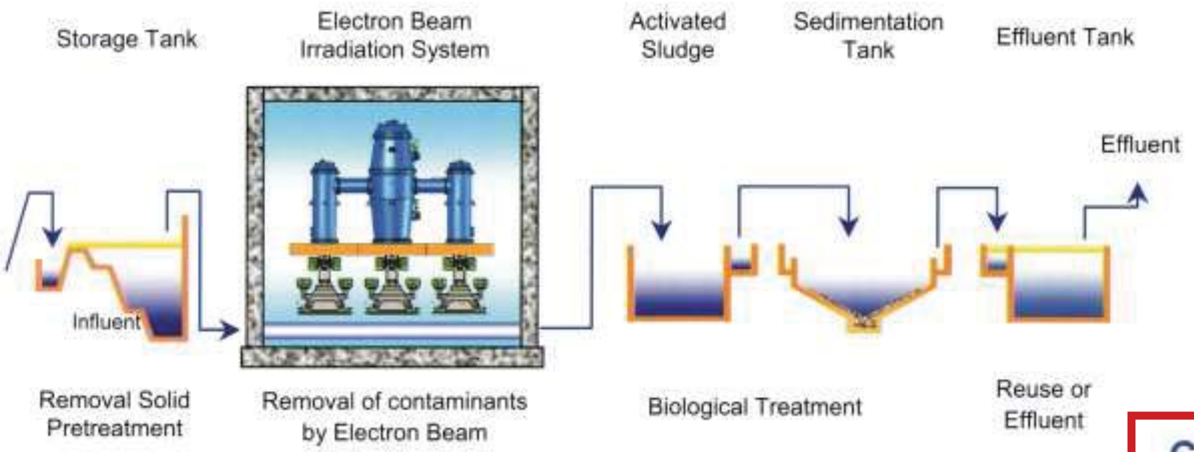
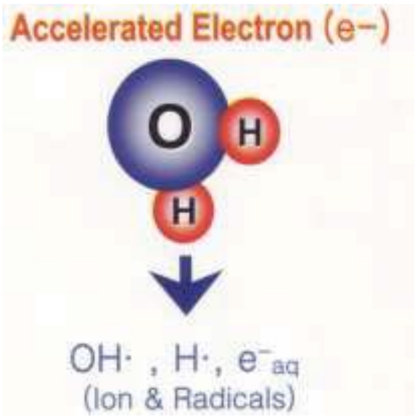
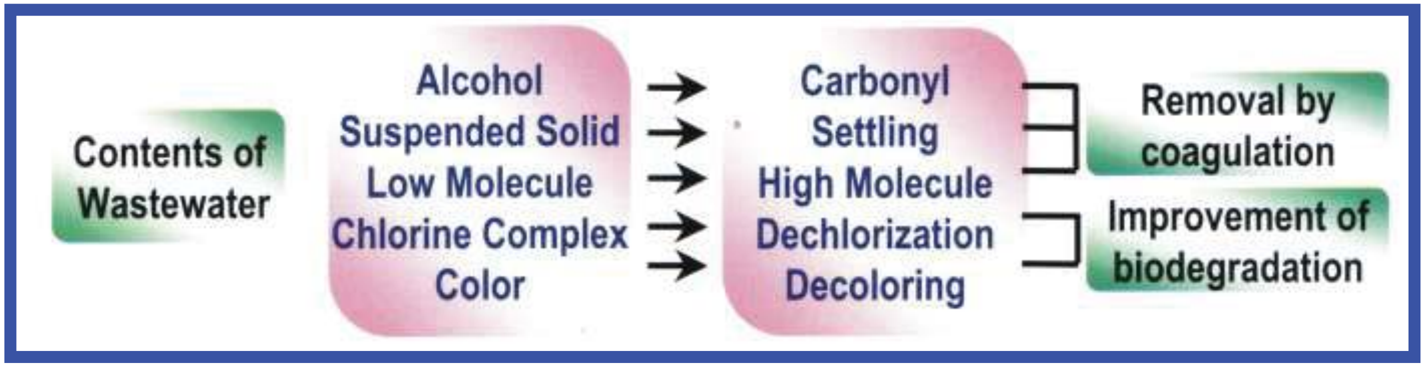
Process of Wastewater Treatment by Electron Beam





Characteristic & Advantages

- No catalyst & chemicals required
- Low energy consumption
- Easy operation & low cost
- Fast, safe & economic
- Disinfection & decolorization
- Good for easy reuse



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Example of Applications of

NAA, IBA and XRF to

Archaeometry and Cultural Heritage Studies

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Application of Nuclear Activation Analysis to Archaeology

To characterize archaeological specimens (e.g., pottery, obsidian, chert, and limestone) and to relate the artifacts to source materials through their chemical signatures is a well-established application.

NAA can detect up to 74 elements depending upon the experimental procedure. With minimum detection limits ranging from 0.1 to $1x10^6$ ng g^{-1} depending on element under investigation.

Heavier elements have larger nuclei, therefore they have a larger neutron capture cross-section and are more likely to be activated.

Sensitivity (picograms)	Elements
1	Dy, Eu
1 - 10	In, Lu, Mn
10 - 100	Au, Ho, Ir, Re, Sm, W
100 - 1E3	Ag, Ar, As, Br, Cl, Co, Cs, Cu, Er, Ga, Hf, I, La, Sb, Sc, Se, Ta, Tb, Th, Tm, U, V, Yb
1E3 - 1E4	Al, Ba, Cd, Ce, Cr, Hg, Kr, Gd, Ge, Mo, Na, Nd, Ni, Os, Pd, Rb, Rh, Ru, Sr, Te, Zn, Zr
1E4 - 1E5	Bi, Ca, K, Mg, P, Pt, Si, Sn, Ti, Tl, Xe, Y
1E5 - 1E6	F, Fe, Nb, Ne
1E7	Pb, S

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Pigments and paintings

Most of the pigments are characterized by inorganic elements and can be thus studied. For example, pigments used in miniatures in medieval manuscripts have been analyzed.

Information about light elements can be determined by means of PIGE, because gamma-rays have a much higher energy than X-rays.

An application of both PIGE and PIXE to the study of a painting is represented by the analysis of the Madonna dei Fusi by Leonardo da Vinci

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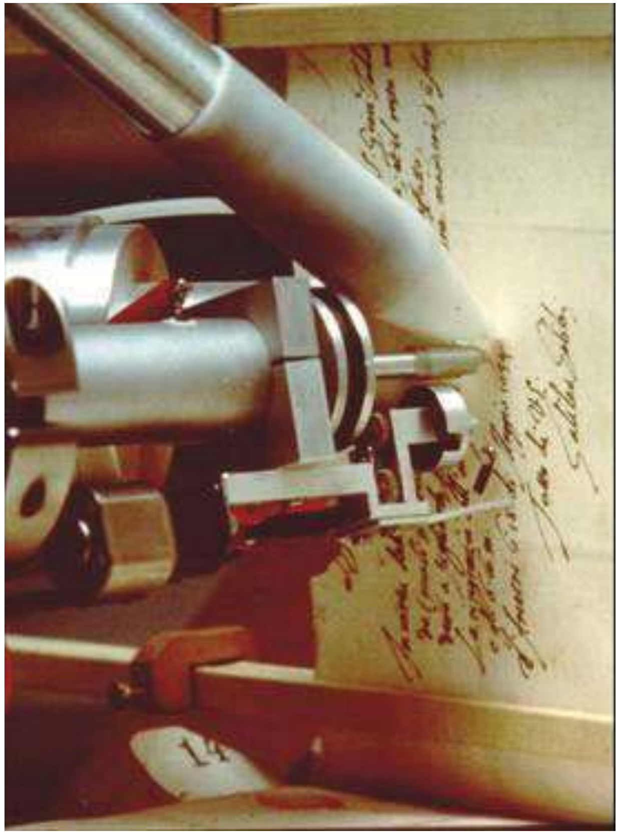
Example: Applications of IBA and XRF to Cultural Heritage Studies

Iron gall inks and manuscripts

Iron gall inks of ancient manuscripts are characterized not only by iron itself but also by other metals, like zinc, copper and lead: their relative abundances represent a sort of fingerprints of a particular typology of ink.

PIXE can provide all the required informations without risk of damage to the paper.

The elemental analysis of inks can give us also the possibility for an indirect dating of manuscripts.



Lots of notes and demonstrations written by Galileo Galilei are sketched on folios without a date. Establishing the chronology of the various folios can be very difficult. Inks in many of these folios have been analyzed and their composition compared with the ones of dated documents (like letters).

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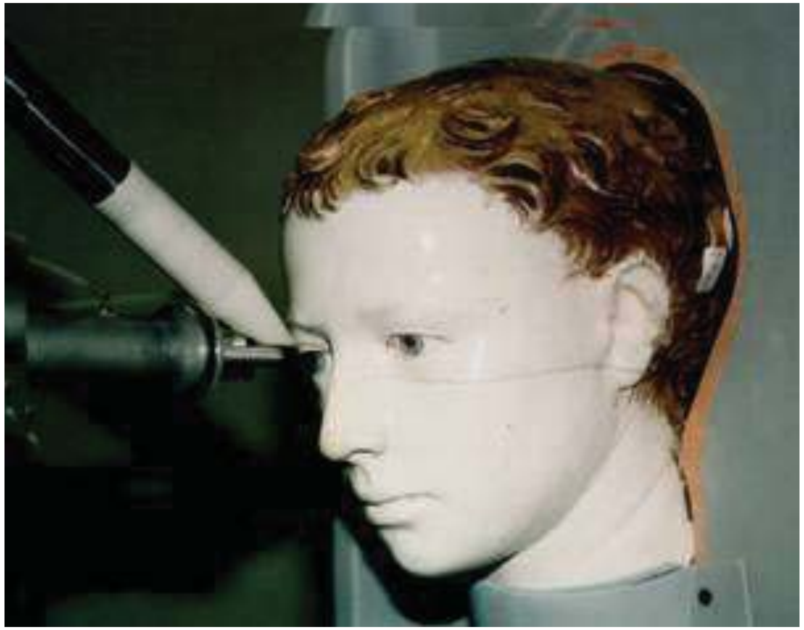
Ceramics

Both major and minor elements concentrations in ceramics, porcelains and glasses can be determined with reasonable accuracy.

This kind of measurements were mainly intended to solve problems of authenticity but also to get important information for restoration.



Example: analysing the glazed terra-cotta sculptures produced during the Florentine Renaissance, and in particular the works of the family Della Robbia.

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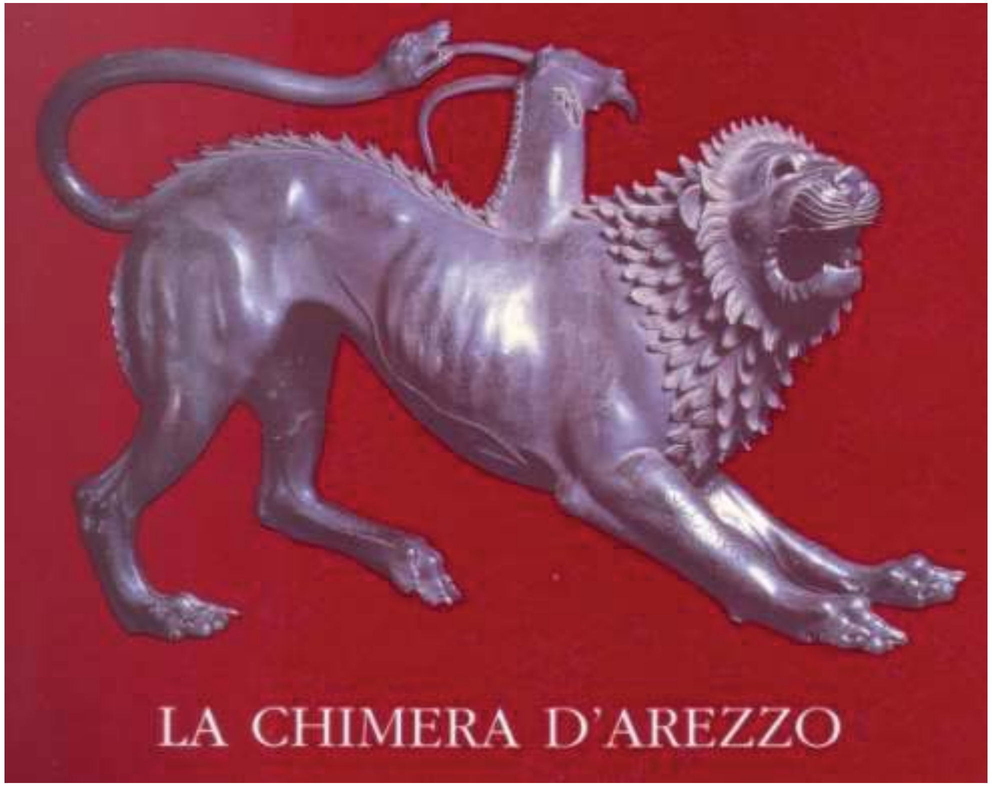
Examples of art objects studied by nuclear techniques



This a bronze Etruscan sculpture made between the last quarter of the Vth century B.C. and the first decade of the IV century B.C.

The following nuclear techniques were use to study the *Chimera:*

- γ Ray Imaging
- Electronic Microprobe
- Nuclear Activation Analysis
- XRF
- Lead Isotopes Ratios

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APPLICATIONS TO HUMAN HEALTH

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Radiation therapy

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Radiotherapy

- **Rapidly dividing cells are particularly sensitive to damage by radiation. For this reason, some cancerous growths can be controlled or eliminated by irradiating the area containing the growth**
- ***Extern*al irradiation can be carried out using a gamma beam from a radioactive cobalt-60 source, though the much more versatile linear accelerators are now being utilised as a high-energy x-ray source**
- **Internal radiotherapy is by administering or planting a small radiation source, usually a gamma or beta emitter, in the target area.**
- **Iodine-131 is commonly used to treat thyroid cancer, probably the most successful kind of cancer treatment. It is also used to treat non-malignant thyroid disorders.**
- **Iridium-192 implants are used especially in the head and breast. They are produced in wire form and are introduced through a catheter to the target area. After administering the correct dose, the implant wire is removed to shielded storage.**

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NUCLEAR MEDICINE

What is it?

- It involves the use of small amounts of radioactive materials (or tracers) to help diagnose and treat a variety of diseases.
- It determines the cause of the medical problem based on the function of the organ, tissue, or bone.
- As an integral part of patient care, it is used in the diagnosis, management, treatment, and prevention of serious disease.
- Nuclear medicine imaging procedures often identify abnormalities very early in the progression of a disease-long before some medical problems are apparent with other diagnostic tests.
- Today, nuclear medicine offers procedures that are helpful to a broad span of medical specialties, from pediatrics to cardiology to psychiatry.
- There are nearly one hundred different nuclear medicine imaging procedures available and not a major organ system, which is not imaged by nuclear medicine.

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NUCLEAR MEDICINE

How does it work?

- Nuclear medicine uses very small amounts of radioactive materials or radiophamaceuticals to diagnose and treat disease

- These tracers are introduced into the body by injection, swallowing, or inhalation

- Radiopharmaceuticals are substances that are attracted to specific organs, bones, or tissues and are used to study different parts of the body

- The radiopharmaceuticals used in nuclear medicine emit gamma rays that can be detected externally by special types of cameras called gamma cameras.

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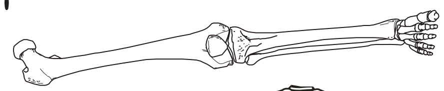
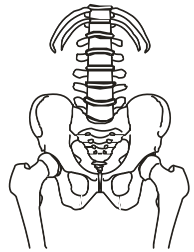
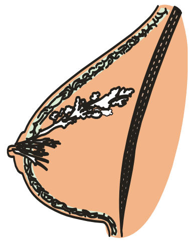
NUCLEAR MEDICINE

Frequently performed examinations

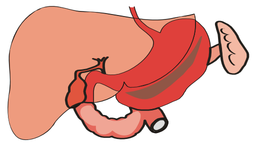




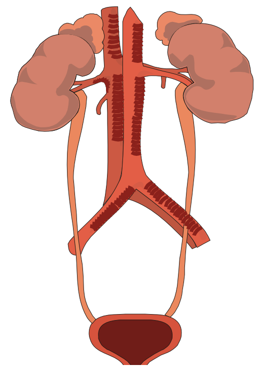
- Bone scans to examine orthopedic injuries, fractures, tumors, or unexplained bone pain. Bone scans may also be ordered for follow-up cancer patients.



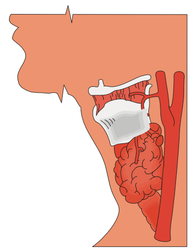
- Breast scans which are used in conjunction with mammograms to more accurately detect and locate cancerous tissue in the breasts.



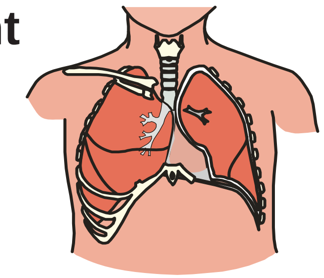
- Liver and gallbladder scans to evaluate liver and gallbladder function.



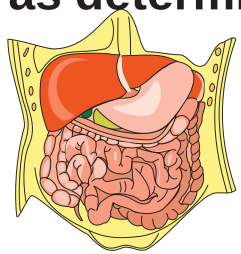
- Renal imagining to examine kidney function.



- Thyroid uptake and scans to analyze the overall function of the thyroid and show the structure of the gland.



- Lung scans to evaluate the flow of blood and movement of air into and out of the lung as well as determine the presence of blood clots.



- Gastrointestinal bleeding scans

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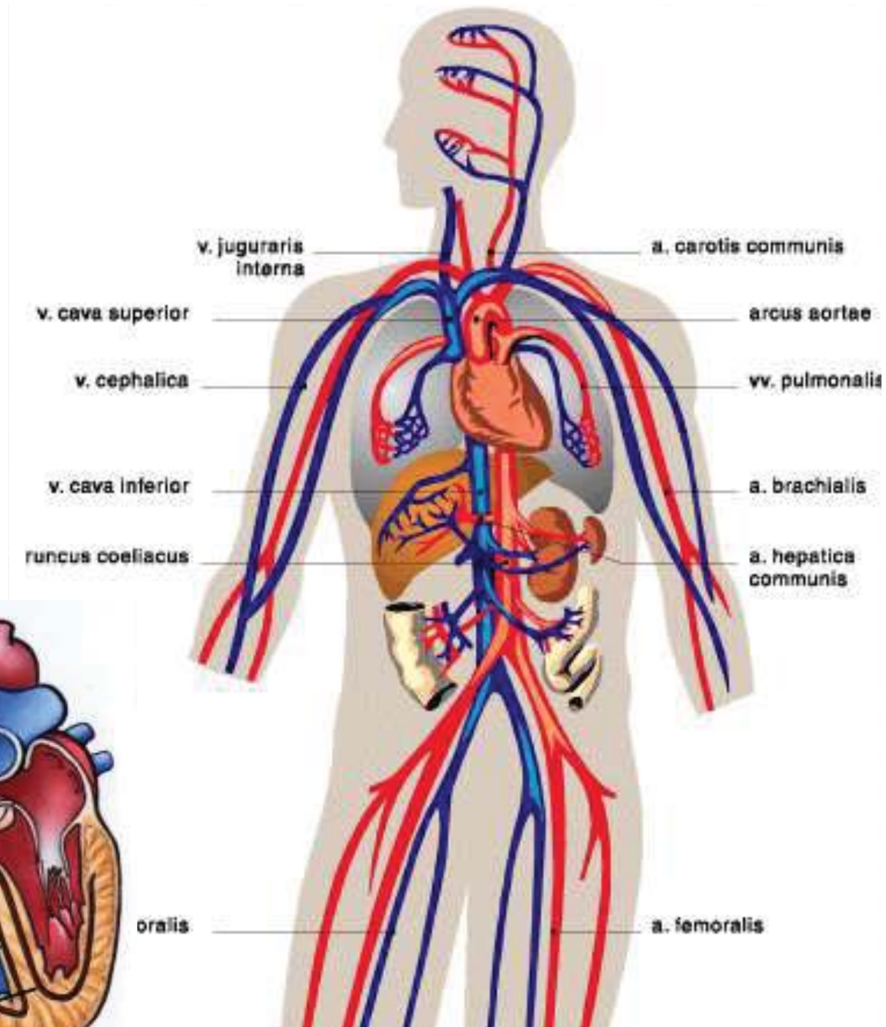
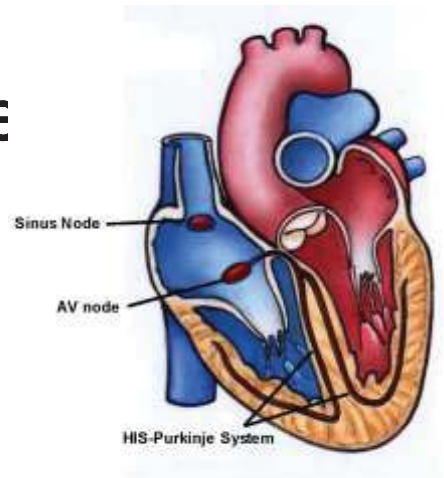
Nuclear Cardiology

Nuclear cardiology uses small amounts of radioactive material to obtain information about the heart

Heart scans to identify normal or abnormal blood flow to the heart muscle, measure heart function or determine the existence or extent of damage the heart muscle a heart attack





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Radiopharmaceutical: general principles

- **Every organ in our bodies acts differently from a chemical point of view**
- **Doctors and chemists have identified a number of chemicals which are absorbed by specific organs**
- **For example, the thyroid takes up iodine and the brain consumes quantities of glucose**
- **Once a radioactive form of one of these substances enters the body, it is incorporated into the normal biological processes and excreted in the usual ways.**

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RADIOPHARMACOLOGY and RADIOPHARMACEUTICAL

Radiopharmacology is the study and preparation of radiopharmaceuticals , which are radioactive pharmaceuticals.

Radiopharmaceuticals are used in the field of nuclear medicine as tracers in the diagnosis and treatment of many diseases.

Many radiopharmaceuticals use technetium (Tc-99m).

31 different radiopharmaceuticals based on Tc-99m are used for imaging and functional studies of the *brain, myocardium, thyroid, lungs, liver, gallbladder, kidneys, skeleton, blood and tumors*.

Radioisotopes used in Radiopharmaceuticals

Calcium-47, Carbon-11, Carbon-14, Chromium-51, Cobalt-57, Cobalt-58, Erbium-169, Fluorine- 18, Gallium-67, Hydrogen-3, Iridium-111 Iodine-123, Iodine-131, Iron-59, Krypton-81m, Nitrogen- 13, Oxygen-15, Phosphorus-32, Samarium-153, Selenium-75, Sodium-22, Sodium-24, Strontium-89, Technetium-99m, Thallium-201, Xenon-133, Yttrium-90

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The radioisotope most widely used in medicine is Tc-99m, employed in some 80% of all nuclear medicine procedures (about 40,000 every day).

It is an isotope of the artificially-produced element technetium and it has almost ideal characteristics for a nuclear medicine scan.

These are:

1. It decays by emitting gamma rays and low energy electrons. Since there is no high energy beta emission the radiation dose to the patient is low
2. The low energy gamma rays it emits easily escape the human body and are accurately detected by a gamma camera.
3. It has a half-life of six hours which is long enough to examine metabolic processes yet short enough to minimise the radiation dose to the patient;
4. The chemistry of technetium is so versatile it can form tracers by being incorporated into a range of biologically-active substances to ensure that it concentrates in the tissue or organ of interest.

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Technetium generators contain Mo-99, with a half-life of 66 hours, which progressively decays to Tc-99. The Tc-99 is washed out by saline solution when it is required. After two weeks or less the generator is returned for recharging.

A similar generator system is used to produce rubidium-82 for PET imaging from strontium-82 - which has a half-life of 25 days.

Myocardial Perfusion Imaging (MPI) uses Thallium-201 chloride or Tc-99m and is important for detection and prognosis of coronary artery disease.

For PET imaging, the main radiopharmaceutical is Fluoro-deoxy glucose (FDG) incorporating F-18 - with a half-life of just under two hours, as a tracer. The FDG is readily incorporated into the cell without being broken down, and is a good indicator of cell metabolism.

In diagnostic medicine, there is a strong trend to using more cyclotron-produced isotopes such as F-18 as PET and CT/PET become more widely available. However, the procedure needs to be undertaken within two hours of a cyclotron.

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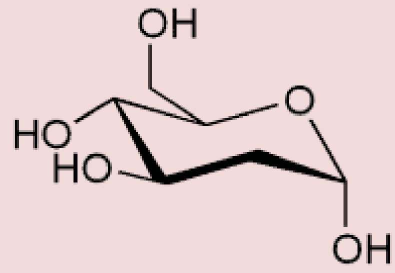
2-DG has been used as a targeted optical imaging agent for fluorescent *in vivo* imaging.



2-Deoxy-D-glucose

2-DG is uptaken by the glucose transporters of the cell. Therefore, cells with higher glucose uptake, for example tumor cells, have also a higher uptake of 2-DG.

In clinical medical imaging (PET scanning), fluorodeoxyglucose is used, where one of the 2-hydrogens of 2-deoxy-D-glucose is replaced with the positron-emitting isotope fluorine-18, which emits paired gamma rays, allowing distribution of the tracer to be imaged by external gamma camera(s).

This is increasingly done in tandem with a CT function which is part of the same PET/CT machine, to allow better localization of small-volume tissue glucose-uptake differences.

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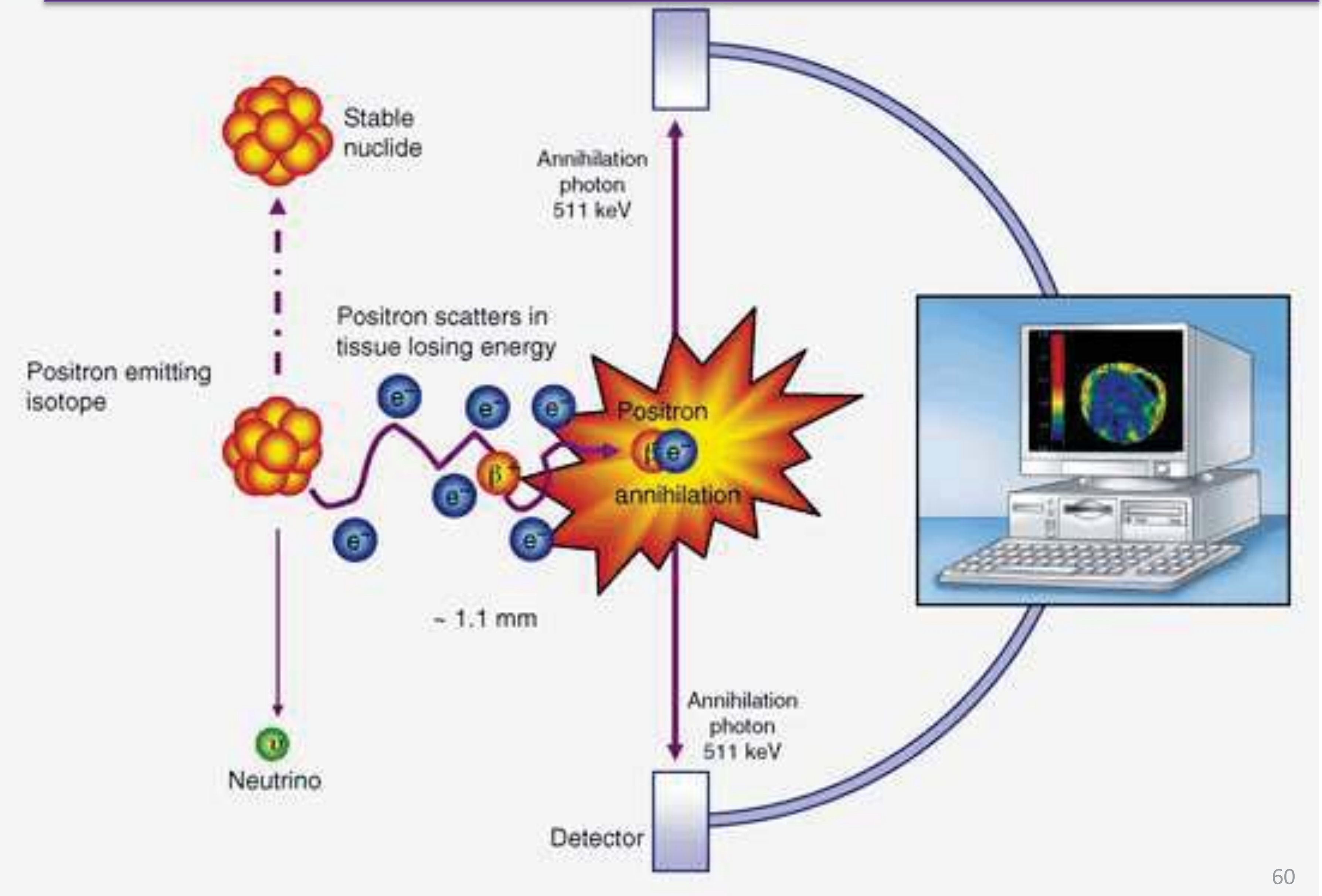
POSITRON EMISSION TOMOGRAPHY - PET



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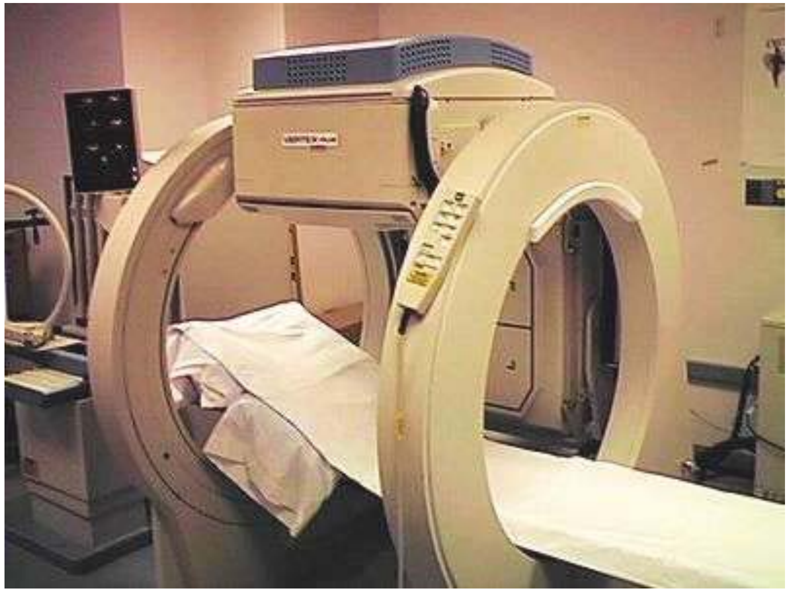
Gamma camera

A device to view and analyse images of the human body due to the distribution of medically injected, inhaled, or ingested radionuclides emitting gamma ray



A gamma camera consists of one or more flat crystal planes or, detectors, optically coupled to an array of photomultiplier tubes connected to a computer system that controls the operation of the camera and the acquisition and storage of acquired images

The system accumulates events or, counts of gamma photons that are absorbed by the crystal in the camera. Usually a large flat crystal of sodium iodide with thallium doping in a light-sealed housing is used

This reconstructed image reflects the distribution and relative concentration of radioactive tracer elements present in the organs and tissues imaged

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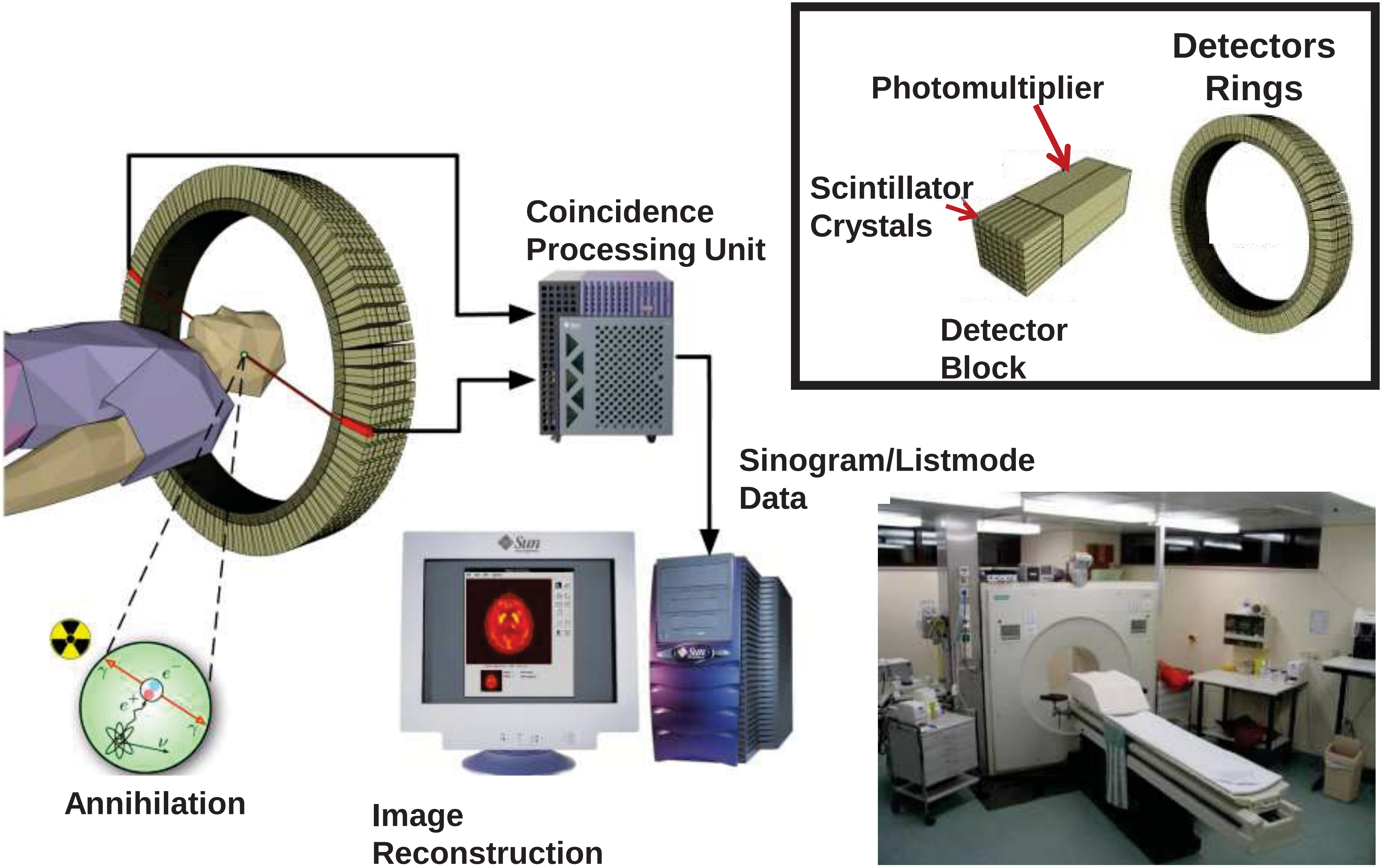
PET
Positron Emission Tomography



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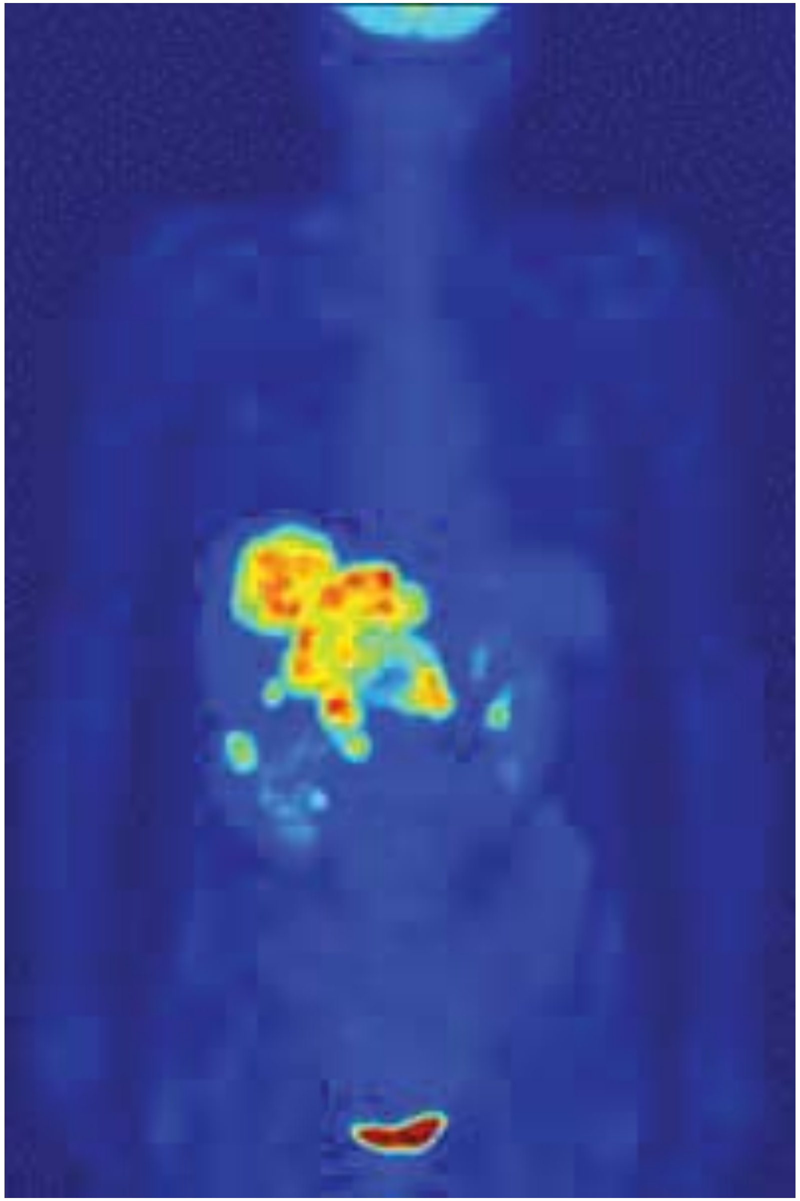

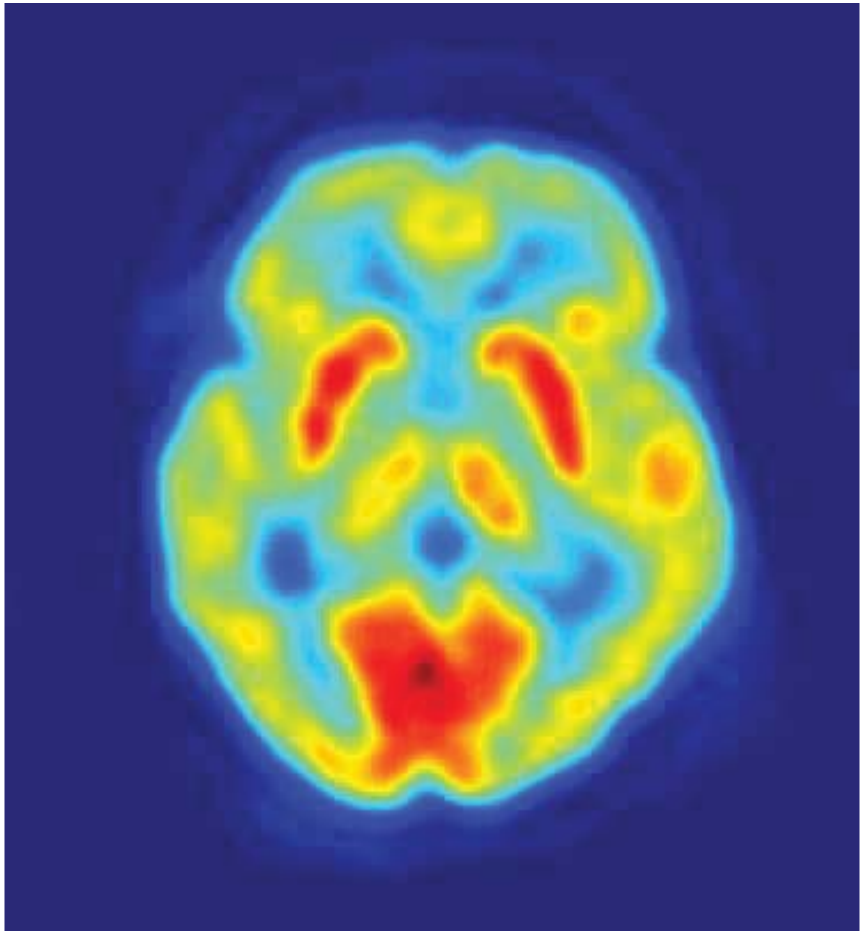

EXAMPLES OF PET IMAGES

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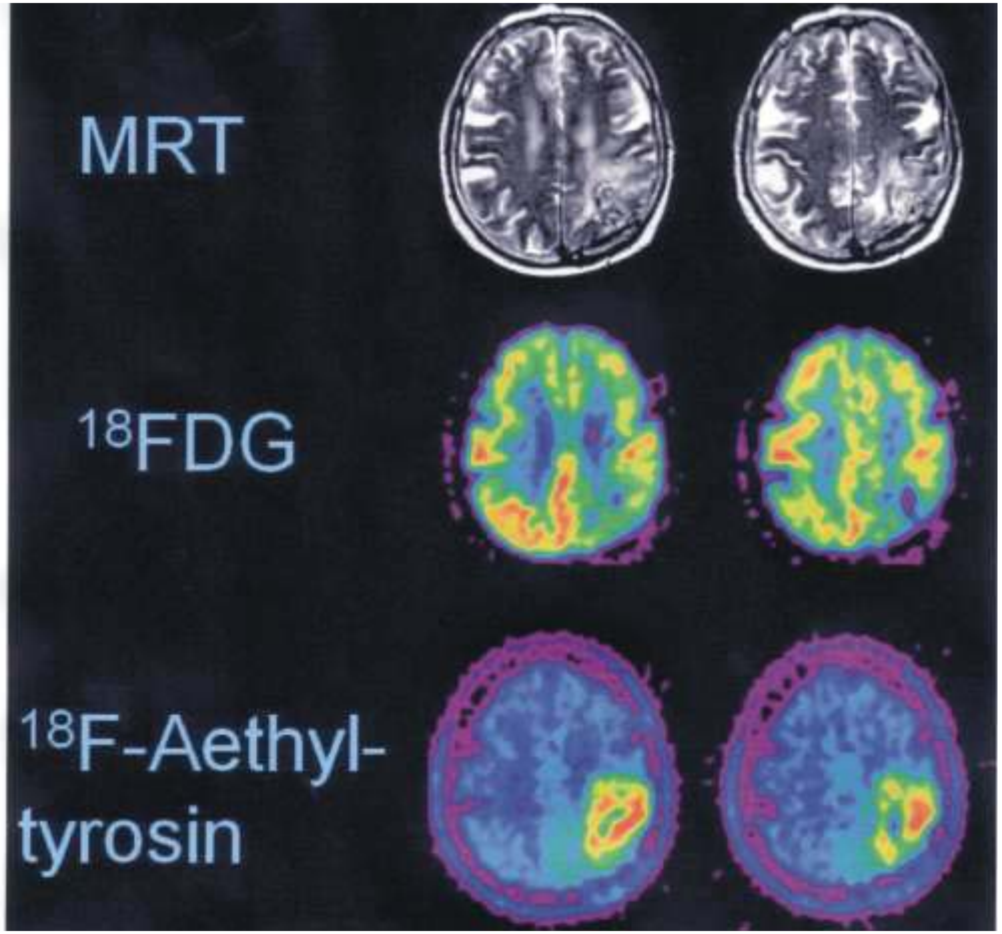
PET Images of the same brain containing a tumor.



Top: anatomical brain sections produced by magnetic resonance imaging (MRI).

Center: images produced using positron emission tomography (PET). The radioactive glucose is absorbed by the entire brain (centre) and therefore not suitable in this instance to diagnose remainders of the tumor.

Bottom: the radioactive amino acids are above all absorbed by the cells of the tumor, thus making an accurate identification of remainders possible

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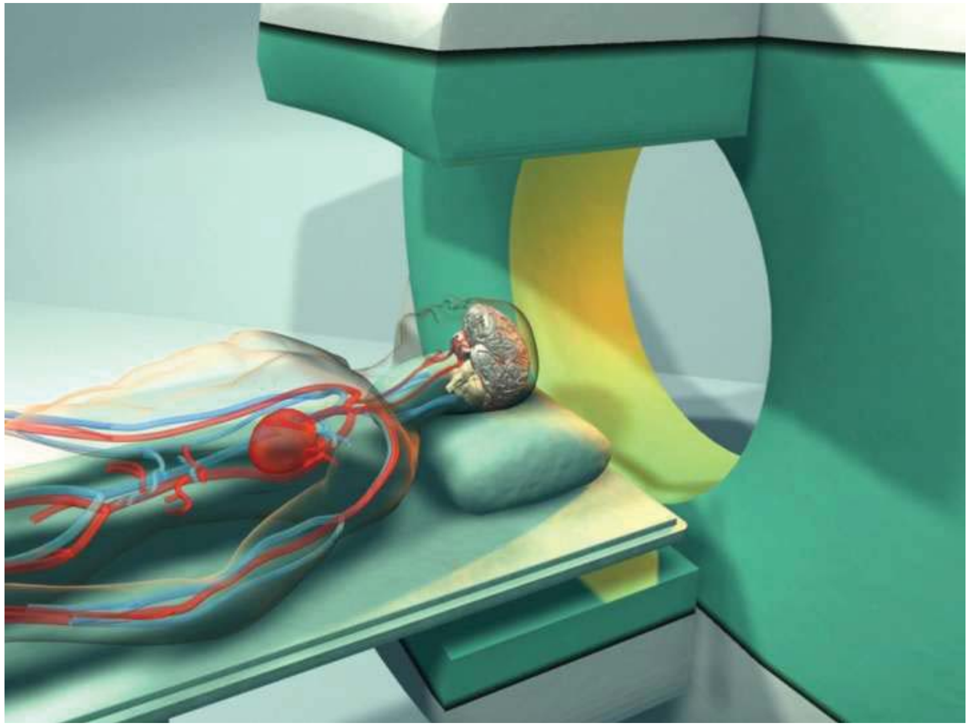
SPECT is a nuclear medicine tomographic imaging technique using gamma rays

It is very similar to conventional nuclear medicine planar imaging using a gamma camera.

However, it is able to provide true 3D information

This information is typically presented as cross-sectional slices through the patient, but can be freely reformatted or manipulated as required

SPECT
Single-Photon Emission Computer Tomography



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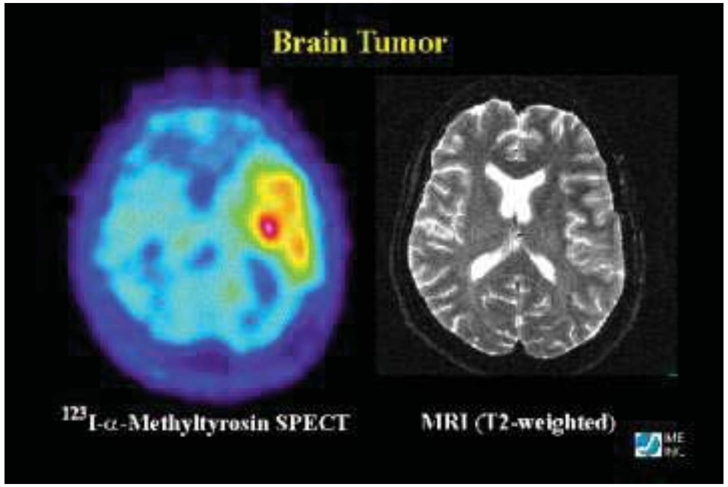
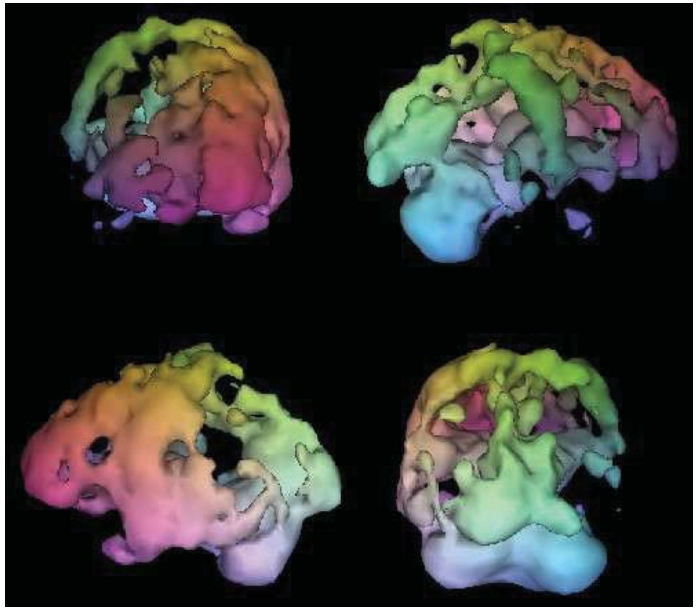


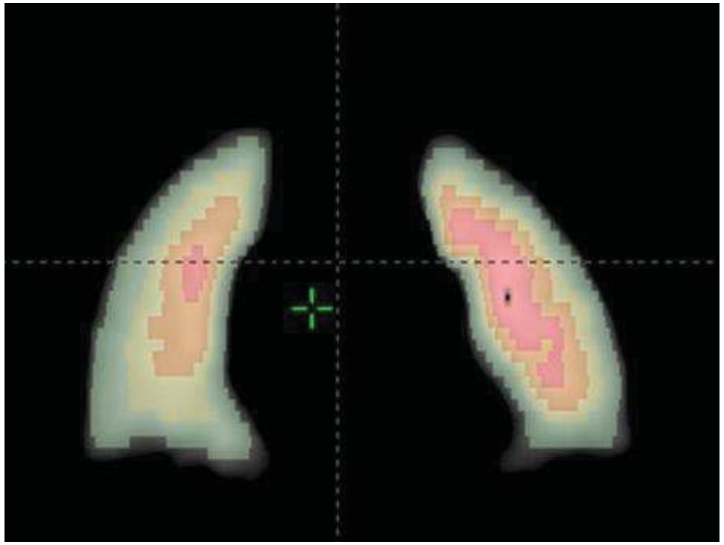


Brain SPECT Showing Alzheimer's Disease

SPECT
Single-Photon Emission Computer Tomography

A gamma camera is rotated to obtain 3-dimensional images from multiple angles.

It can locate precisely the position of a physiological abnormality through a series of computer-generated images.



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Technique for the treatment of diseases

RADIOIMMUNOTHERAPY (RIT)

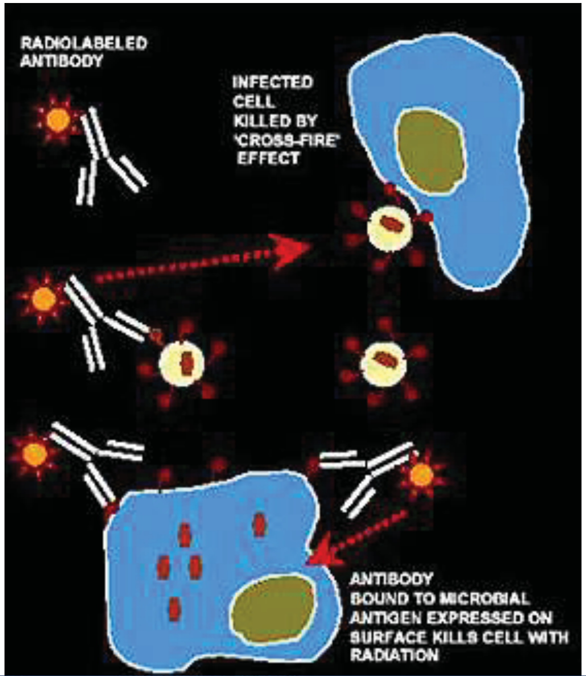
The drug injected is labeled with a proper radioisotope and is capable to accumulate preferentially in the tumor tissue.

These radiopharmaceuticals are also called "magic bullets" or cytotoxic agents.

The cytotoxic agent bombards the tumor cells with the radioisotope radiation.

Short range radiation is preferred to perform localized irradiation and minimise damage to healthy cells.

The most common cytotoxic agents are monoclonal antibodies labeled with Y-90, Re-188, Bi-212.



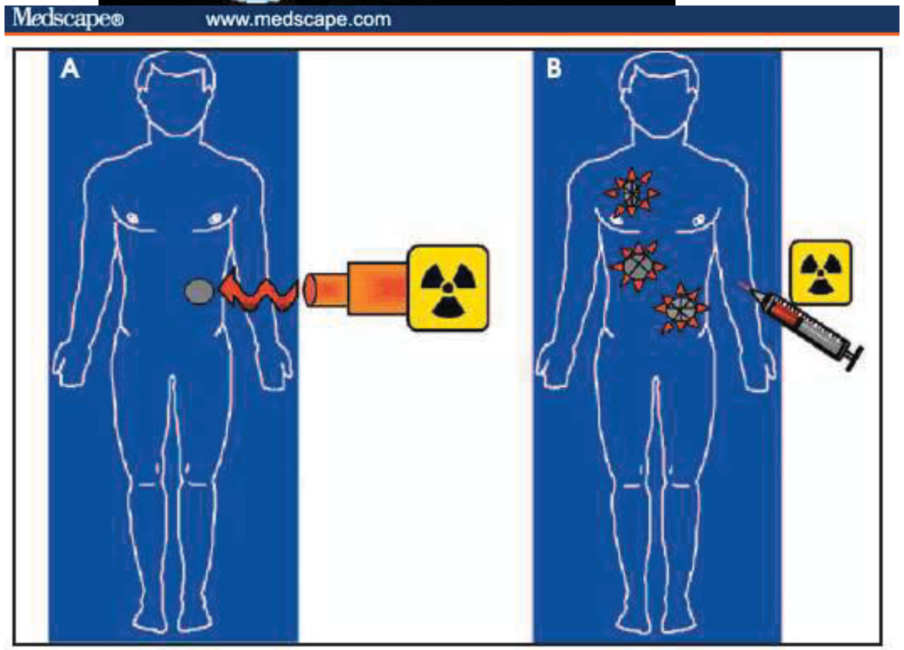


FIGURE 7. (A) External-beam X-ray therapy uses an external source of radiation and focuses the beam to a localized region of tumor. (B) Radioimmunotherapy involves injecting radioactive-labeled antibodies into the bloodstream, then the radioactivity will accumulate in tumors, even those spread throughout the body.

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Applications in Food and Agriculture

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Radiation Induced Mutation Techniques

- *Improving crop cultivars*
- *Enhancing biodiversity*
- *Increasing farmer's income*

Gamma Irradiator

Gamma Greenhouse

Gamma Fields


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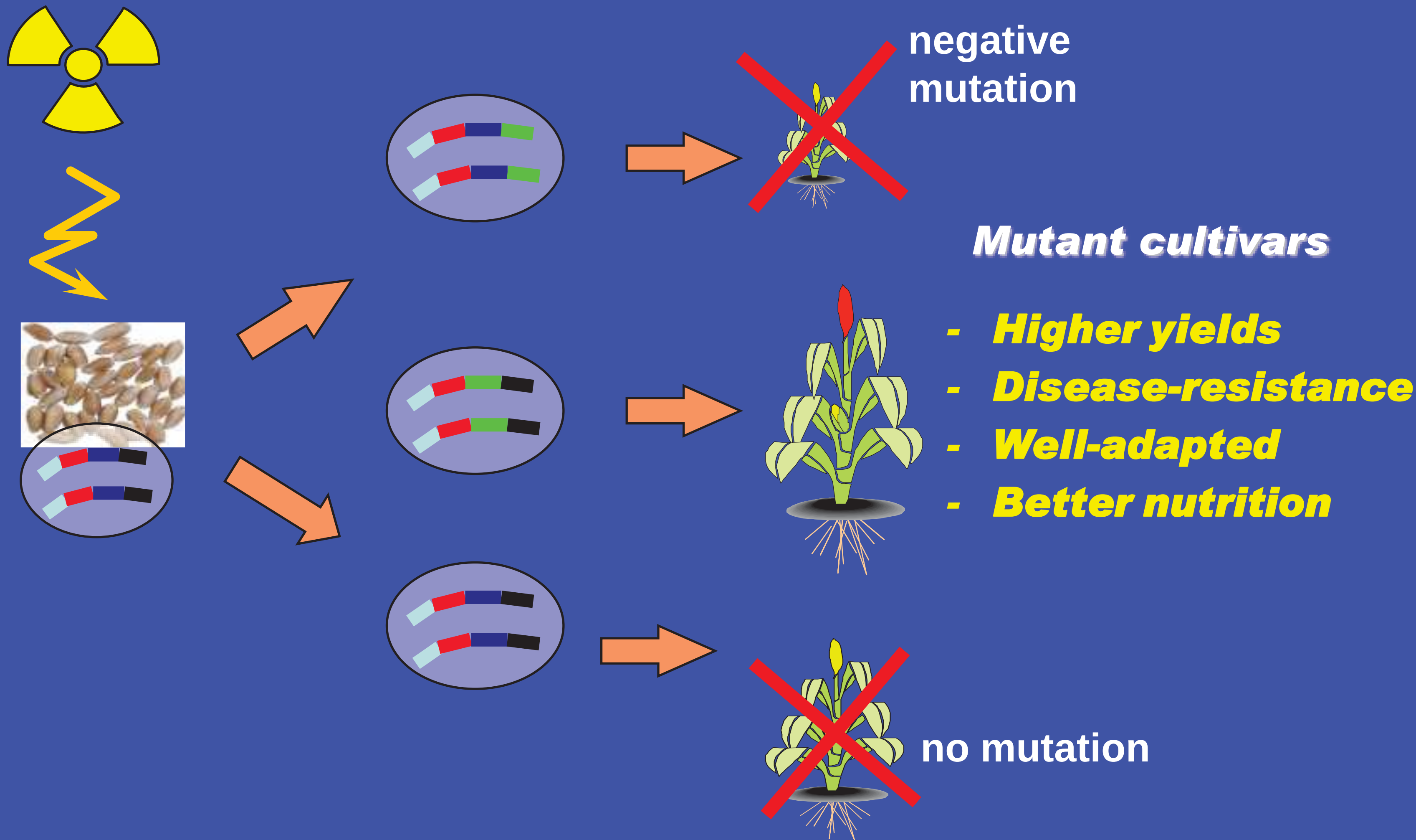
Crop Improvement by Radiation Induced Mutation Techniques



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Technical Basis of Radiation Induced Mutation

- **Variation is the source of evolution**
- **Spontaneous mutation rate (at any one gene locus at each generation) is 1×10^{-8} ~ 1×10^{-5}**
- **Radiation can cause genetic changes in living organisms and increase mutation rate up to 1×10^{-5} ~ 1×10^{-2}**
- **Induced mutation is useful for crop improvement**

Induced mutants are not GMOs, as there is no introduction of foreign hereditary material

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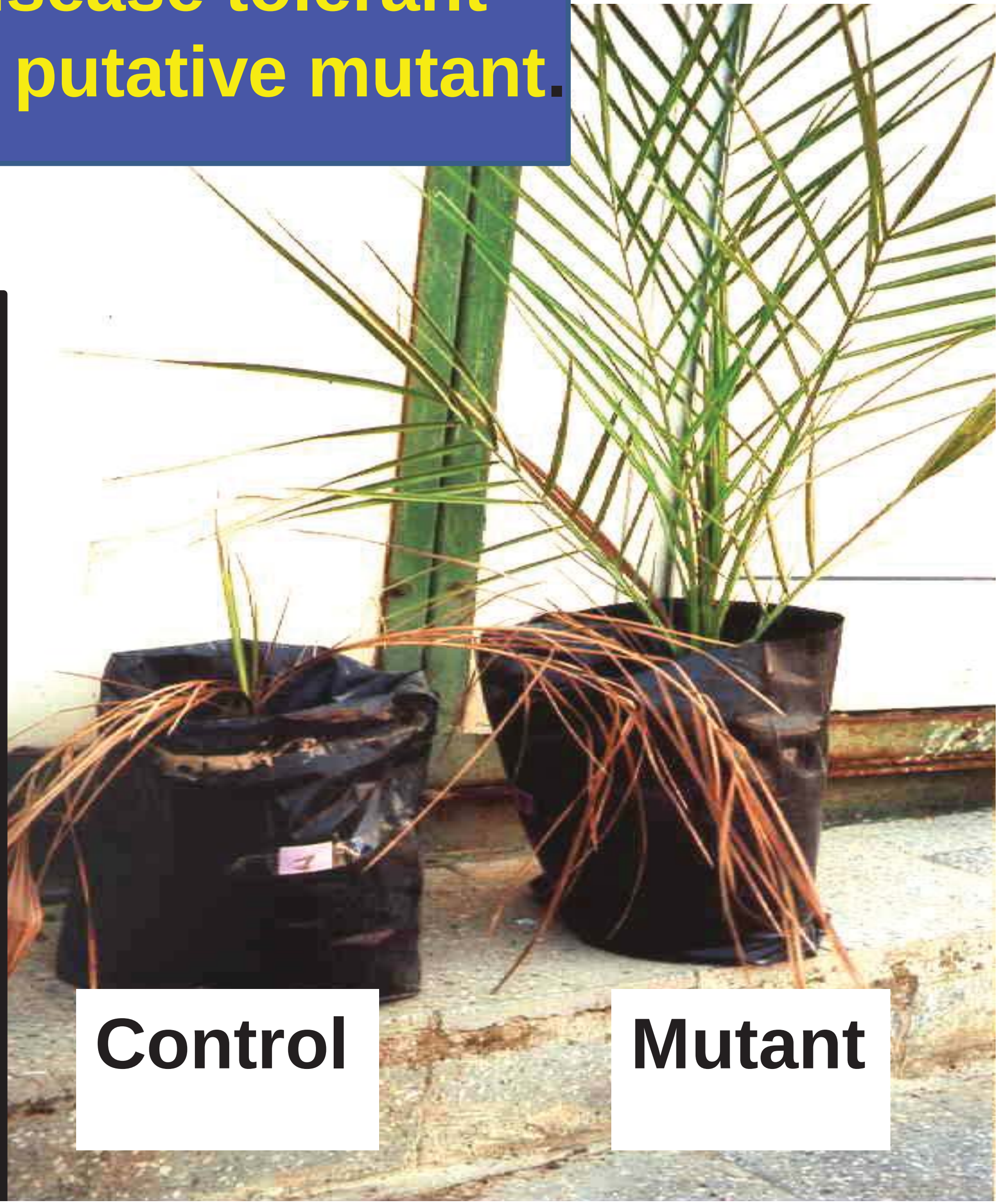
Example

Bayoud disease tolerant date palm putative mutant.

Well developed root formation in date palm shoots



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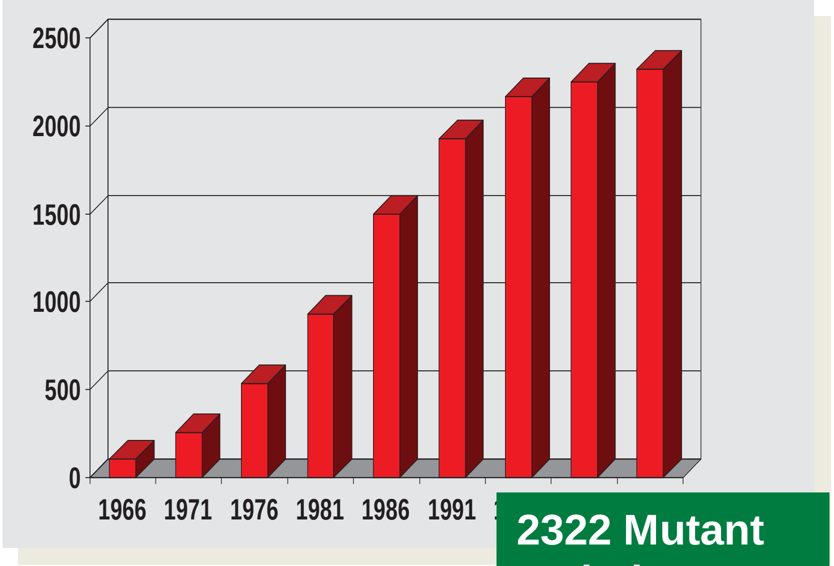
Global Impact of Mutant Varieties

- More than 2,600 plant varieties released world-wide
  - 1,625 (70%) derived as direct mutants
    - 89% induced through radiation, covering 175 crop and plant species
  - 697 (30%) derived largely through crosses with induced mutants



2322 Mutant varieties

The impact of mutant varieties is enormous, e.g.

•Rice in Thailand $1.7 billion per annum additional income
•Cotton in Pakistan $120 million per annum additional income
•Wheat in China 2 million tonnes per annum additional yield

- Potential yield increase in security crops, such as e.g. Banana in Sudan, of up to 40%

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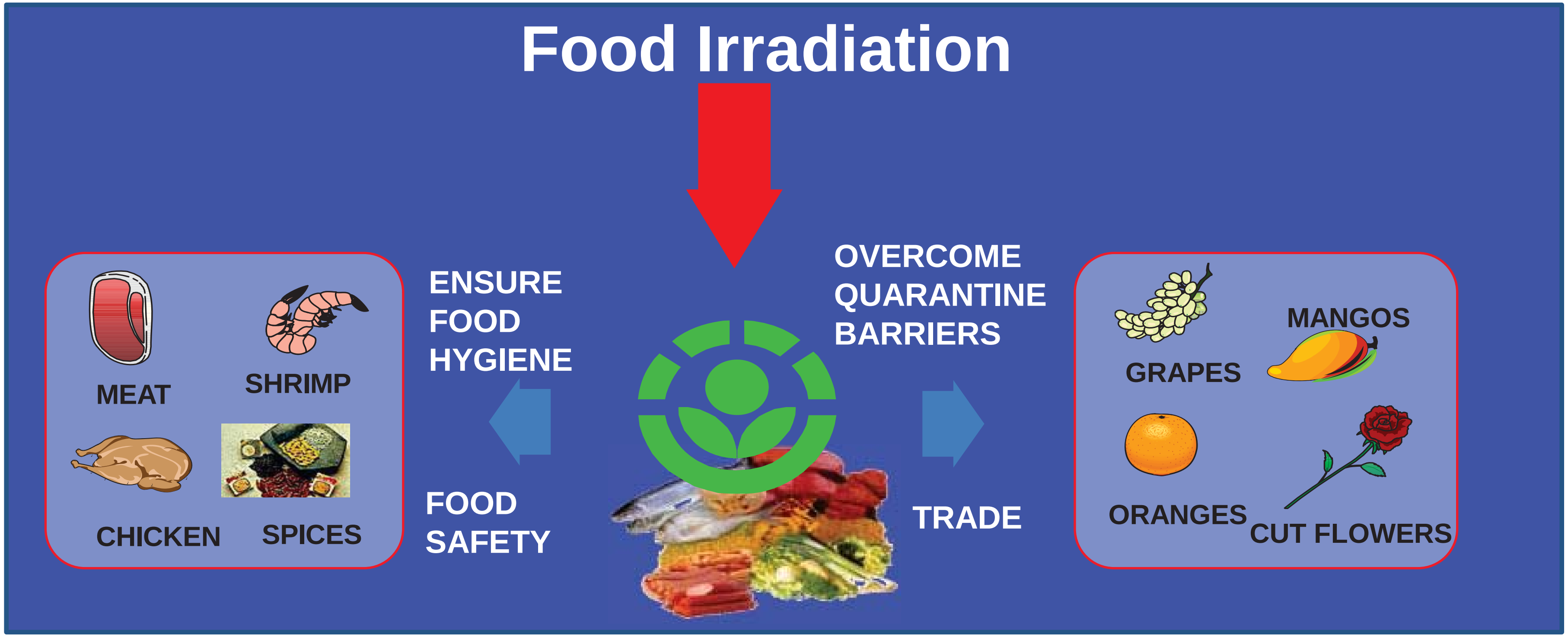

Food Quality and Safety - Technical basis

- **Food irradiation is the treatment of food by ionizing radiation**
- **Radiation at appropriate doses can kill harmful pests, bacteria, or parasites, and extend shelf-life of foods**

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FOOD IRRADIATION

- **To reduce post-harvest losses through spoilage and insect infestation**
- **To control food-borne diseases (9000 deaths annual through food-borne disease in USA)**

- **To replace chemical fumigants and for post harvest and quarantine treatment (Methyl bromide will be banned in most countries)**

More than 60 countries permit the application of irradiation in over 50 different foods

An estimated 500,000 tons of food are irradiated annually

About 180 Cobalt-60 irradiation facilities and a dozen electron beam (EB) machines are used to treat foods worldwide

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Thank you for your attention

Any question?

For clarifications or further information you can write or phone to:

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