″Nuclear Physics in everyday life″

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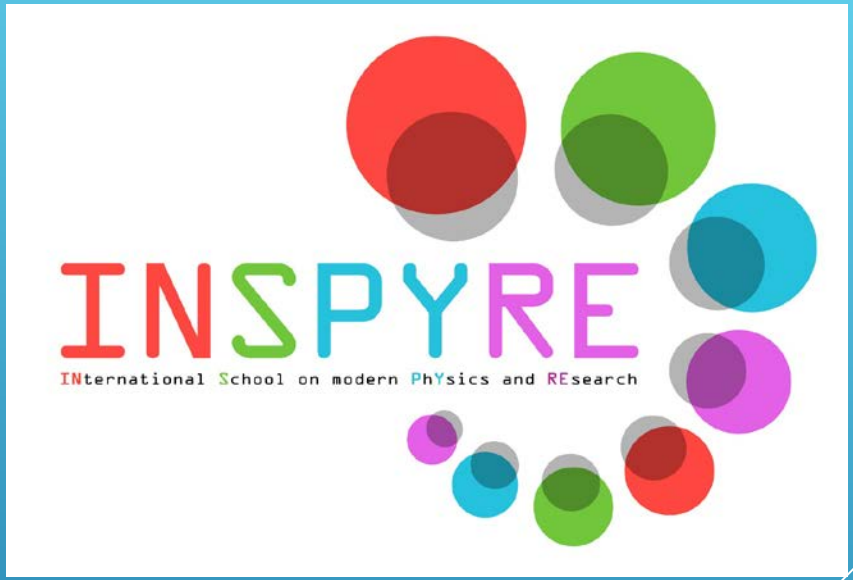
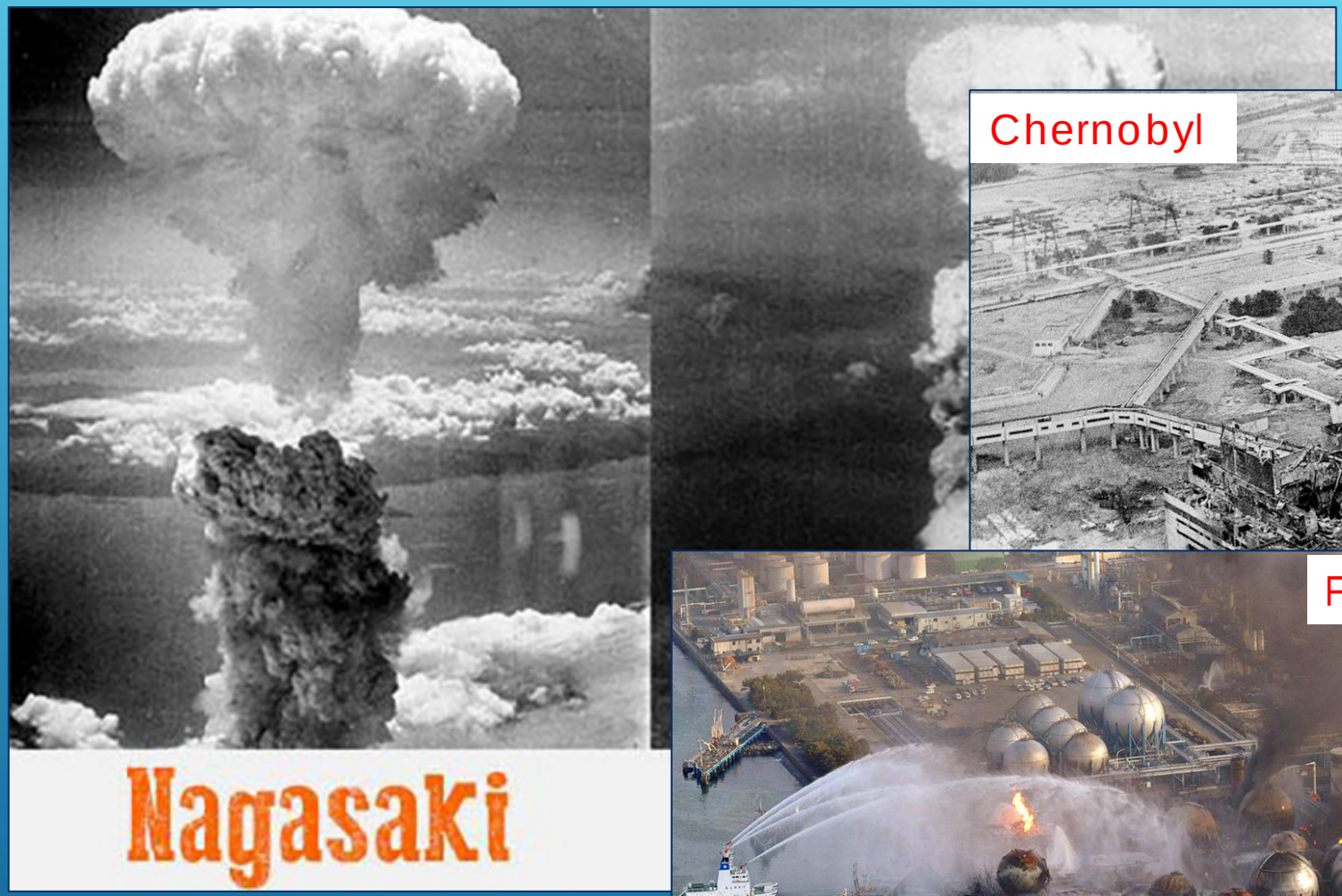


NUCLEAR = POWERFUL, DANGEROUS AND UNCONTRALLABLE



Today we are going to see how research into the atomic nucleus has contributed to the modern world, improving our quality of life

ATOM

Atom dimension : ~ 10^{-10} m (Å)
Nucleus dimension : ~ 10^{-15} m (fm)

Neutron Mass ~ Proton Mass ~ 2000 Electron Mass

Nucleus = neutrons and protons bound by Nuclear Force - Strong Interaction

The number of protons Z, identifies the chemical element, and with the number of neutrons N, identifies different isotopes of that element

Z=8 Oxigen
N=8 16O
N=9 17O
N= 7 15O

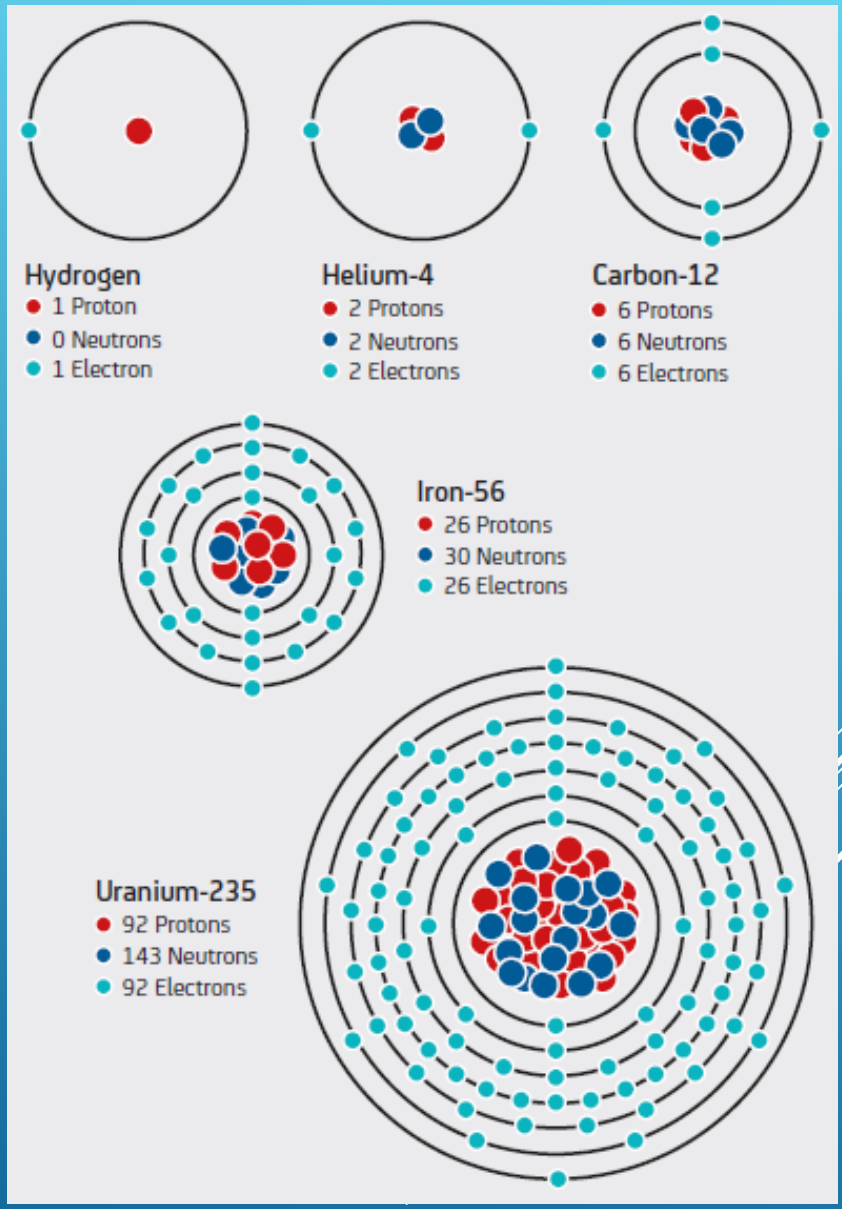
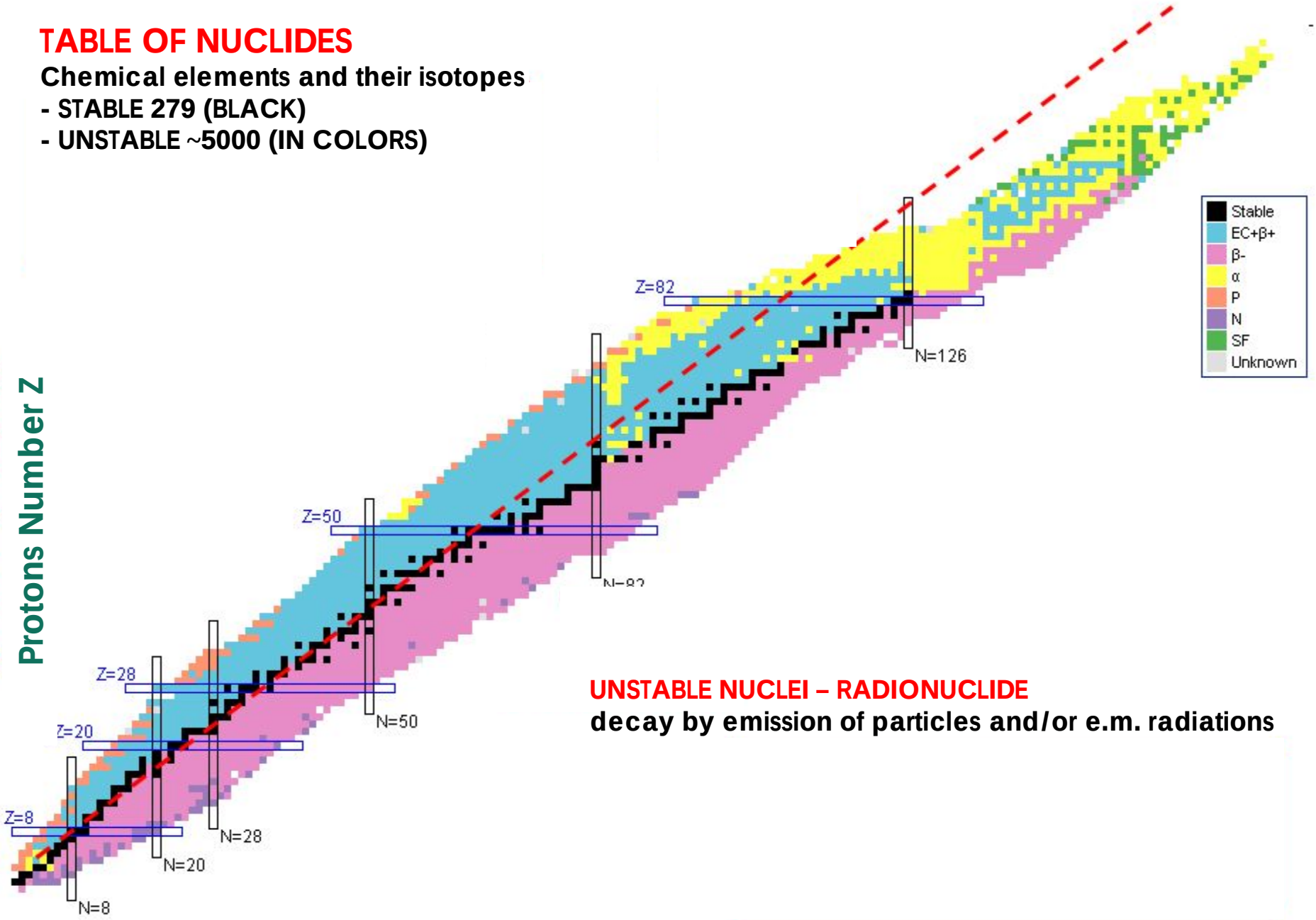


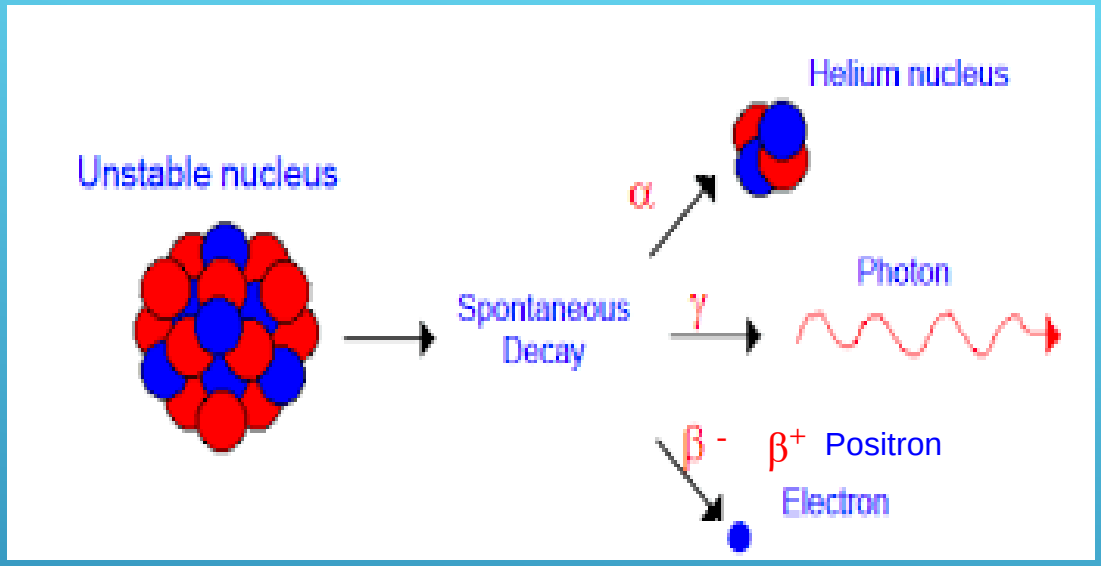
TABLE OF NUCLIDES

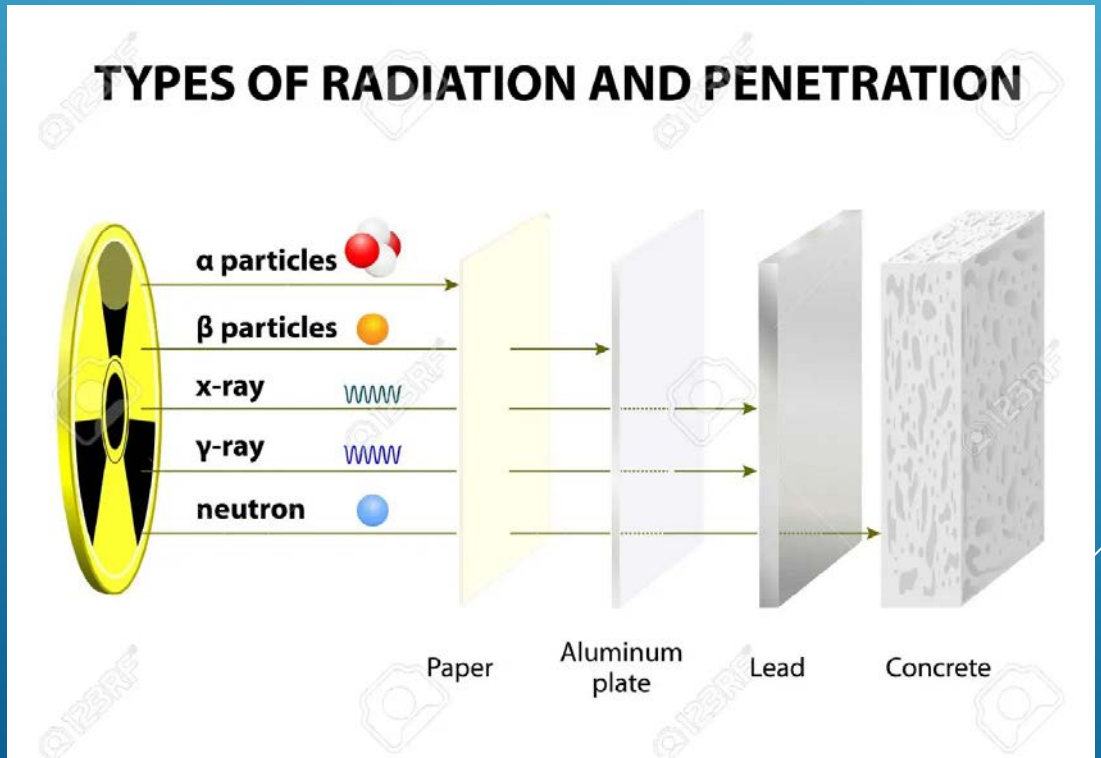
Chemical elements and their isotopes
- STABLE 279 (BLACK)
- UNSTABLE ~5000 (IN COLORS)



UNSTABLE NUCLEI – RADIONUCLIDE
decay by emission of particles and/or e.m. radiations

1 - RADIACTIVE DECAY





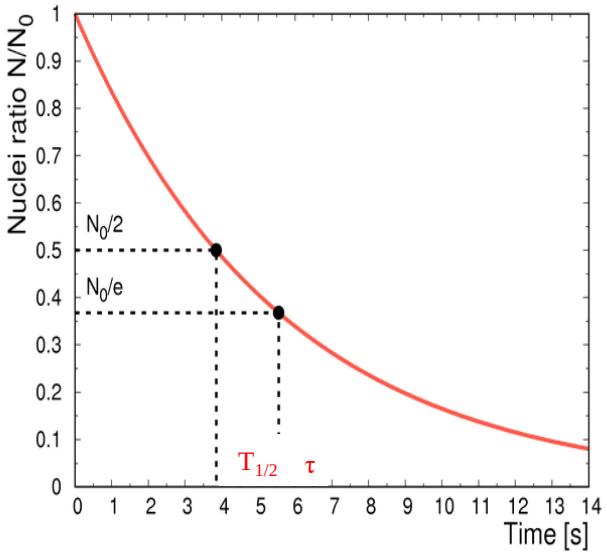
Radiactive Decay Law

How the initial number of nuclei changes as a function of time:

$$N(t)=N_0\, e^{-t/\tau}$$

τ , mean life of a radionuclide
It is the required time to reduce the number of nuclei in the system by a factor e

$T_{1/2}$, half time of a radionuclide
It is the time in which half of the initial number of nuclei is decayed

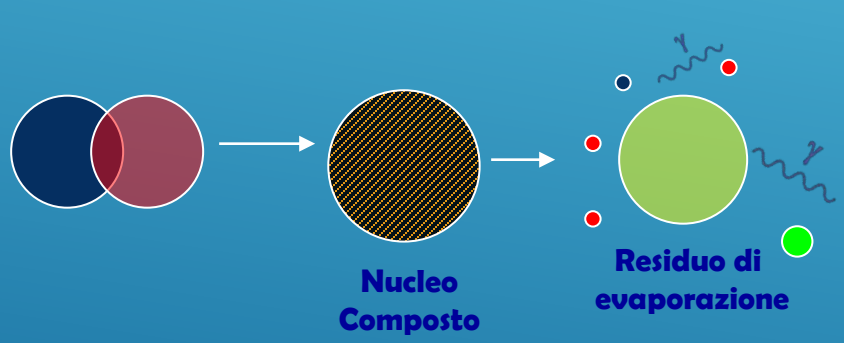


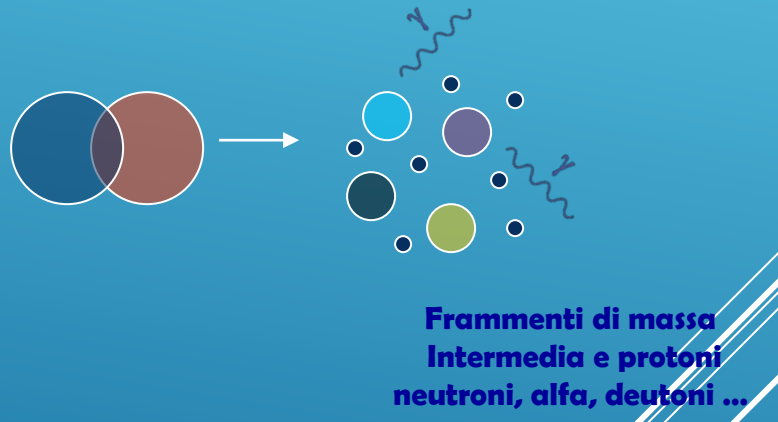
Examples of Radioactive Materials

Radionuclide	Physical Half-Life	Activity	Use
Cesium-137	30 yrs	1.5x10⁶ Ci	Food Irradiator
Cobalt-60	5 yrs	15,000 Ci	Cancer Therapy
Plutonium-239	24,000 yrs	600 Ci	Nuclear Weapon
Iridium-192	74 days	100 Ci	Industrial Radiography
Hydrogen-3	12 yrs	12 Ci	Exit Signs
Strontium-90	29 yrs	0.1 Ci	Eye Therapy Device
Iodine-131	8 days	0.015 Ci	Nuclear Medicine Therapy
Technetium-99m	6 hrs	0.025 Ci	Diagnostic Imaging
Americium-241	432 yrs	0.000005 Ci	Smoke Detectors
Radon-222	4 days	1 pCi/l	Environmental Level

2- NUCLEAR REACTIONS

Nuclear reactions are a relevant tool in the field of nuclear physics and applications.
We can study the nuclear forces with the indirect method, that is studying the distribution and the energy of the products of the reactions to get information.
We can obtain new nuclei as product of the reactions.





Fusion reaction

Multifragmentation reaction

Nuclear Collisions need accelerator machine and detector arrays

Nuclear Physics Application

- CLIMATE AND ENVIROMENT
- ENERGY
- HEALT
- FOOD
- MATERIAL
- FORENSICS AND HERITAGE
- SPACE

ENERGY

ENERGY – NUCLEAR POWER

Nuclear strong force binds together protons and neutrons in the nucleus it is the most concentrated form of energy in existence and nuclear reactions are the way to exploit this force, by using the released energy.

There are two possible ways to produce energy by means of nuclear reactions.

The first one involves the breaking of a heavy nucleus - nuclear fission
The second one is when two lighter nuclei fuse together - nuclear fusion

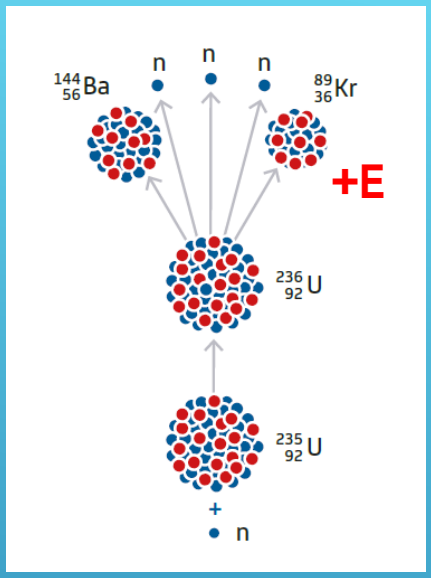
In nuclear fission or fusion, emitted energy
Is converted into heat and used to produce electricity.

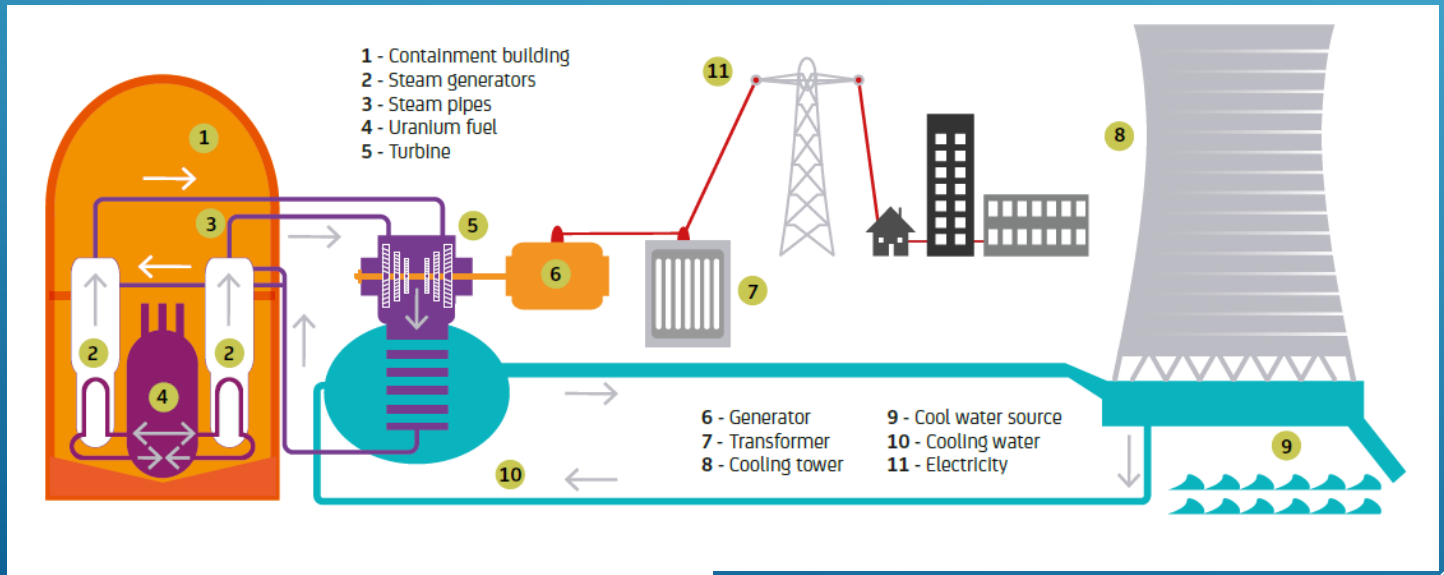
ENERGY – NUCLEAR POWER

NUCLEAR FISSION

Nuclear power plants work since 1960 . Today in the IV generation with high level of security, efficiency and (enough) low rate of radioactive waste.

In progress there are new approaches to reduce high radiactive waste by using chemical and nuclear reactions.

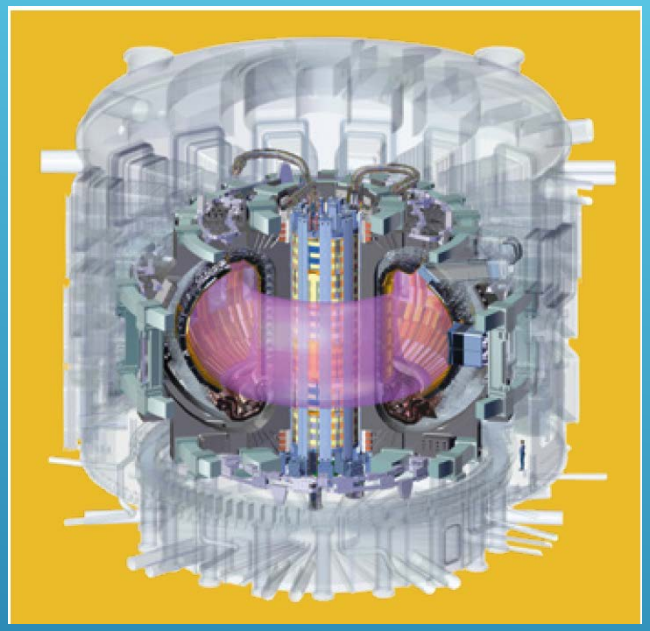




Layout of a typical nuclear power plant.

ENERGY – NUCLEAR POWER

NUCLEAR FUSION

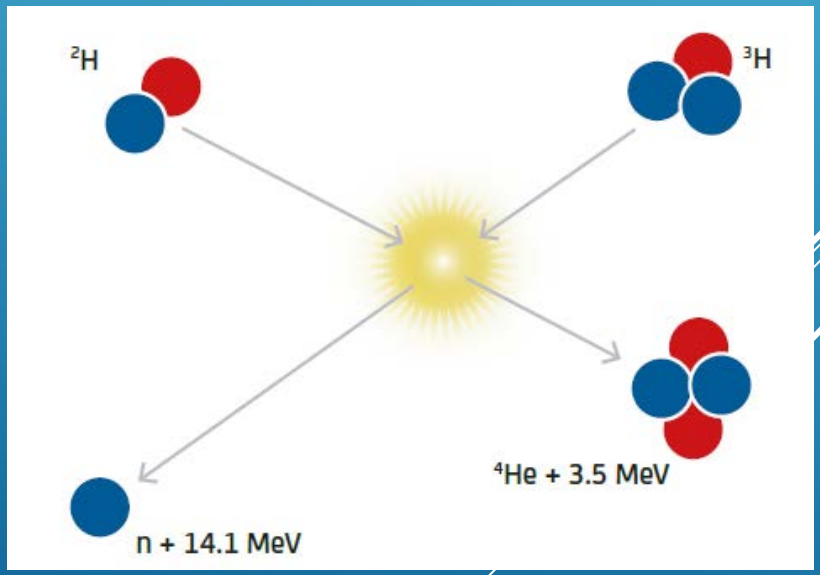


ITER tokamak

Tecnological challenges expecially in the material field (2035?)

High temperature (10^8-10^9 °C),
plasma formation that has to be confined in selected volumes for selected times
by high magnetic fields

VERY CLEAN – very low rate RADIACTIVE WASTE



HEALT

HEALT

Nuclear Physics contributes hugely to improving Human Healt, providing unic methods for diagnostic and treatment.

- Radiations - particles and e.m. radiation
Are used both in diagnostic and treatment

- Particle beams - protons, ions
Are used expecially in treatment

Radio pharmaceutical

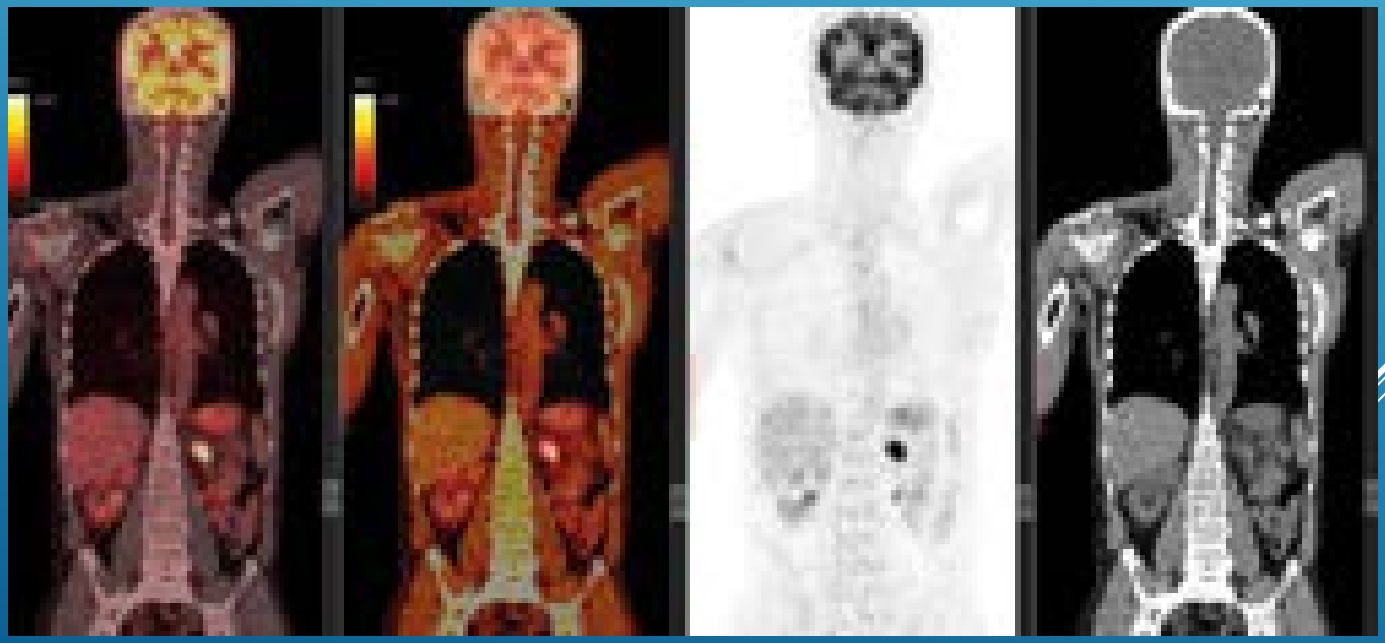
Treatment room

DIAGNOSTIC

- Radionuclides can be injected, ingested or inhalated by the patient

- Inside the body radiations interact with specialized cells of blood, brain, heart, urinary tract, intestin,…

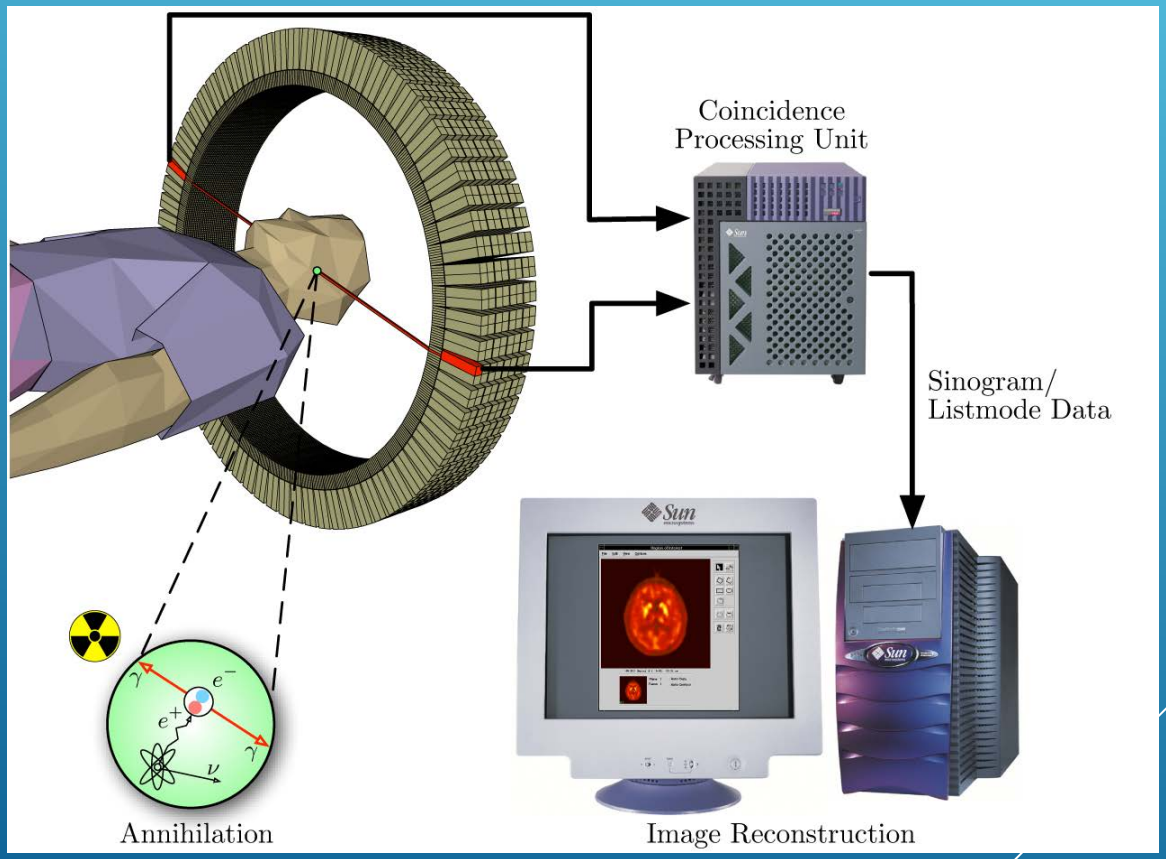
- A detector system (diagnostic machine) allows to make an IMAGING of that organ, that will help in diagnosis



PET - positron emission tomograph

A positron-emitting radionuclide (tracer) (^{11}C, ^{13}N, ^{15}O, ^{18}F) is introduced into the body and the system detects the gamma rays coming from interaction.

Three-dimensional images of the body are then constructed by computer analysis.



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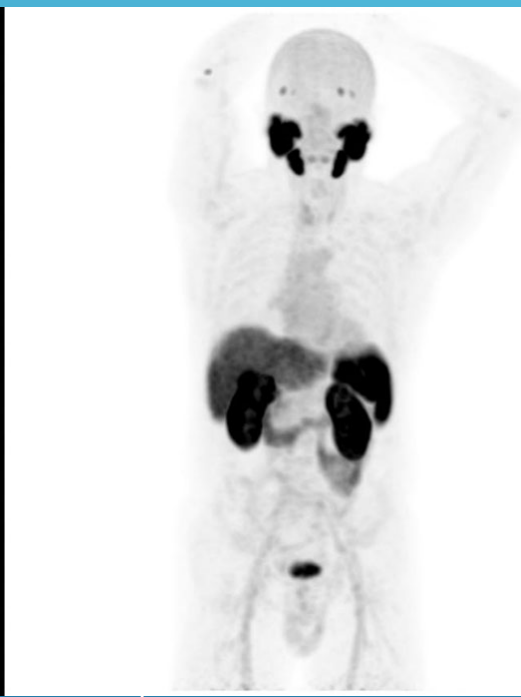
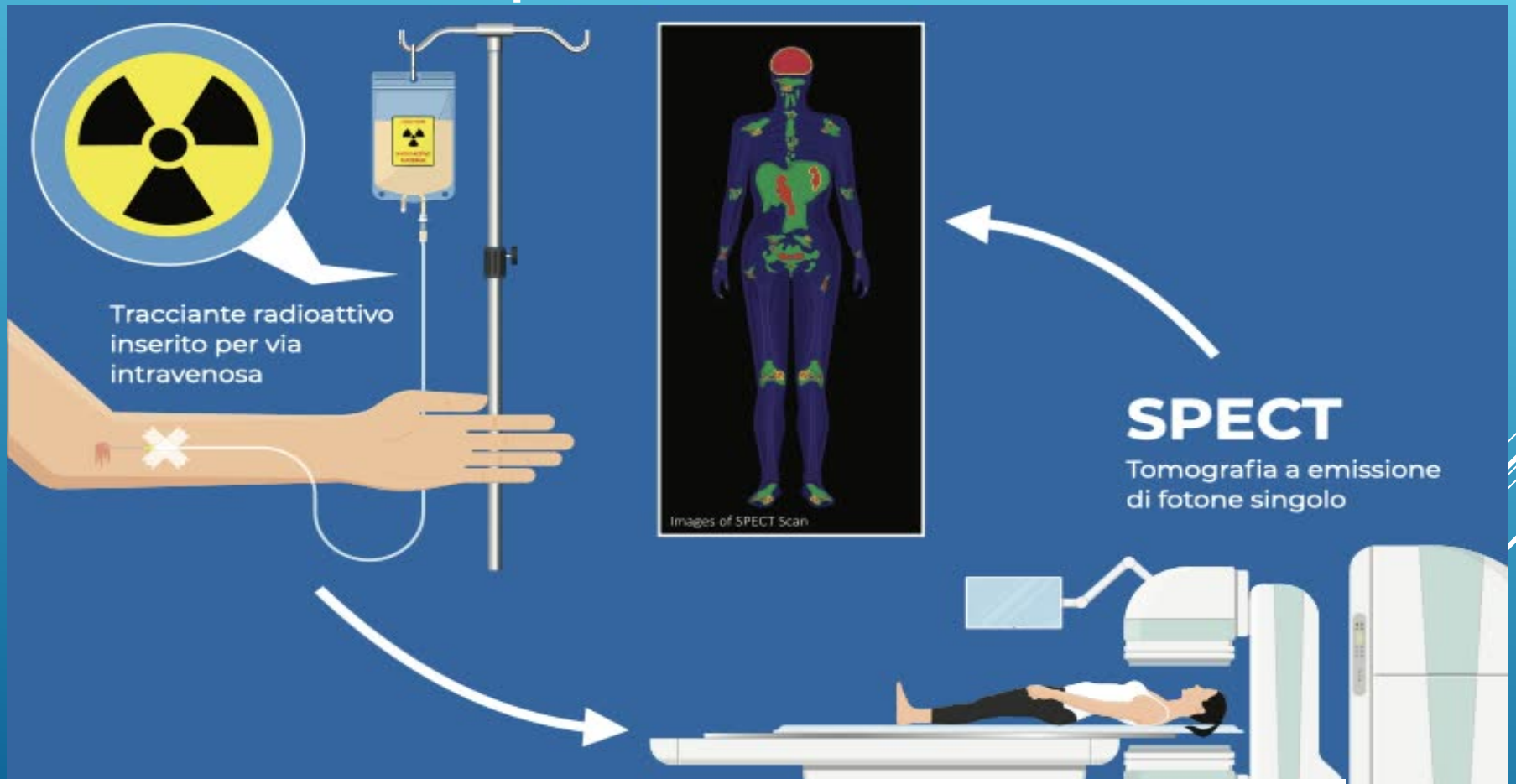


SPET Single-photon emission computed tomography

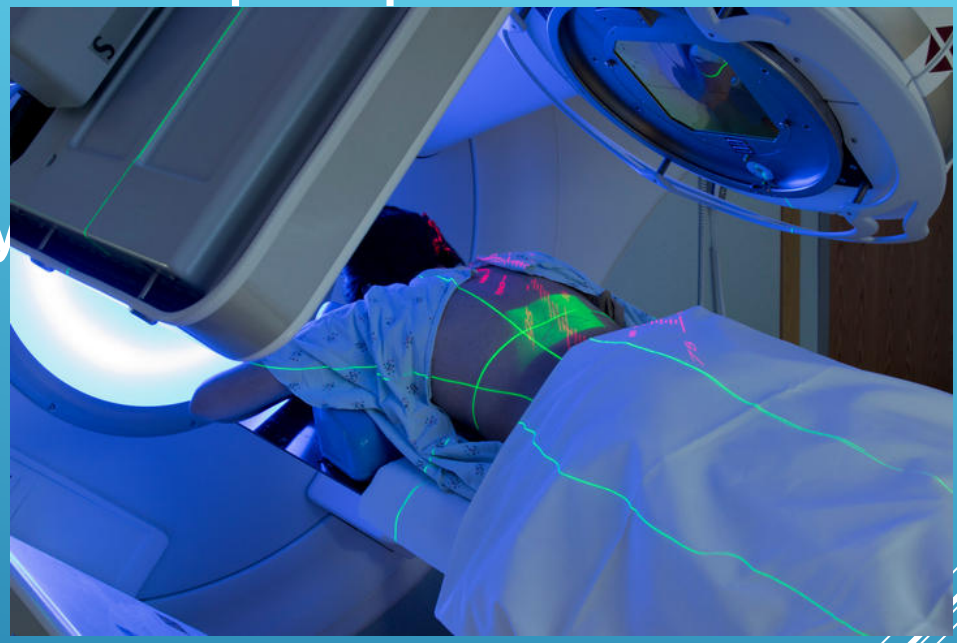
The technique requires delivery of a gamma-emitting radioisotope, ^{99m}Tc, ^{123}I, ^{111}In, into the patient, normally through injection into the bloodstream. it is able to provide true 3D information.



Tecnetium 99 metastable – ^{99m}Tc, 10 millions of procedure/day!!!!
Produced by nuclear reactions – accelerator in hospital

TREATMENTS (radiations)

- Radiations have been applied for treatments since 1946 in USA , by using **Iodine 131** that emitted γ and β radiations, on thyroid cancer.



- Today high energy radiations, in combination with chemotherapy and surgey, are employed.

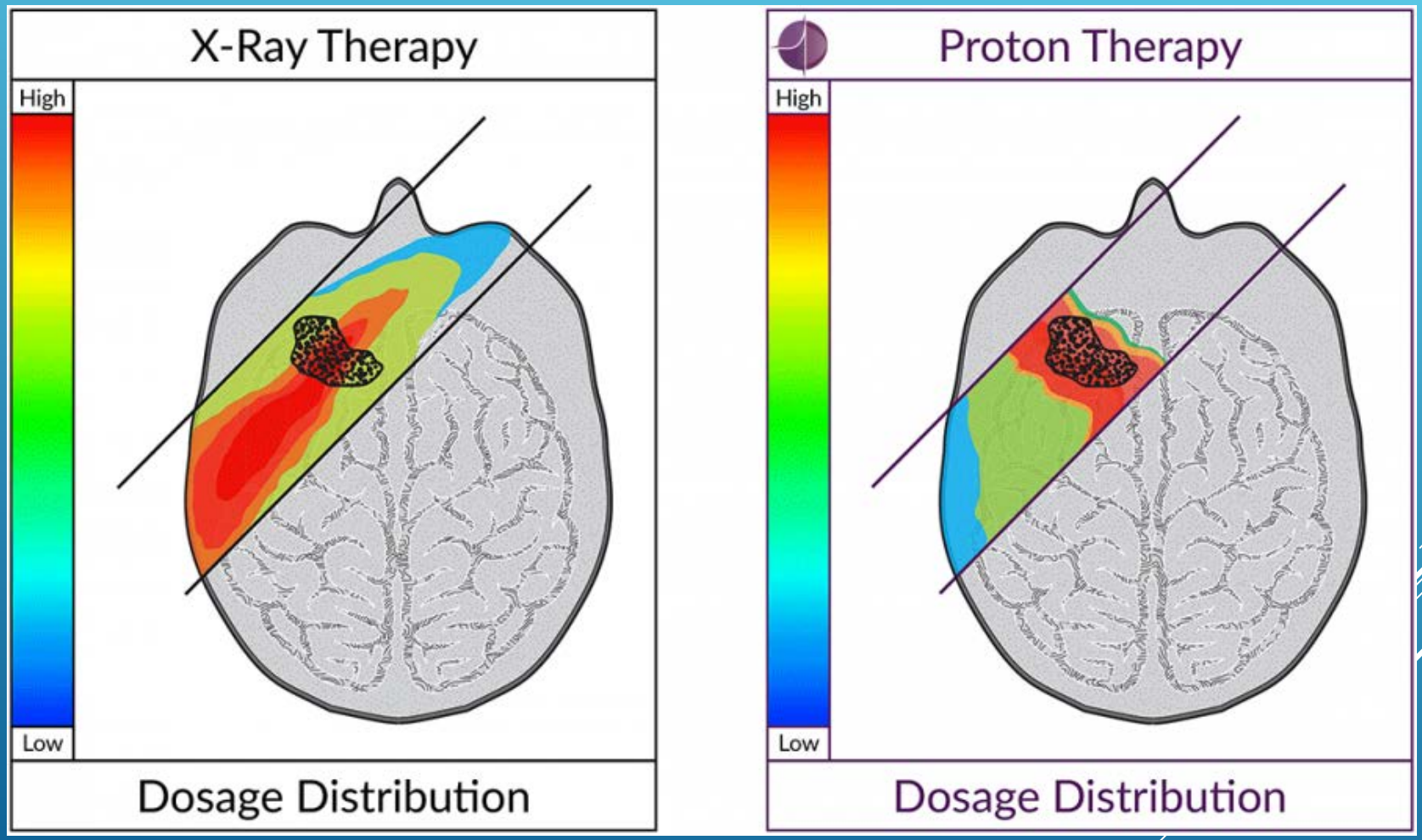
- Example
- **Cobalt 60** , for deep cancer high energy γ

- For brachitherapy , that is introducing the radioisotope inside the body, for prostate and uter cancer are used:

- **Lutetium 177,** 0.5-2 mm – β
- **Yttrium 90,** 2.5-11mm – β

TREATMENTS (particles beam – protons or ions)

Protons, or ions as Carbon , can be accelerated in a beam, and used as projectiles against a disease



Vantage : a smaller good healt region interested by radiations respect X or γ ray

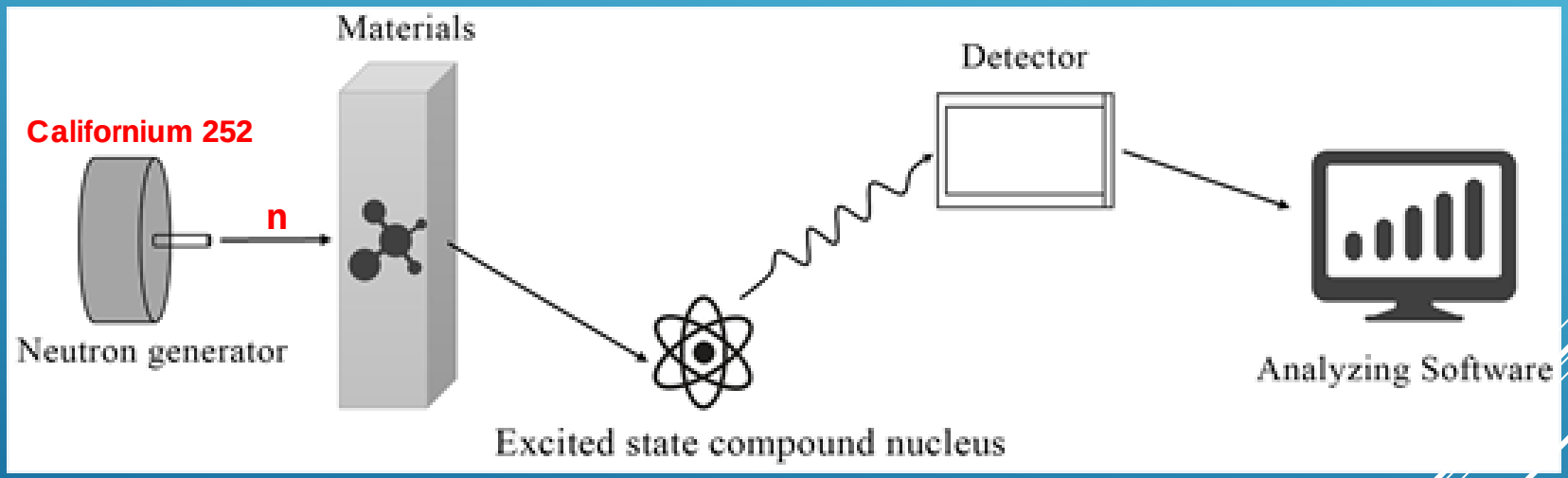
FOOD

FOOD

Nuclear methods are important to analize and protect land fertility and water resources, as well as controlling pest, crop and animal diseases, increasing production of food (vegetables and meat)

-NAA (Neutron Activation Analysis technique)

- Sample of soil (for ex.) can be irradiated by neutrons,
- producing radioactive nuclei reacting with the elements contained in the sample, that can be identified and quantified
- Lack or excess of elements (oxigen, nitrogen, manganes…) can be put in light and equilibrated/optimised for the good healt of the soil and crop.

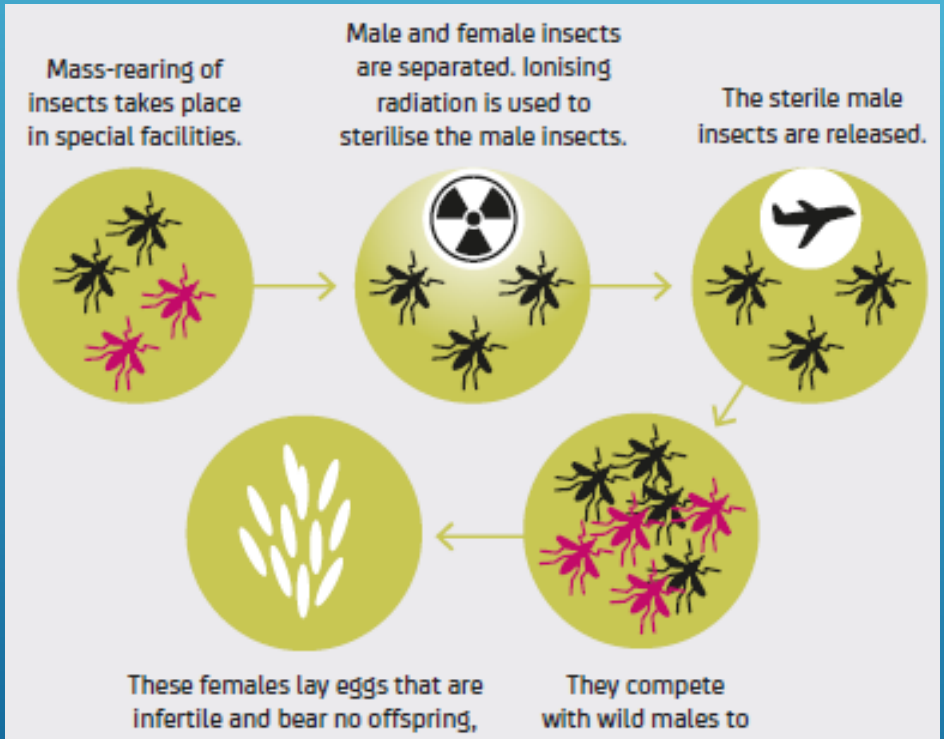


For example during the past decade, nitrogen-labelling studies in Benin in Africa enabled farmers to optimise their use of fertilisers and quadruple their yields of soya beans

CONTROLLING PEST

Insect pest can cause huge damage to both plants and animals.

SIT (Sterile insect tecnique) by irradiation with gamma ray, has been extremely successful in eradicating agricultural pests mediteranean fruit fly and also tsetse fly in many country in the world.



The Sterile Insect Technique to combat the Aedes mosquito, which carries the Zika virus.

PLANT BREEDING AND ANIMAL HEALT (GENETIC)

Nuclear irradiation can be used to induce genetic mutations that are beneficial to plants and animals breeding.

Sometimes this changes happened in a «natural way» but they can be speeded up by irradiating organic cells with gamma ray, X ray, neutrons or electrons beams (OGM).

- **Growing resistence of plants to enviroment changes and dideases.**

- **Enanching breeding of animals very relevant in large region of Africa (as food or other use)**

FORENSIC AND HERITAGE

FORENSIC AND HERITAGE

Many of powerful nuclear analytical techniques are applicable to both forensic science and cultural heritage studies.

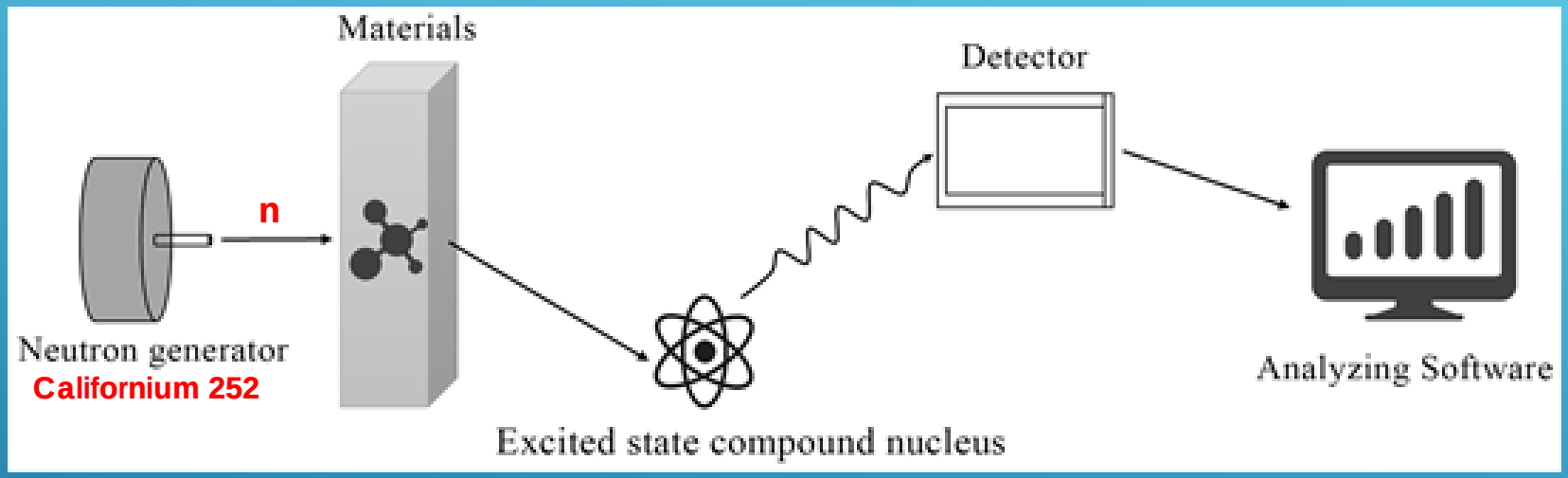
Forensic and heritage are joined (with different aims) by the interest to know the *material, age, composition* of paintings, artifacts, objects.

Most of the applyed techniques* are based on the use of a «beam» of particles/radiations that hits the object, exciting atoms. These decaying emitt radiation that allow the identification.

These methods are non-invasive!

NAA- NUCLEAR ACTIVATION ANALYSIS

- Non-destructive technique that can identify many elements of forensic interest.



- NAA has been used in hundreds of homicide cases by the FBI to examine bullet fragments and gunshot residues.
- It is also deployed in many other forensic-science applications such as cases of poisoning, hair analyses, forgeries, explosives, and illicit drugs.

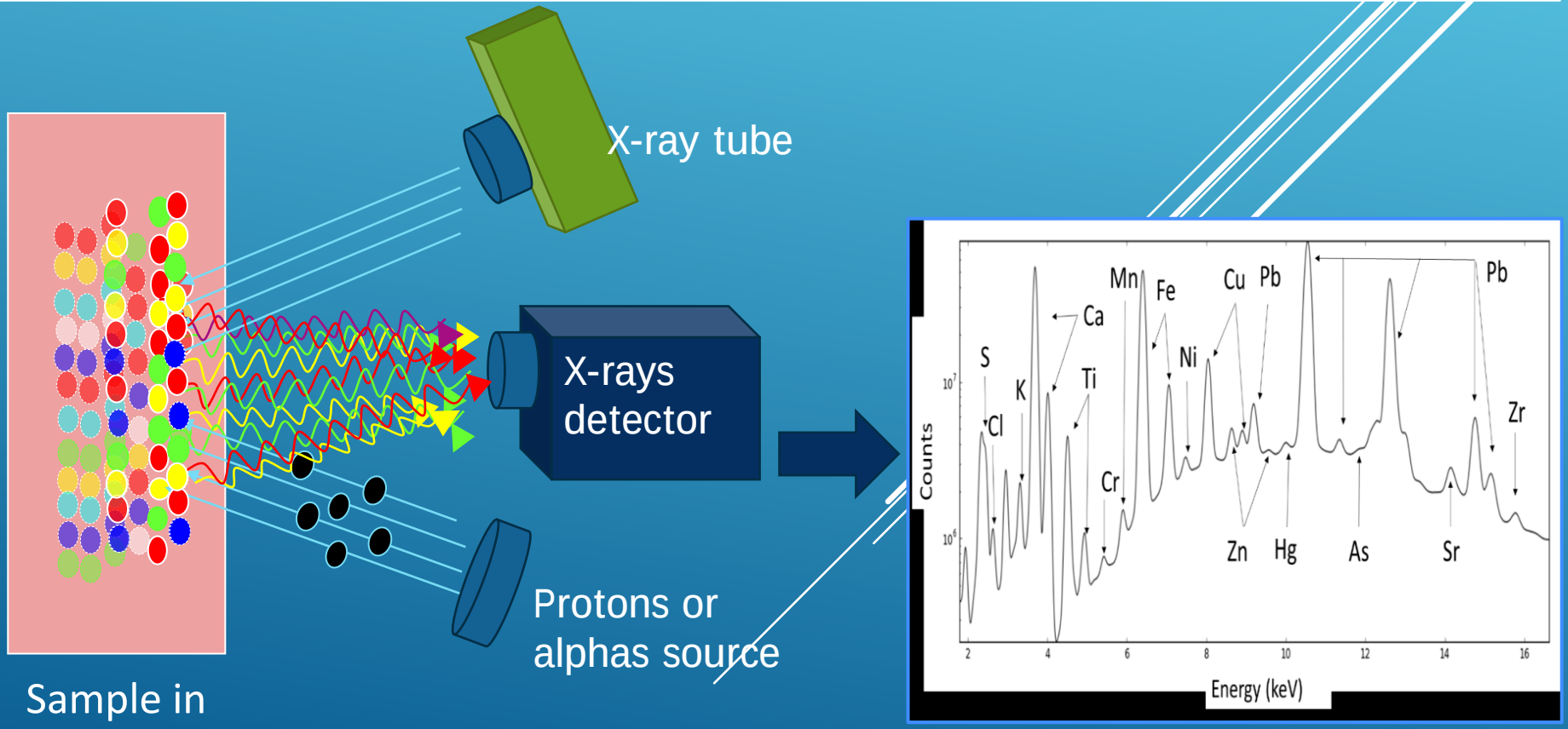
NAA- NUCLEAR ACTIVATION ANALYSIS

For example, NAA was used to determine whether the French Emperor Napoleon, or Tycho Brahe the Danish nobleman and astronomer, were poisoned by arsenic and mercury respectively.

(this was no true in both cases)

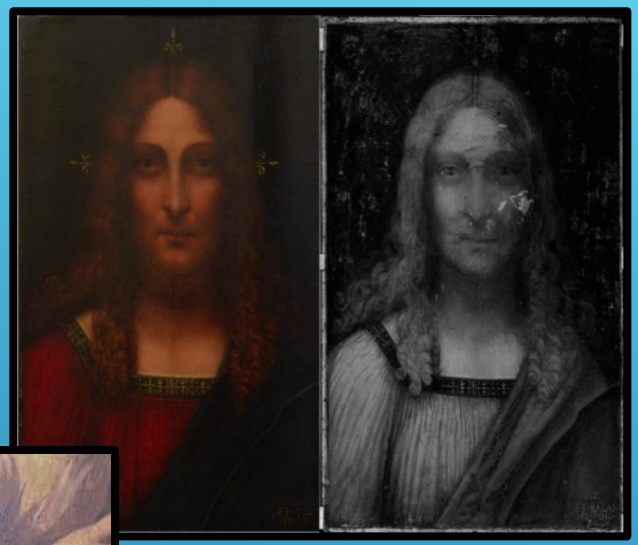
PIXE – PARTICLE INDUCED X-RAY ANALYSIS

It can be realized by using X-ray or protons /alphas on the sample in study. The excided atoms will emitt X-ray of different energy from which we'll be able to recognise the elements components of the sample



PIXE methods allow

- To identify the palette of the artist through the chemical analysis of pigments
- To understand the pictorial procedure: preparatory drawing, changes during the realization of the painting
- To know the conservation status of the object to plan a suitable method for restorations and preservation
- To estabilish if the work is true or false, original or copy

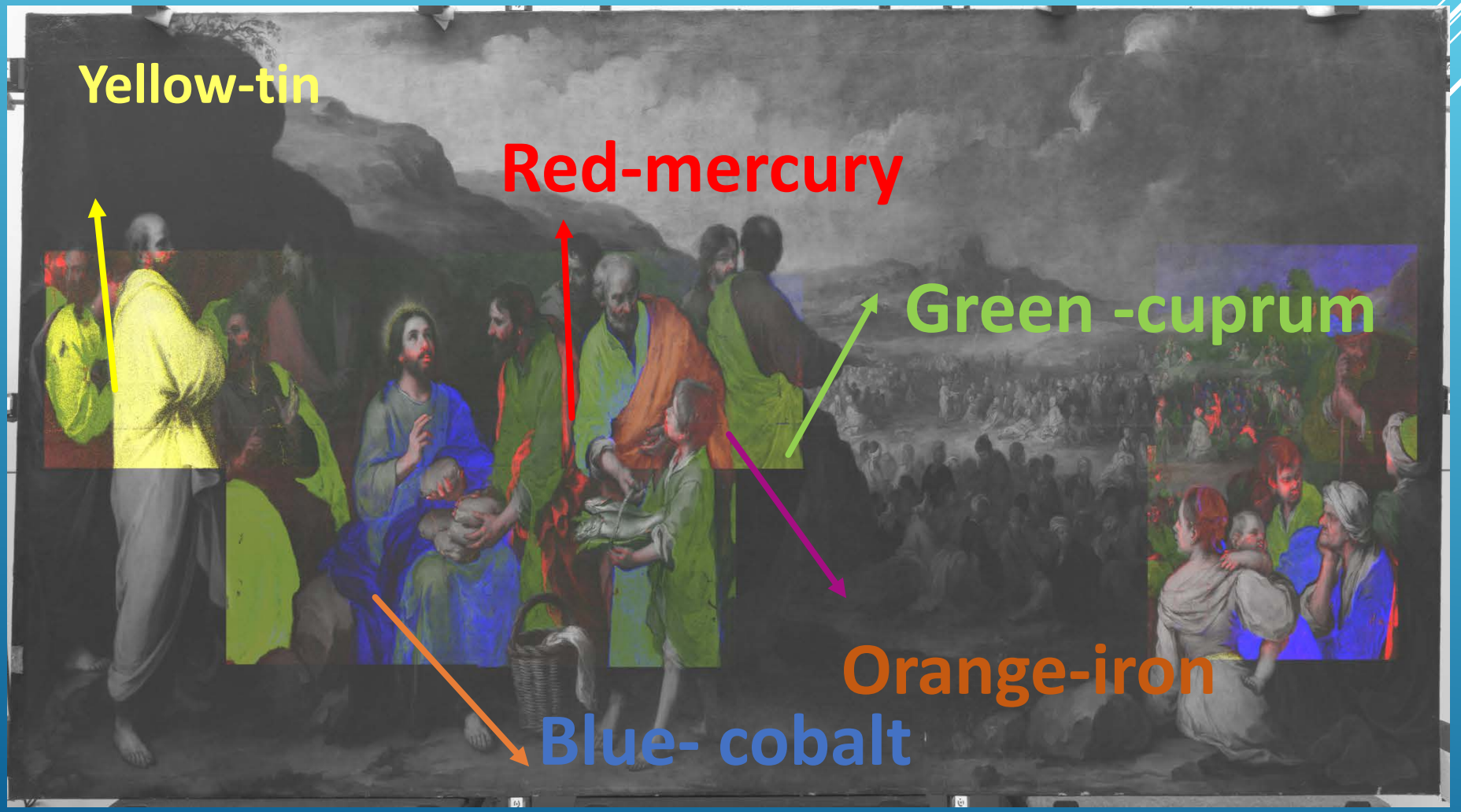


PIXE application in Museum

Very useful for study of large storical painting in Museum, directly in site avoid problems of trasportation and security

Esteban Murillo, La multiplicación de los panes y los peces, 236 cm x 575 cm
olio su tela, 1669-1670, Andalusian Historical Heritage Institute, Siviglia (Spagna)

X-rays analysis identified chemical composition of the pigments



SPACE

SPACE

Space beyond our planet is full of high-energy subatomic particles and electromagnetic radiation including X-rays and gamma-rays.

COSMIC RAYS (supernova explosions, black hole collisions, solar processes…)

- **85% protons**
- **12% alpha**
- **1% heavy ions (U)**
- **2% electrons**

All of these are radiotions that can damage both biological tissue and sensitive electronic materials such as semiconductors

Fortunately for us, the Earth's magnetic field prevents much of the radiation from reaching the ground, but it has to be considered for satellite communications and air travel, and for space exploration.

SPACE EXPLORATION (Mars- Moon)

-HUMAN HEALT - Space radiation can increase risks for cancer, neurological damage and degenerative dideases

- ELETRONIC DEVICES – space radiation can damage electronic devices assigned for example, to control, operation and communication systems

Technological solutions for both the problems are in progress and the nuclear/biologic study of interaction of radiation with organic and inorganic matter are fundamental for that

(new radiation hardening materials, shielding systems, genetic and biomedical approaches,.....)

NUCLEAR ENERGY FOR SPACE MISSIONS

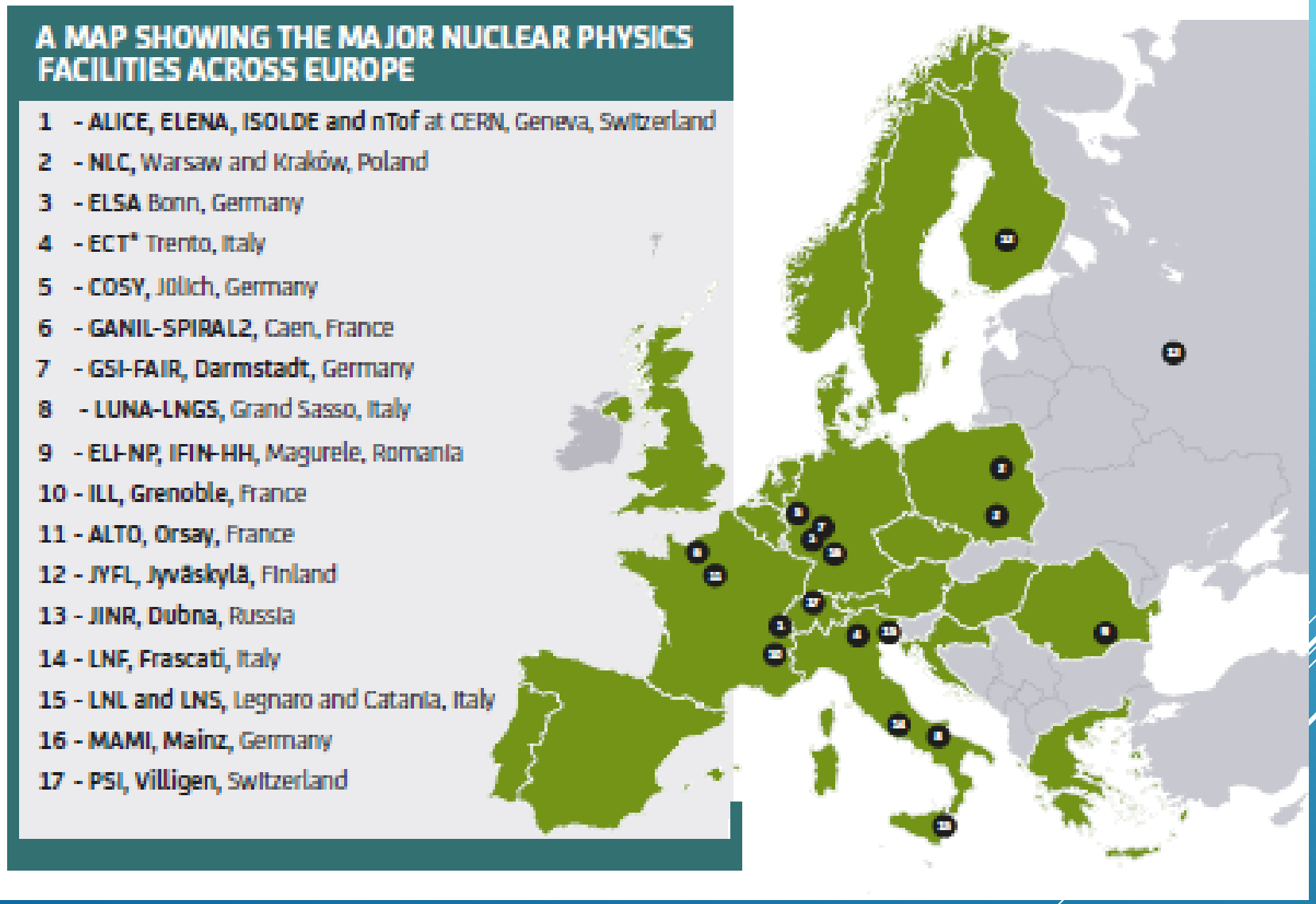
- Solar energy does not work much beyond Mars and only in line-of-sight with the Sun.

- The best candidate to supply energy both as a space drive, and to produce electricity for general use, is nuclear power source.

Nuclear battery, by the decay of radioisotopes (plutonium 238 – half life 88 years)

Fission reactor – as TOPAZ, developed by the USSR in the 1970s.
- 12 kg of highly enriched uranium.
- total weight of the reactor was 320 kg
- operating time of 12 months.

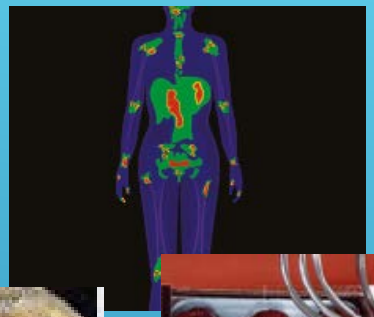
TO CONCLUDE (1)



EUROPEAN NP RESEARCH LABORATORIES
4 ITALIAN LABs by INFN – LNF-LNL-LNGS-LNS

TO CONCLUDE

We have seen many applications of Nuclear Physics in a large number of fields



All these applications improve our life under different aspects.

But remember:

It is the study of the fundamental nuclear physics (nucleare structure, nuclear reactions, nuclear principia) that allows us to take advantages of NP for applications in many fields.