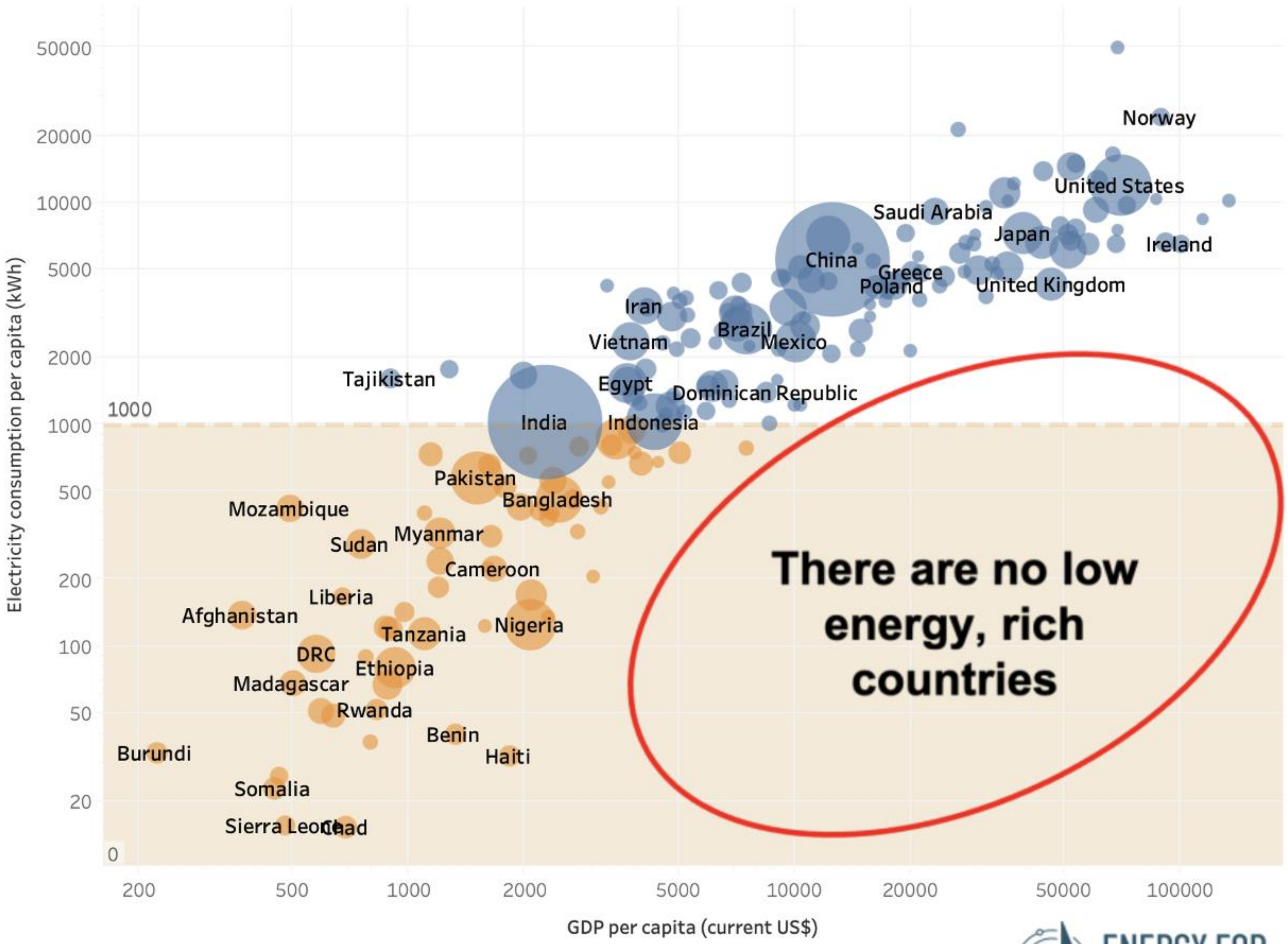
- **Energy**
- **renewable energy**
- **nuclear energy**
- Radioactivity in the industrial production process
- Radioactivity in the art market
- Radioactivity and **medical applications**
- Radioactivity and homeland security
- Radioactivity in **war**
- Radioactivity and fear

Visible Energy Consumption of Mankind



Source: US Energy Information Administration, World Bank (2021)
$R^2 = 0.8$

ENERGY FOR GROWTH HUB

Ի՞նչ է տալիս մեզ էներգիան:

Human Development Index: 0.78

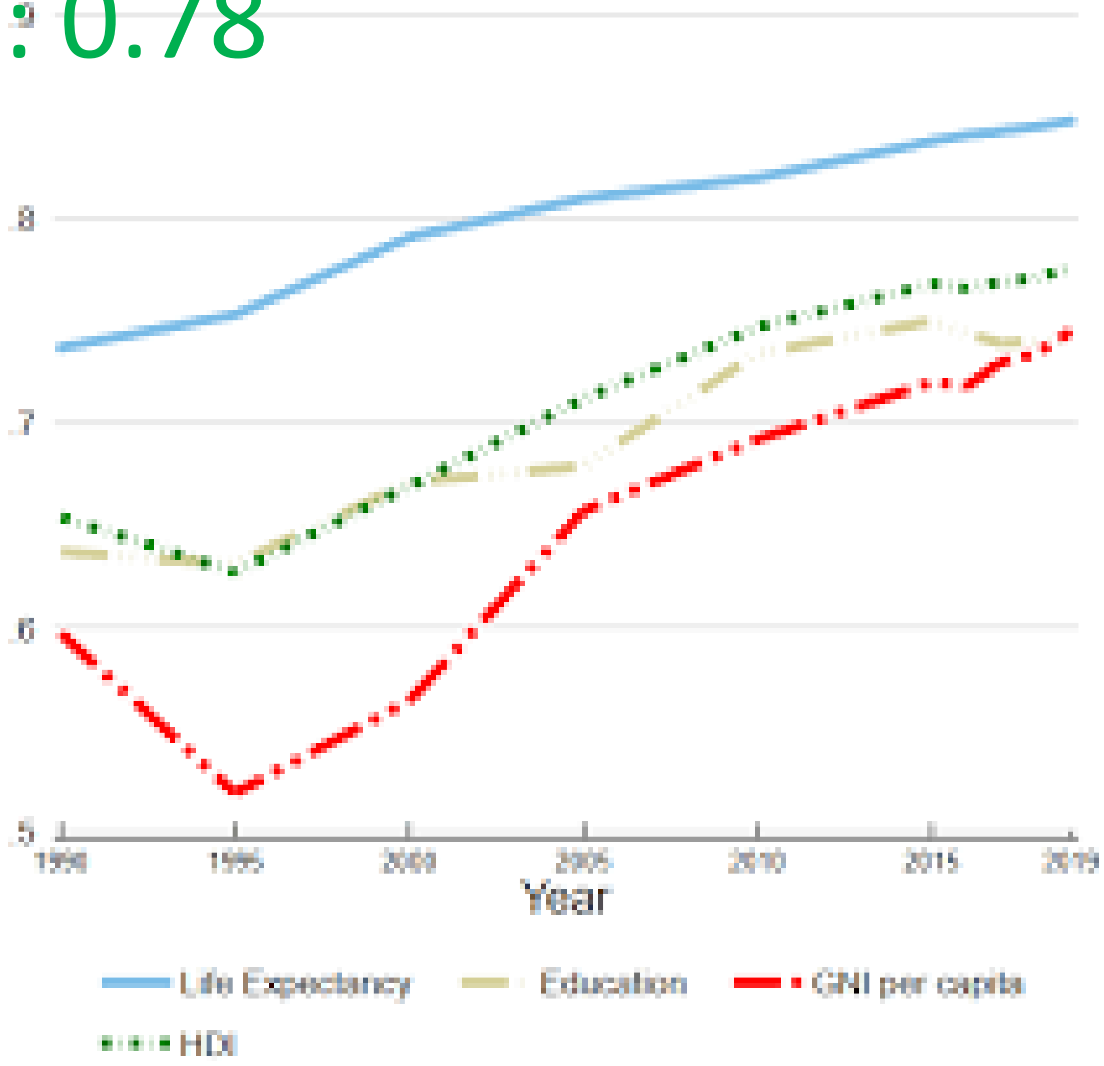
81 out of 189 countries

Կրթություն

Հարստություն

Առողջություն

Անվտանգություն



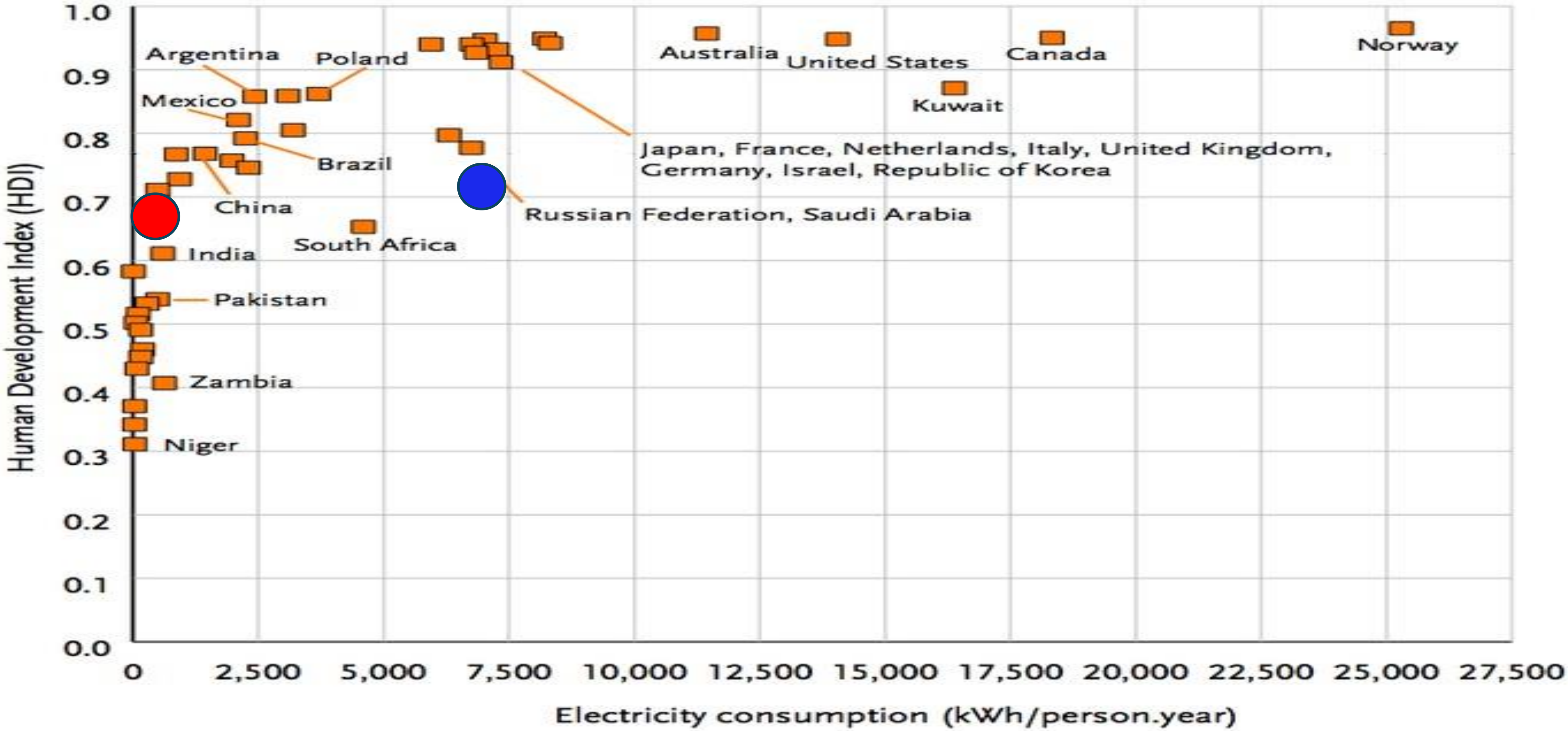
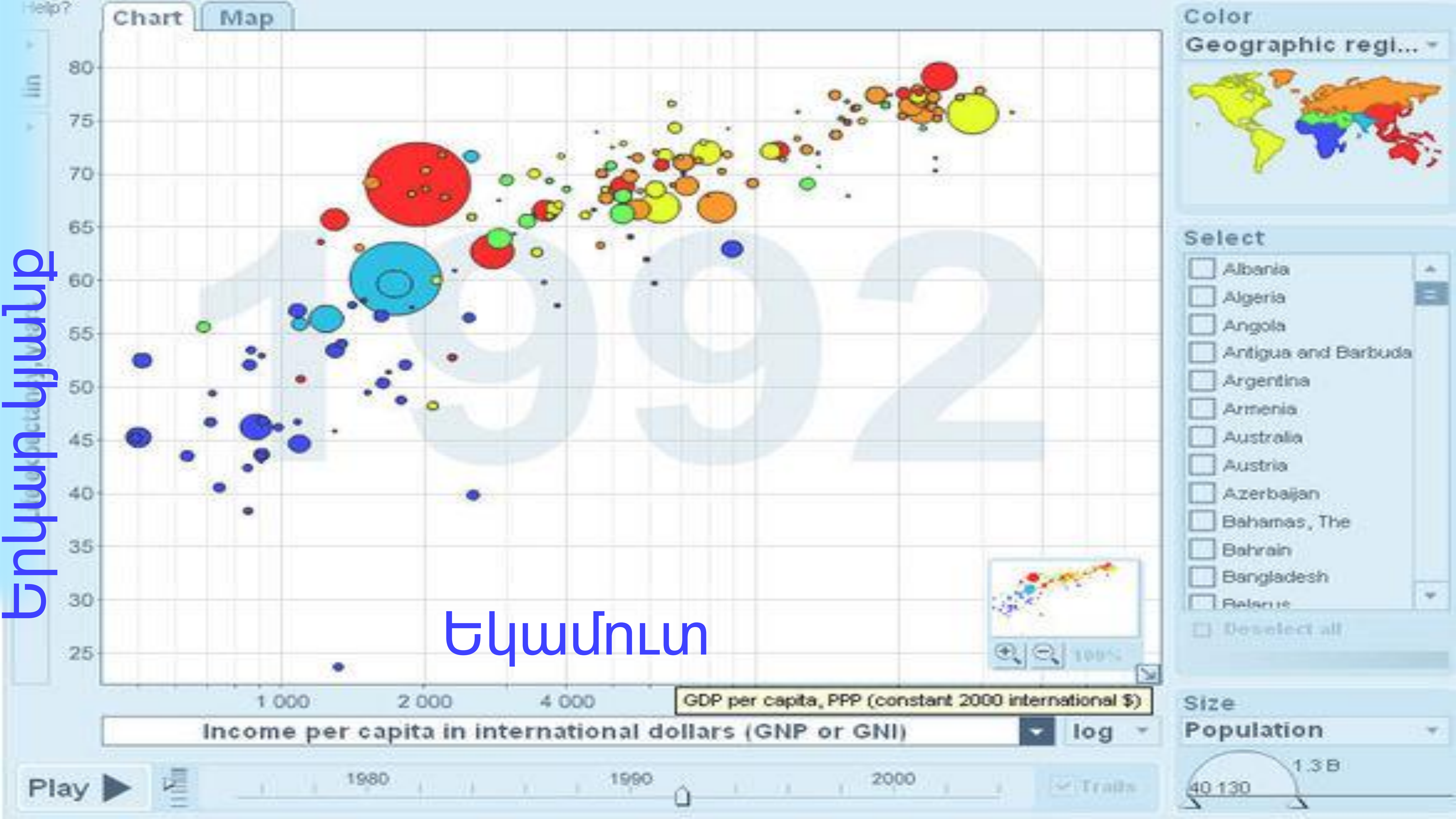


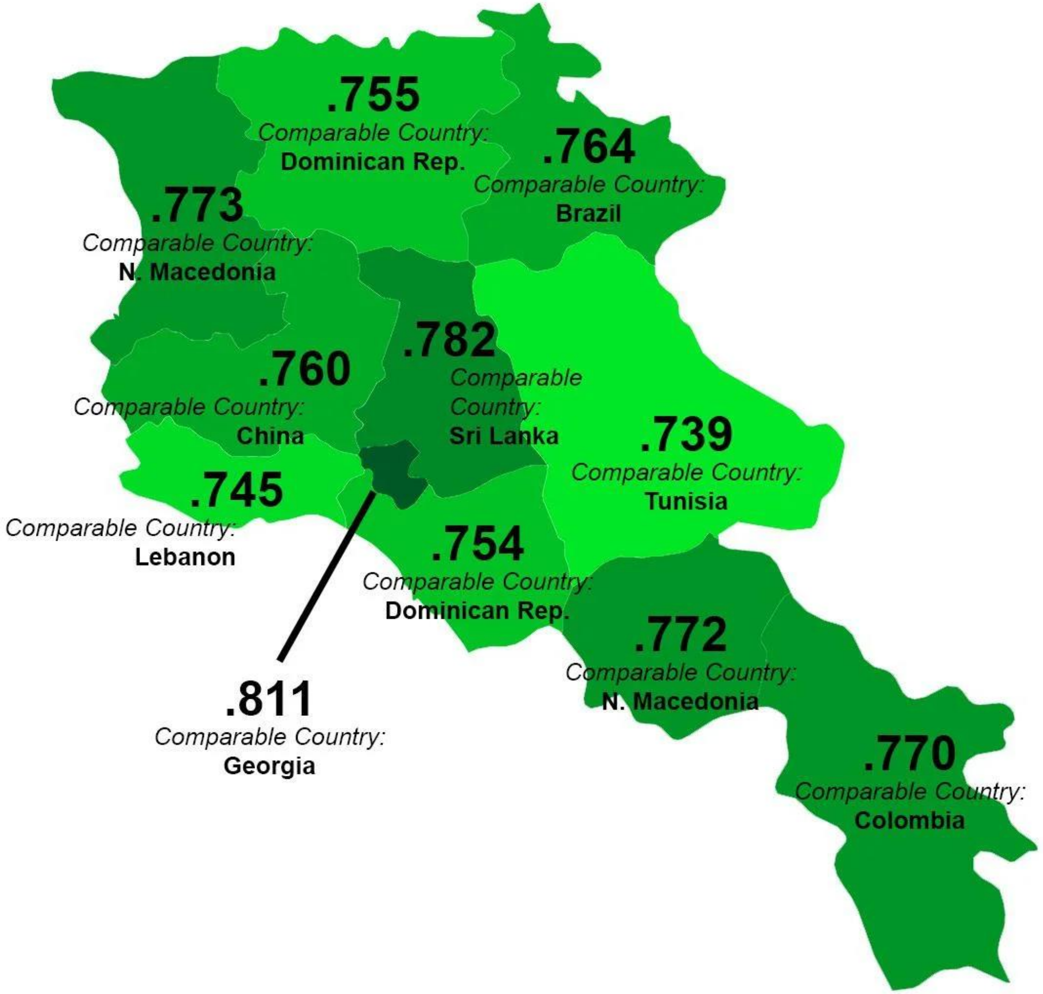
Figure 1.6 Relationship between human development index (HDI) and per capita electricity consumption, 2003 – 2004

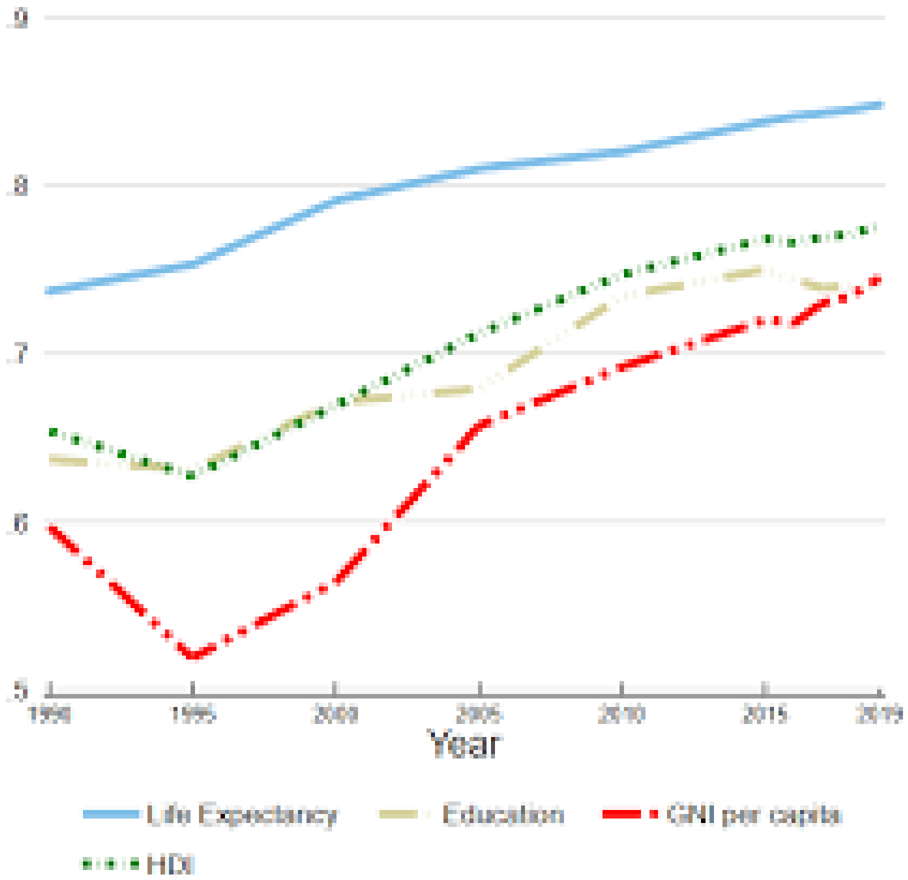
Note: World average HDI equals 0.741. World average per capita annual electricity consumption, at 2,490 kWh per person.year, translates to approximately 9 gigajoules (GJ)/person.year [10,000



Երկար կյանք

Եկամուտ


.755
Comparable Country:
Dominican Rep.
.764
Comparable Country:
Brazil
.773
Comparable Country:
N. Macedonia
.782
Comparable
Country:
Sri Lanka
.760
Comparable Country:
China
.739
Comparable Country:
Tunisia
.745
Comparable Country:
Lebanon
.754
Comparable Country:
Dominican Rep.
.772
Comparable Country:
N. Macedonia
.811
Comparable Country:
Georgia
.770
Comparable Country:
Colombia

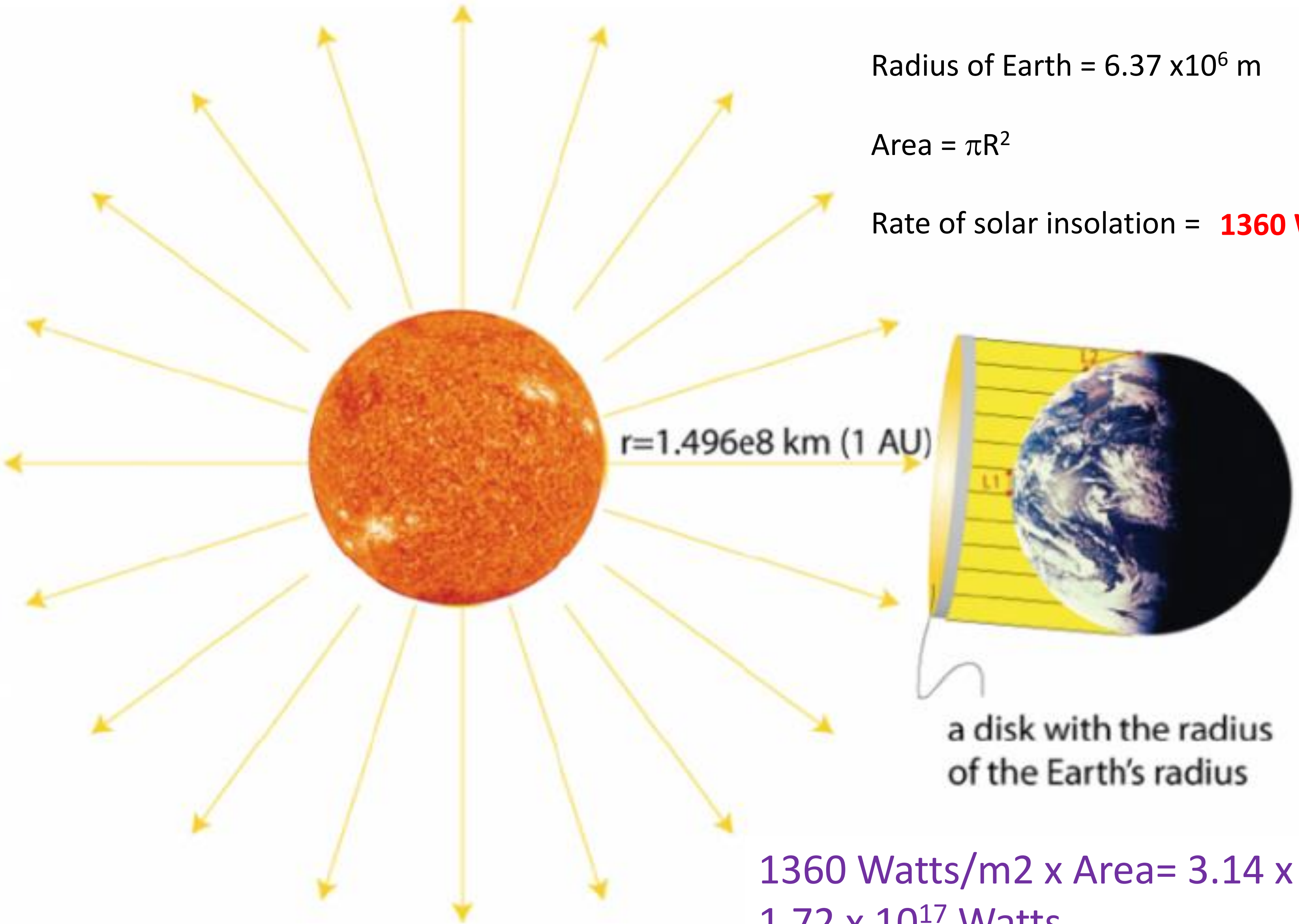

.9
.8
.7
.6
.5
Year
Life Expectancy
Education
GNI per capita
HDI

Հայաստան

Radius of Earth = 6.37×10^6 m

Area = πR^2

Rate of solar insolation = **1360 Watts/m2**

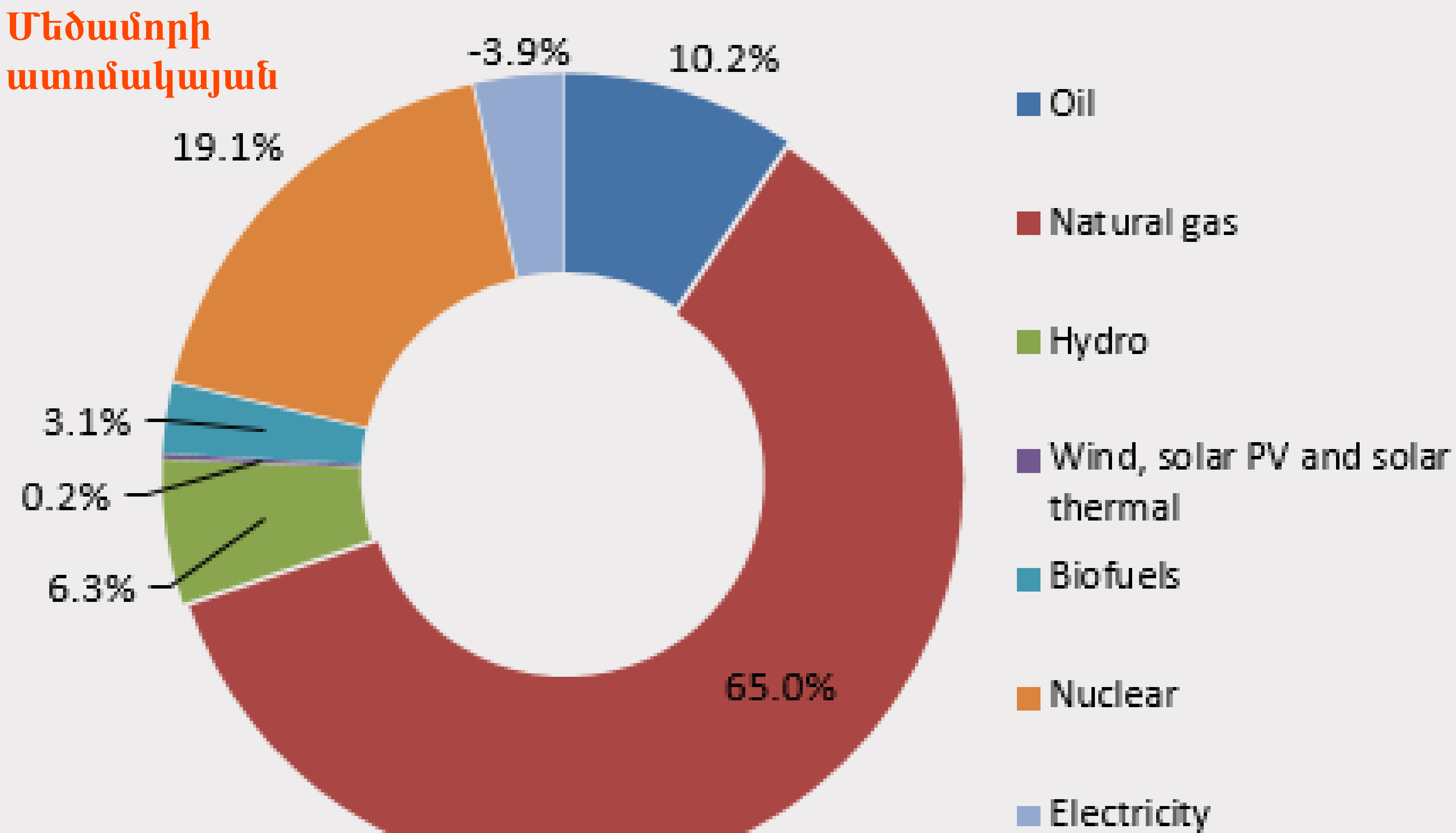


1360 Watts/m2 x Area= $3.14 \times [6.37 \times 10^6]^2$

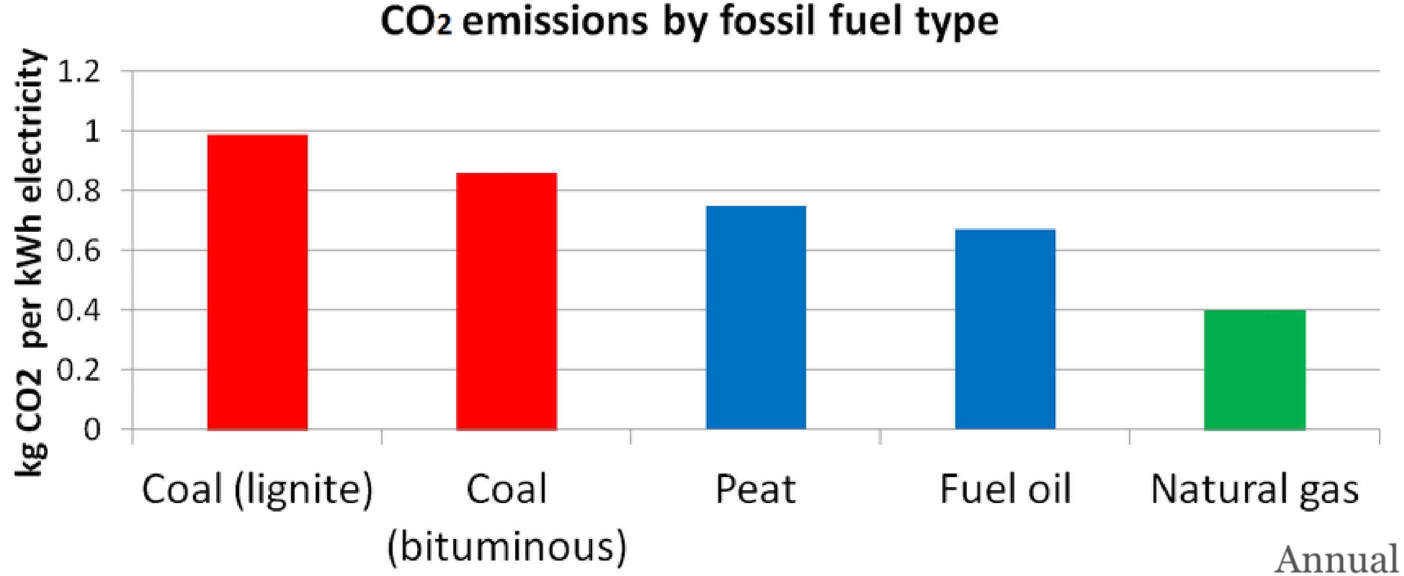
1.72×10^{17} Watts

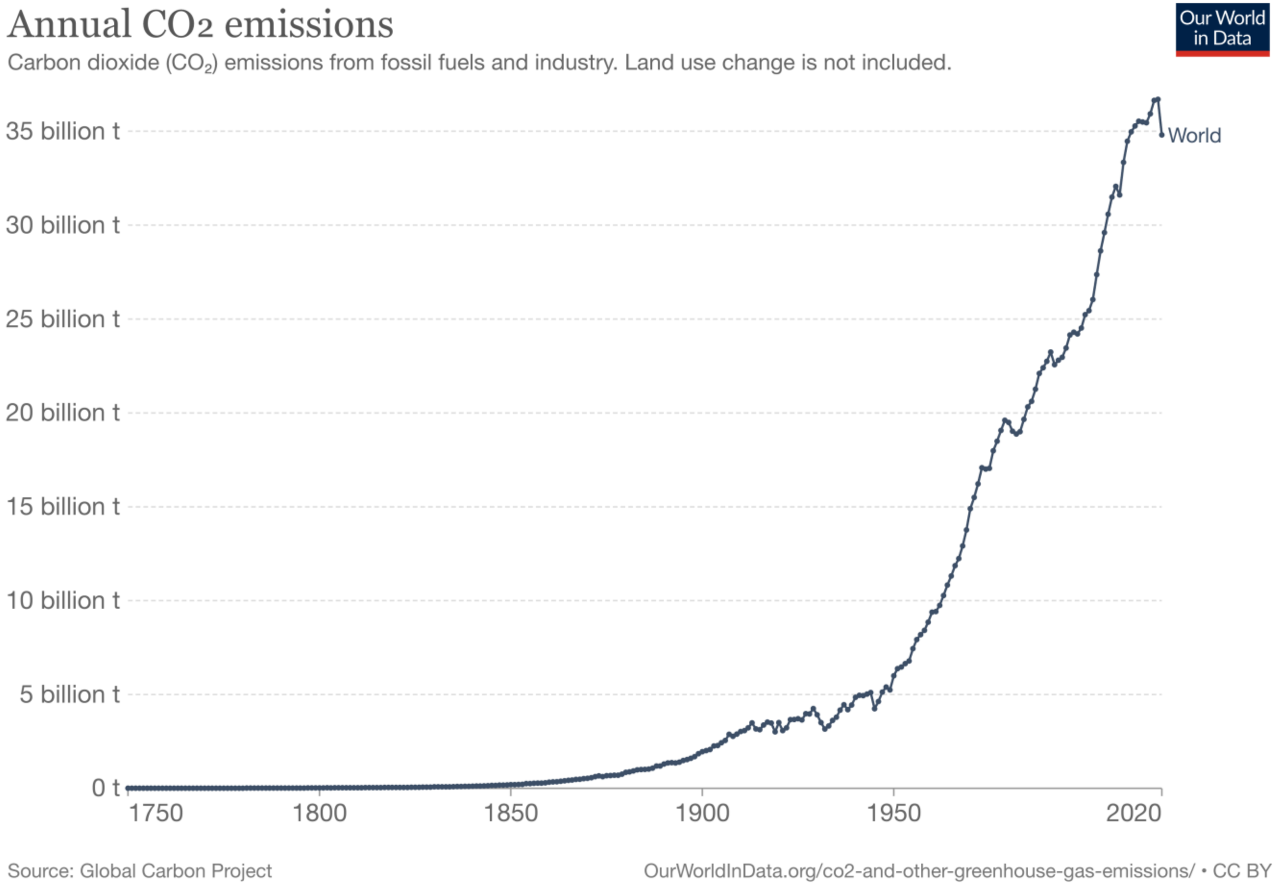
ARMENIA ENERGY MIX

Total Primary Energy Supply (TPES)



Natural gas is the main energy source of Armenia


CO2 emissions by fossil fuel type
kg CO2 per kWh electricity
1.2
1
0.8
0.6
0.4
0.2
0
Coal (lignite)
Coal (bituminous)
Peat
Fuel oil
Natural gas


Annual CO2 emissions
Our World in Data
Carbon dioxide (CO2) emissions from fossil fuels and industry. Land use change is not included.
35 billion t
30 billion t
25 billion t
20 billion t
15 billion t
10 billion t
5 billion t
0 t
World
1750
1800
1850
1900
1950
2020
Source: Global Carbon Project
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

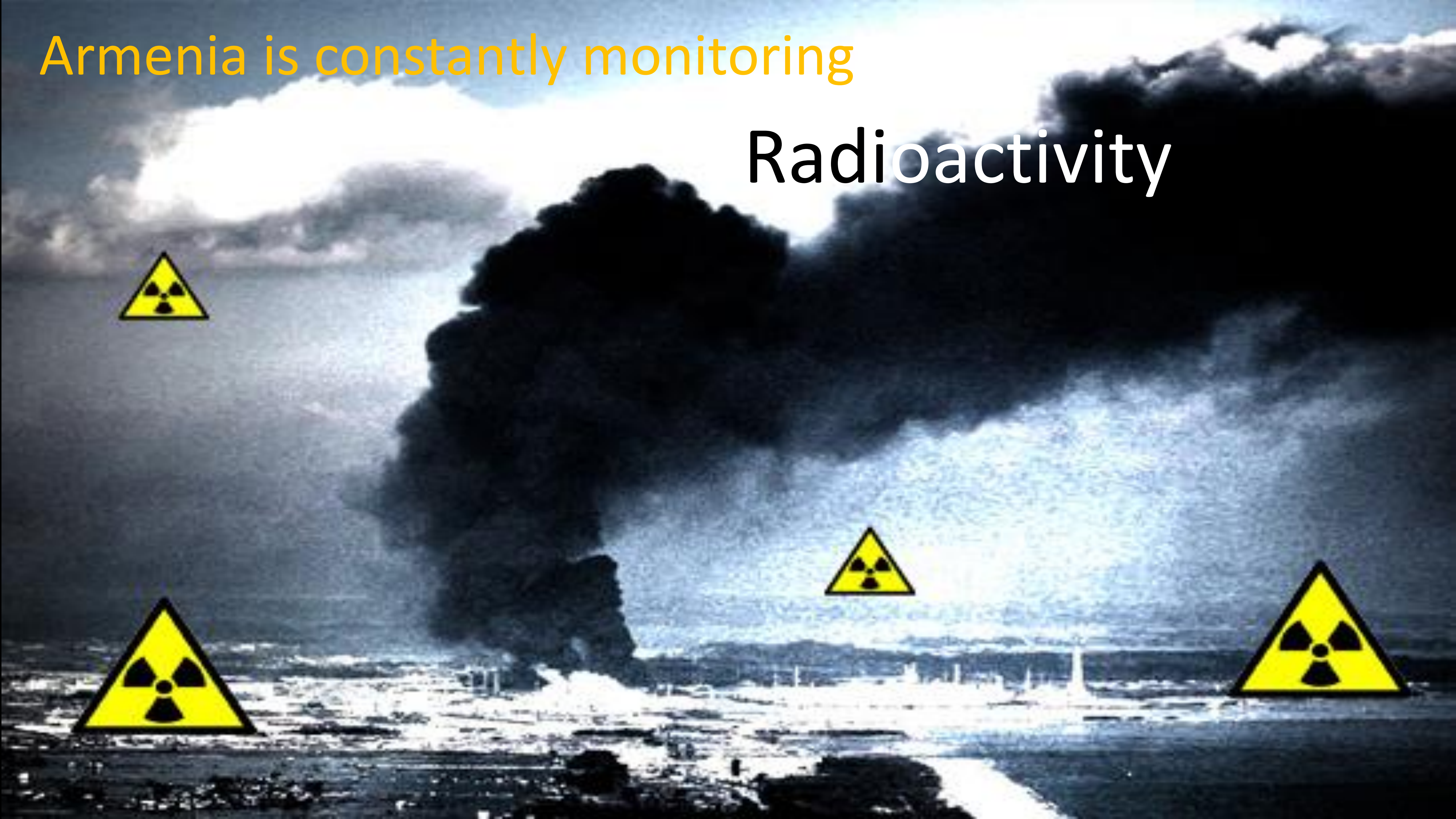

Climate Change for Armenia: Very Strong


76 WEST 30 WEST
Valley Forge
76 EAST
Int'l Airport
EXIT ONLY
EXIT

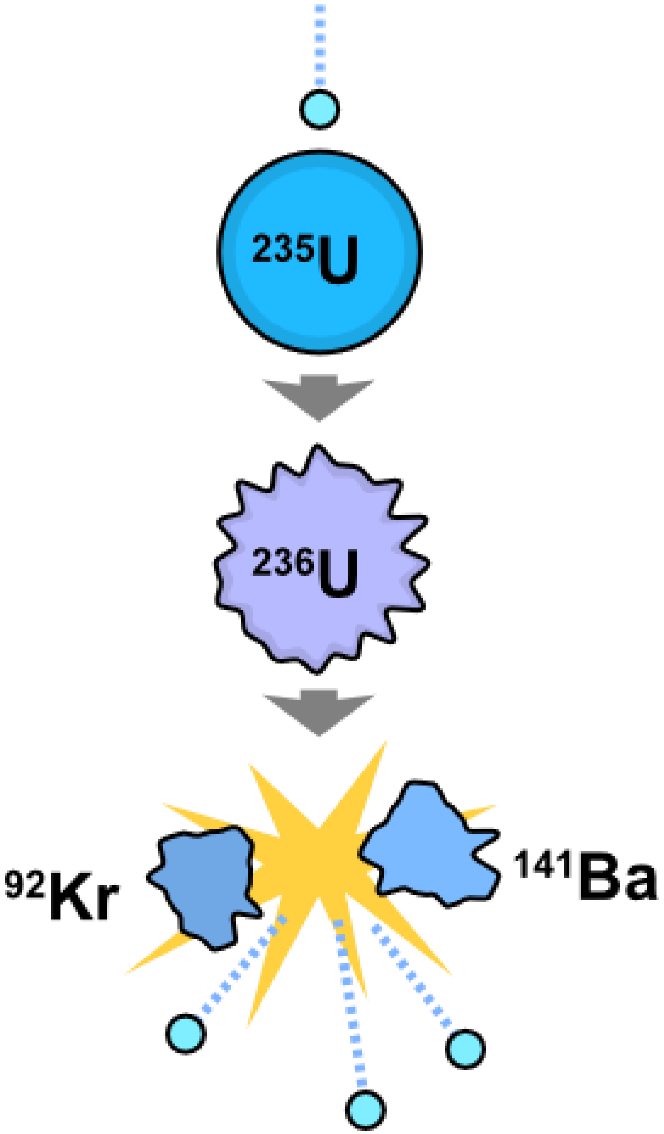
wnn world nuclear news
Celebrating 15 years

Metsamor 2 to operate until 2026

17 November 2021


Armenia is constantly monitoring
Radioactivity

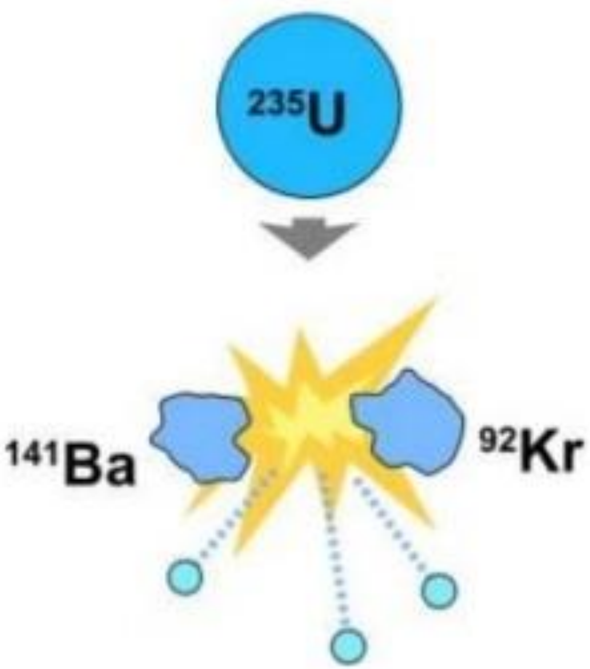
More than 2000 Nuclear Weapons Tests 1945-1999, with major emission of radioactivity into the atmosphere

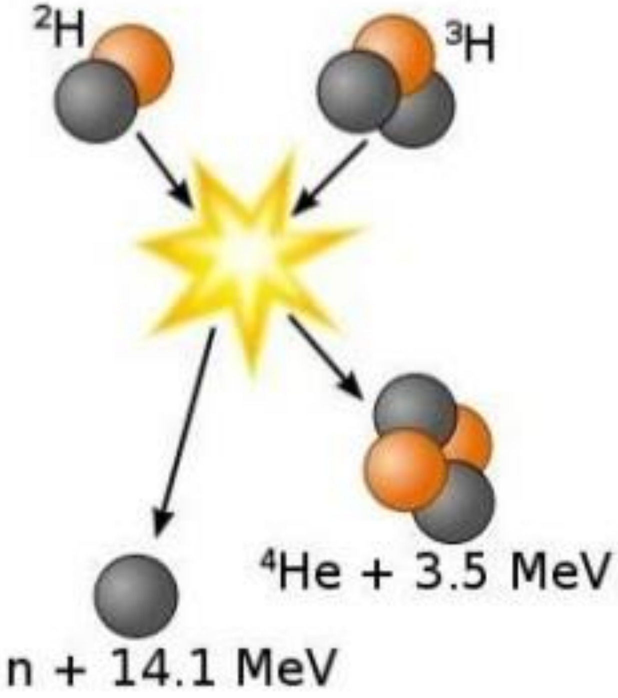
Each fission releases more than 1 neutron

$$E=mc^2$$

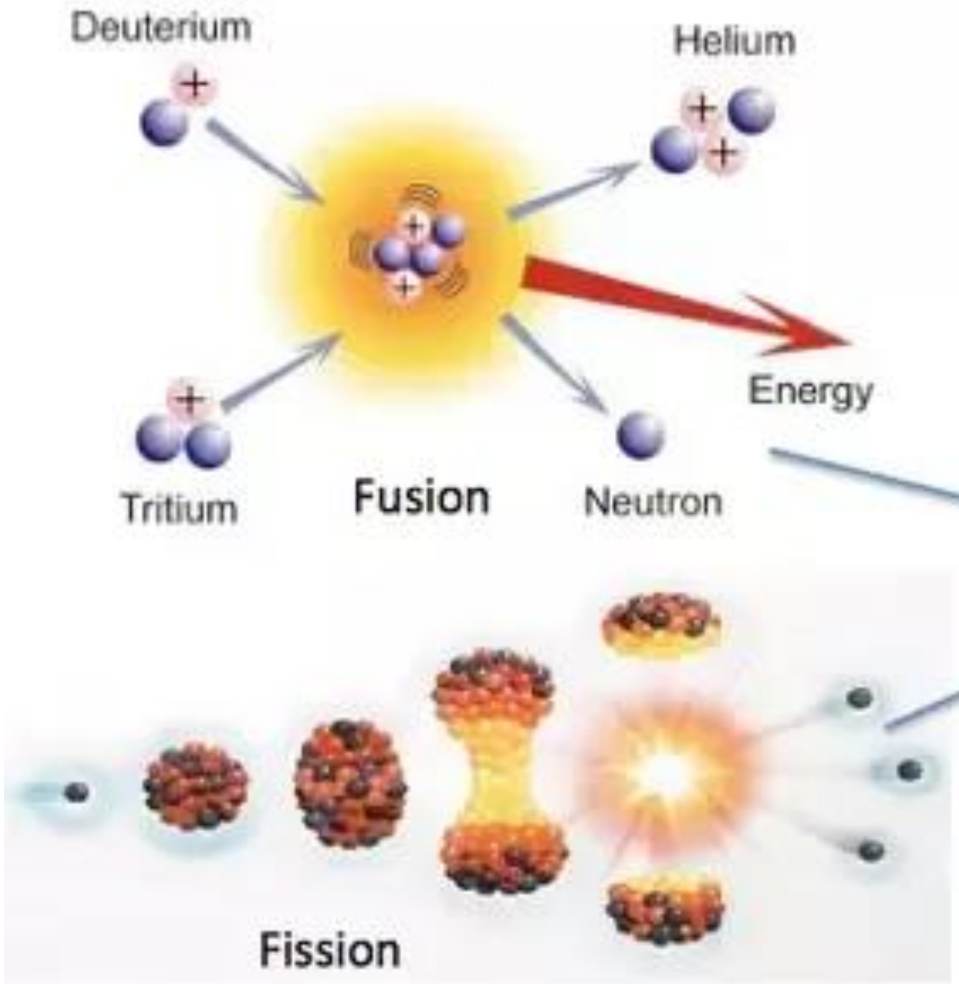
Fission



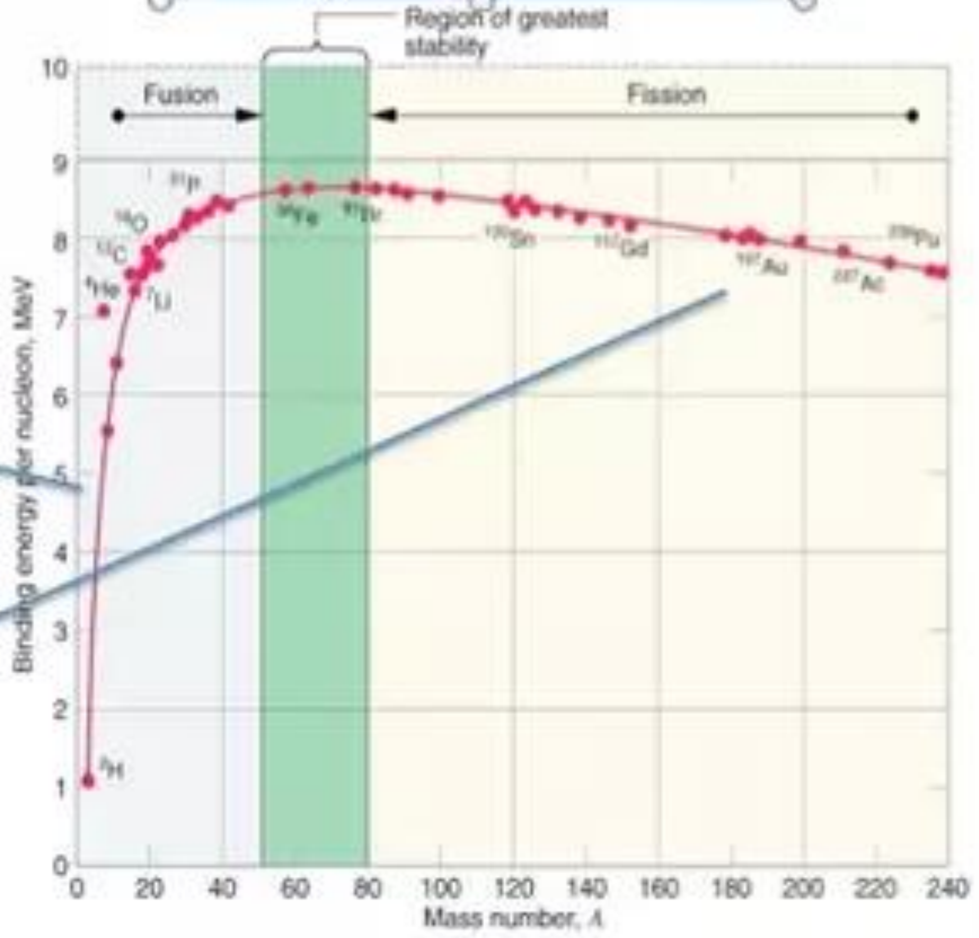
Fusion



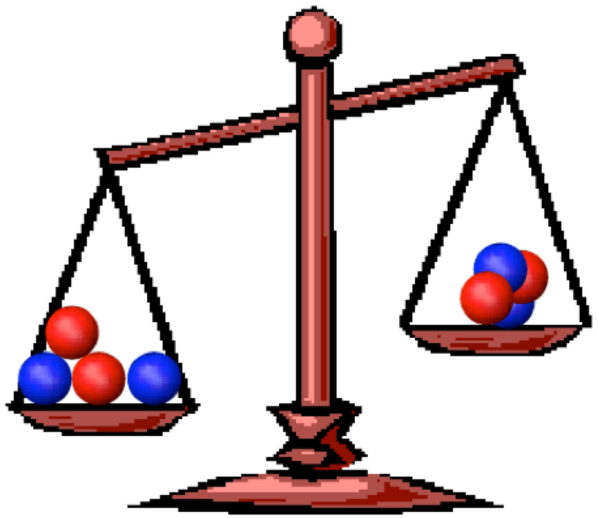
Nuclear Fusion



Binding energy of nucleons



Nuclei weigh less than the sum of the masses of their protons and neutrons



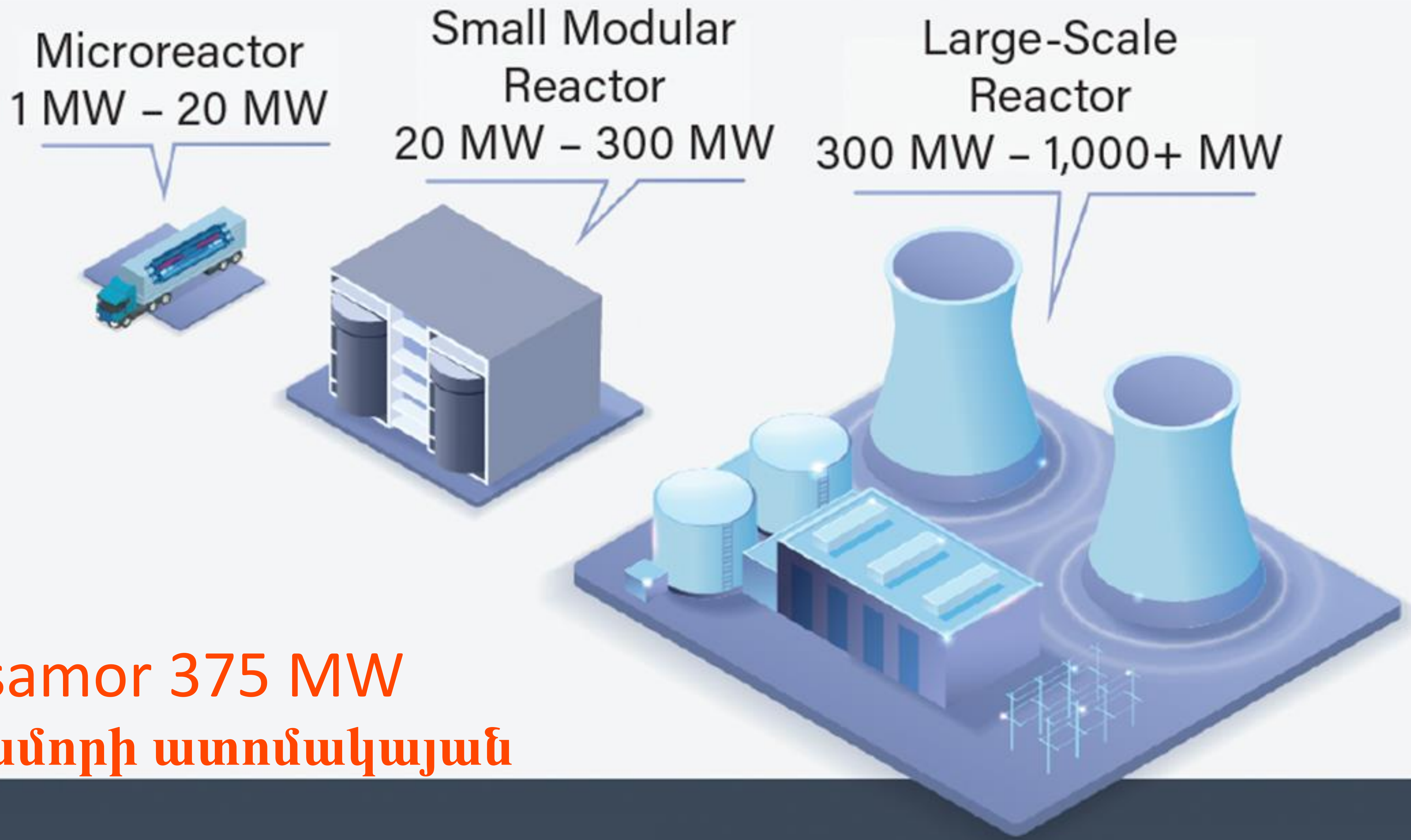
Energy and mass are related

Nuclear binding energy

$$(2m_p + 2m_n) > m(^4He)$$

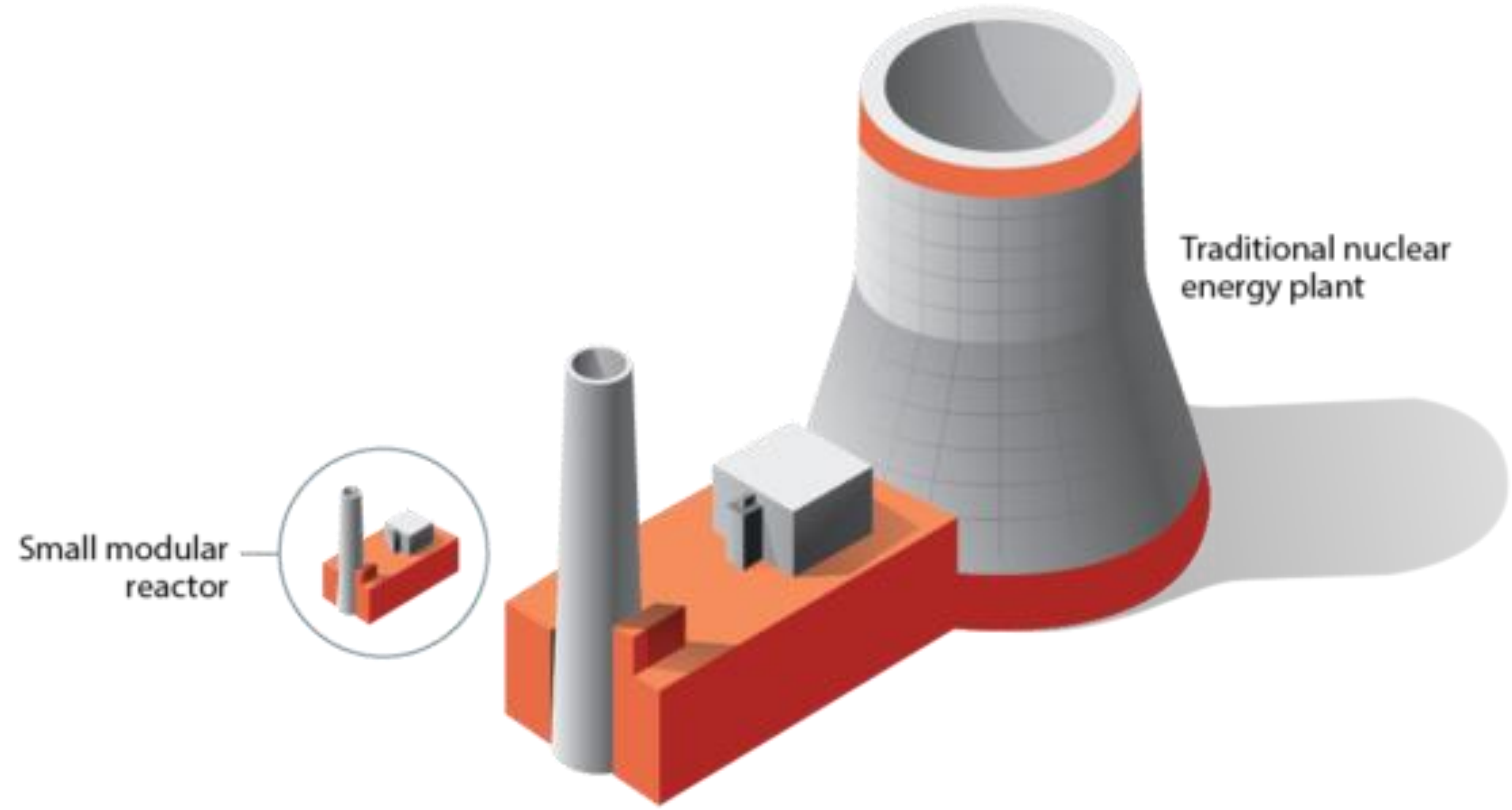
$$BE = (2m_p + 2m_n) - m(^4He)$$


SUBJECT ZERO
SCIENCE
SMALL
MODULAR
REACTORS
Հայաստանը և ԱՄՆ

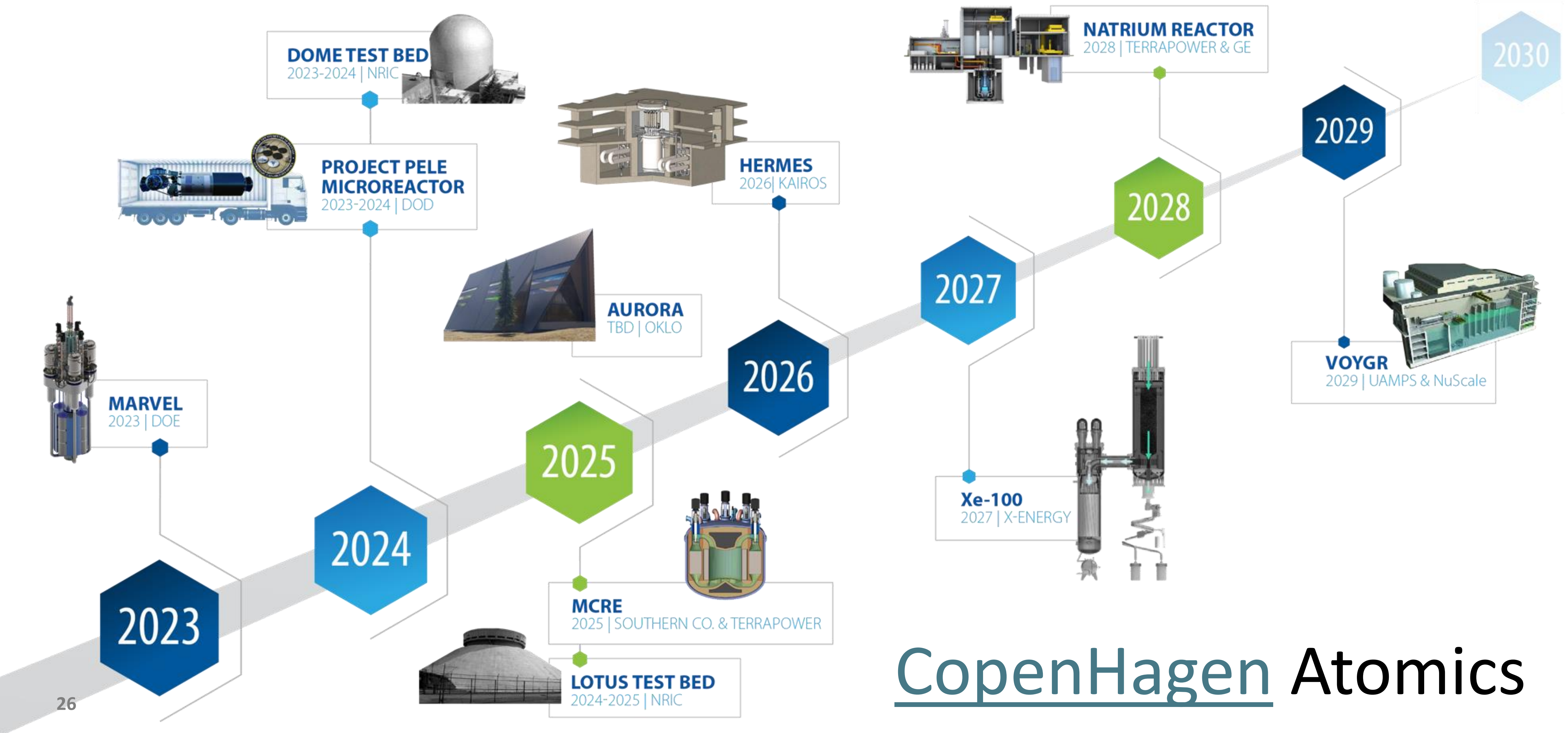


Metsamor 375 MW

Մեծամորի ատոմակայան


Traditional nuclear energy plant
Small modular reactor

Accelerating advanced reactor demonstration & deployment



CopenHagen Atomics

Radioactivity in Industry: Potential

Nuclear Medicine

18 MeV Cyclotron Proton Beams

^{64}Cu
^{68}Ga
^{99}Mo

PET-1

SPECT-5

Experimental hall: External Beam line + data acquisition and analysis rooms

Two similar ones in the world

- University Hospital of Bern
- University of Seville

Research:
Fundamental Nuclear Science
Fundamental Nuclear Astrophysics
Research in the development of new Isotopes
Material Science
Many other possibilities…

Cultural Heritage
Manusrcipts/artifact
Testing electronics

AANL enabled the operation of the cyclotron located at the Isotope production center

Life Sciences

- **Medical Diagnostics, Drug Testing**
- Medical Therapy
- Radiobiology
- Biomedical tracers

18 MeV Cyclotron from IBA

Isotope Production

Creation and development of accelerator based methods of isotopes production, ^{99m}Tc, ^{67}Ga, ^{64}Cu and others.

First Beam June 12, 2019 !!!

^{18}F Isotopes (9 Ci) produced July 3, 2019

Several Experiments in 2020!

Diagnostic Tool during COVID-19 pandemic

Radioisotopes in Medicine

(Updated May 2020)

^{99m}Tc : SPECT

Traditionally Produced from Fission

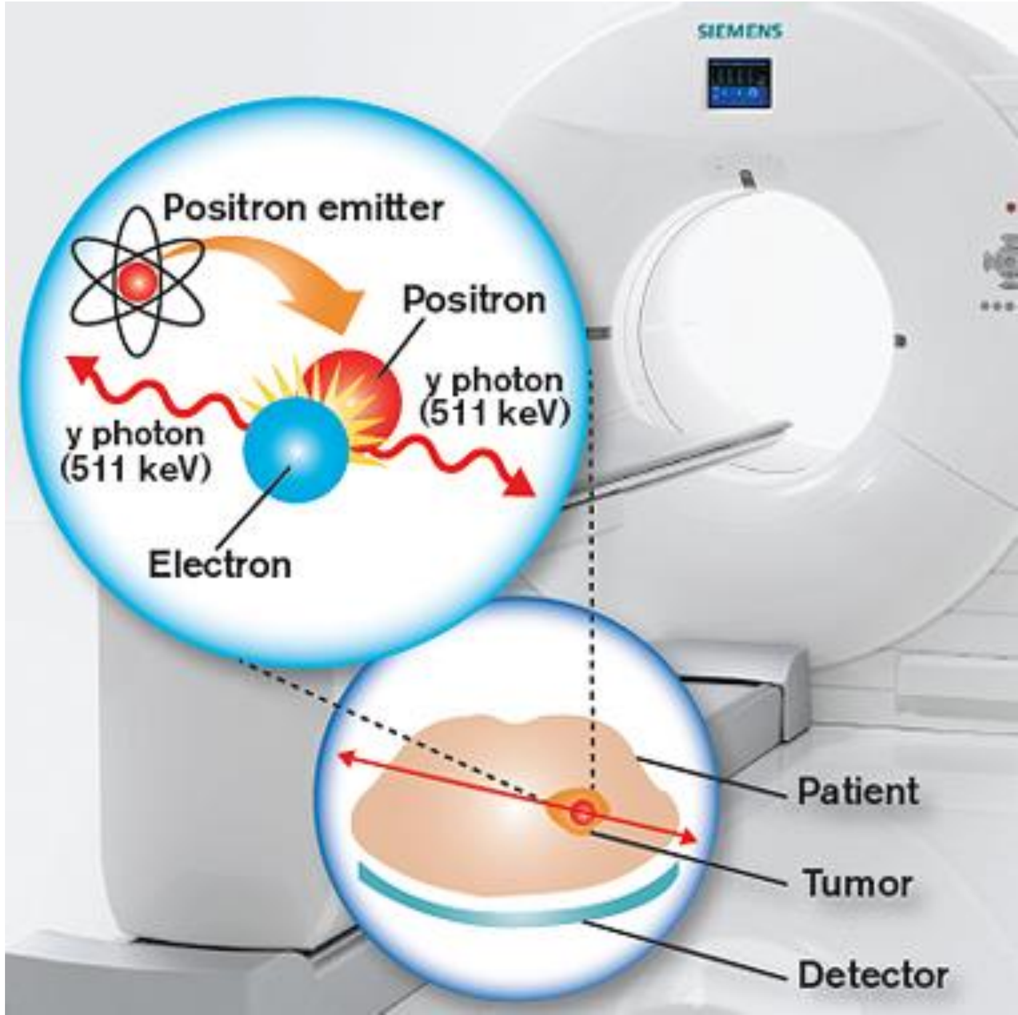
- **Nuclear medicine** uses radiation to provide diagnostic information about the functioning of a person's specific organs, or to treat them. Diagnostic procedures using radioisotopes are now routine.
- **Radiotherapy can be used to treat some medical conditions, especially cancer, using radiation to weaken or destroy particular targeted cells.**
- **Over 40 million nuclear medicine procedures are performed each year, and demand for radioisotopes is increasing at up to 5% annually.**

Diagnostic radiopharmaceuticals can be used to examine blood flow to the brain, functioning of the liver, lungs, heart, or kidneys, to assess bone growth, and to confirm other diagnostic procedures. Another important use is to predict the effects of surgery and assess changes since treatment.

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 towards using more **cyclotron-produced isotopes such as F-18,** as PET and CT/PET become more widely available.

Positron Emission Tomography 1 in Armenia that began in June 2020



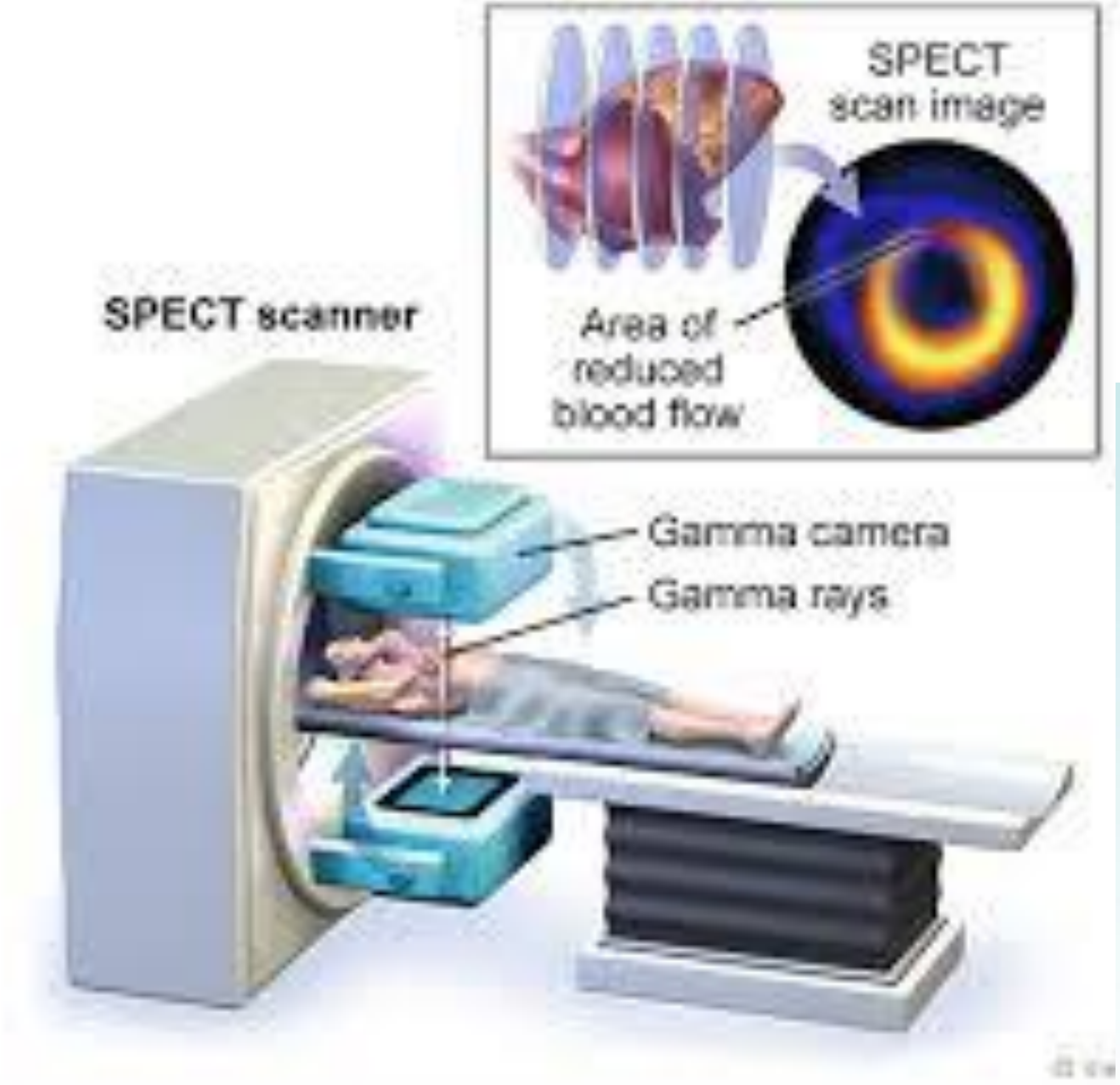
Beyond Diagnostics, isotopes for Targeted therapeutic use in cancer treatments

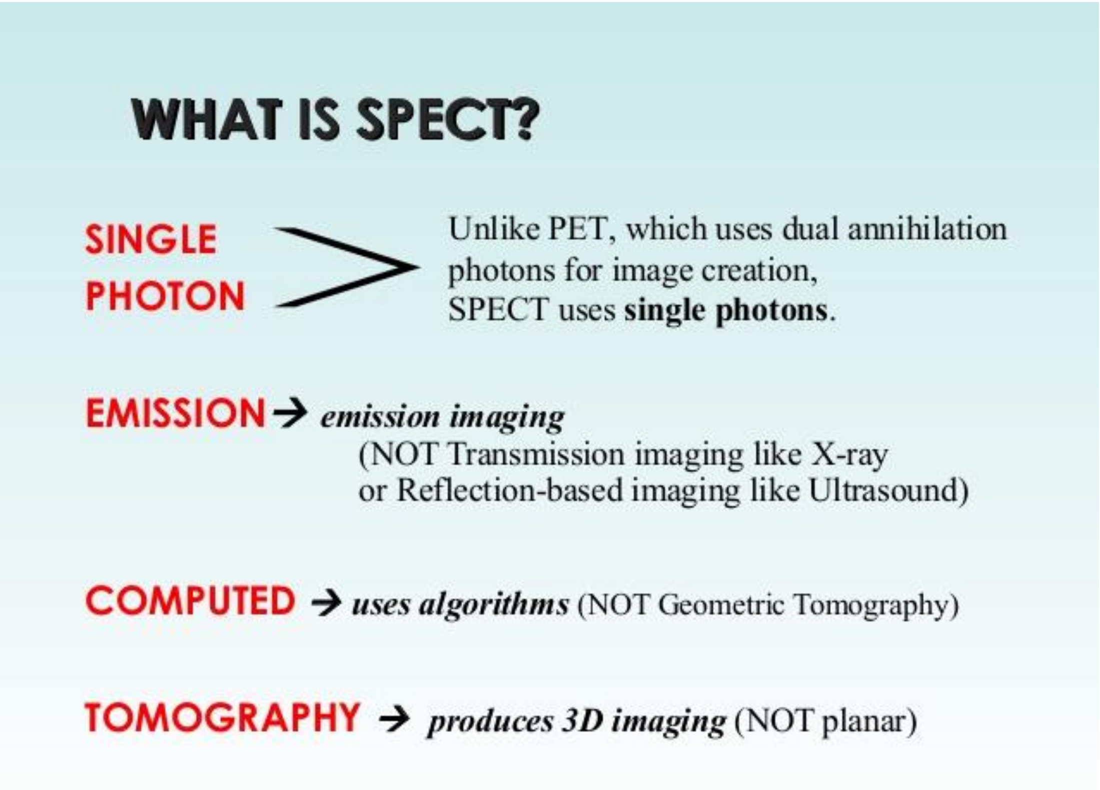
Armenian Isotope Production
Presently: Diagnostic Radioisotopes
Future: Targeted Therapeutic ones as well

Over 10,000 hospitals worldwide use radioisotopes in medicine, and about 90% of the procedures are for diagnosis. The most common radioisotope used in diagnosis is **technetium-99 (Tc-99),** with some 40 million procedures per year, accounting for about 80% of all nuclear medicine procedures and 85% of diagnostic scans in nuclear medicine worldwide.

SPECT stands for single-photon emission computerized tomography. It uses a radioactive substance and a special gamma camera to create 3-D pictures of your organs at different angles.

Technetium-99m ^{99m}Tc ($T_{1/2}$= 6h; Eγ~140 keV) Emission of a gamma-ray





Canadian Model: cyclotrons located In geographically centralized areas with accessibility for the population of CANADA.

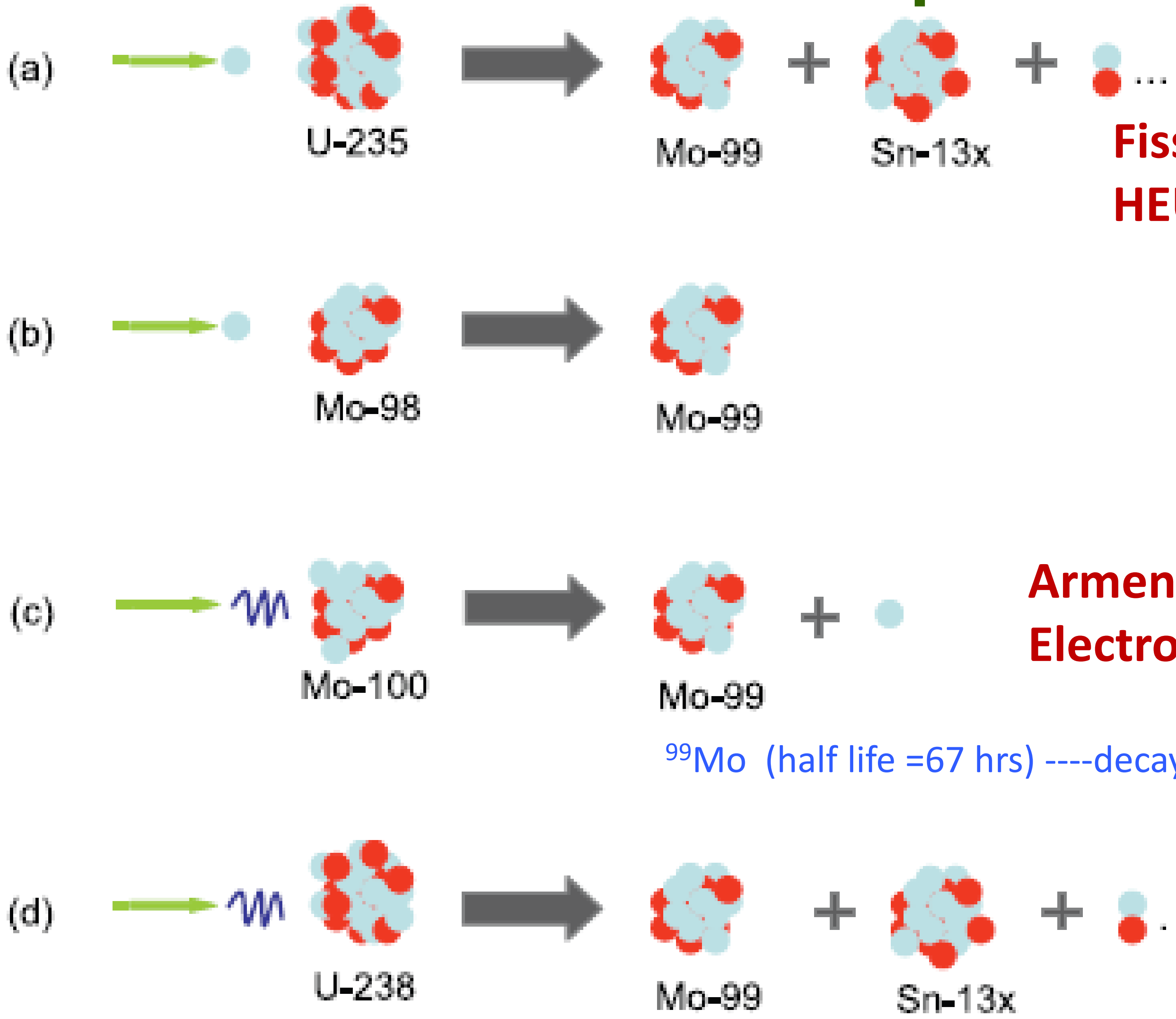
Extracting ^{99m}Tc from Mo/Tc generators irradiated material during 6-7 days using centrifuge extractor one can "milk" total up to 2-3 Ci of activity.

Armenia: There are 5 clinics in Armenia having SPECT scanners –

Oncocenter,
Cardiocenter
Center of radiology and burns,
Erebuny clinic and
Radioisotopes Production Center.

All 5 are located in Yerevan.
Before COVID-19 Mo/Tc generators were purchased and delivered

Different methods of Mo/Tc production



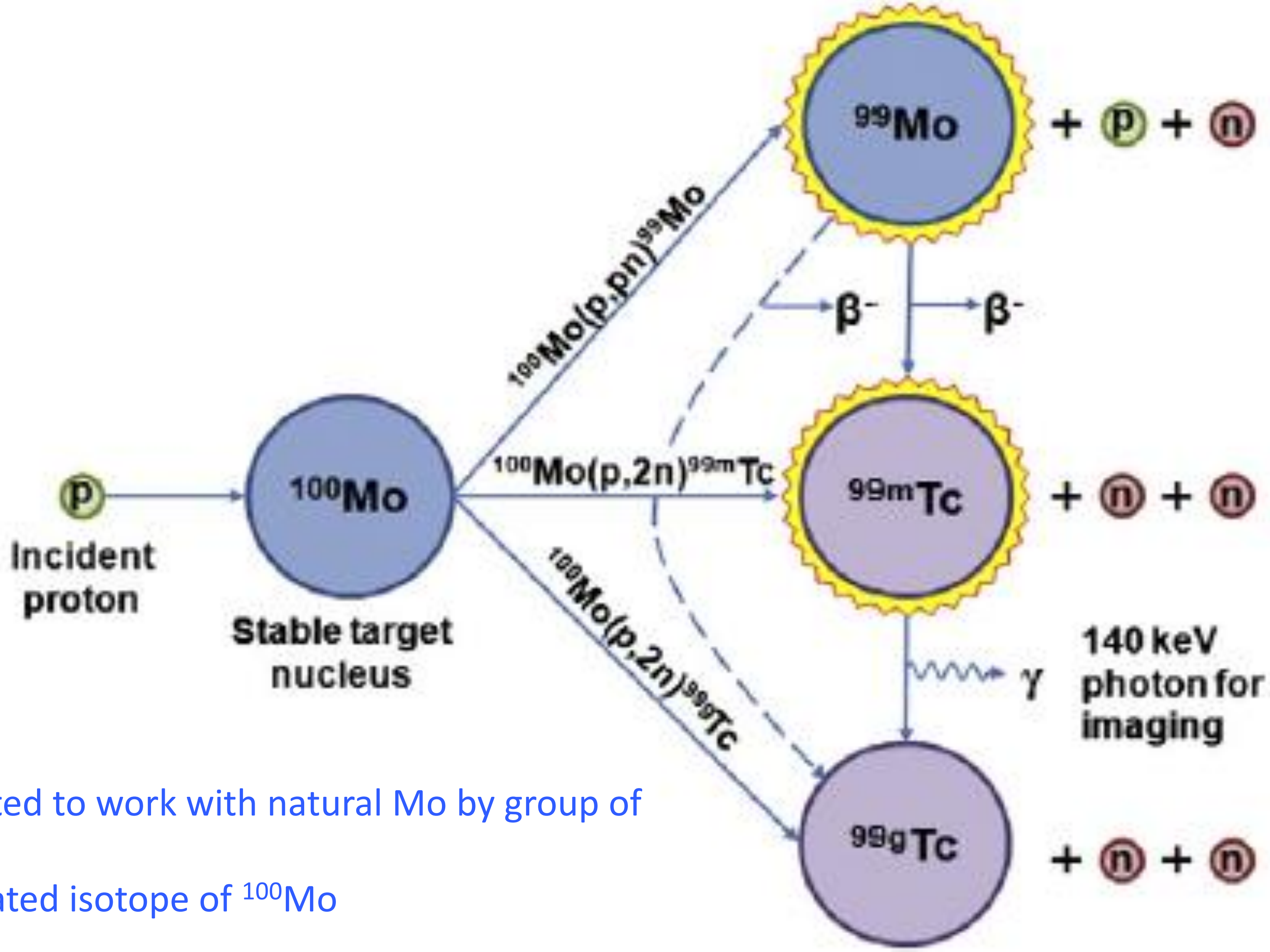
Fission in Reactors
HEU

AANL)

Armenia with linear
Electron accelerator

^{99}Mo (half life =67 hrs) ----decays to ^{99m}Tc (half life = 6 hrs)

Alternative Production Methods for ^{99m}Tc using cyclotron



Technique demonstrated to work with natural Mo by group of Dr. Avetisyan at AANL.
Next steps with separated isotope of ^{100}Mo

Therapeutic Isotopes: Big Advance in Cancer Treatments

Targeted Radioisotope Therapy

β^-, alpha, and Auger electrons

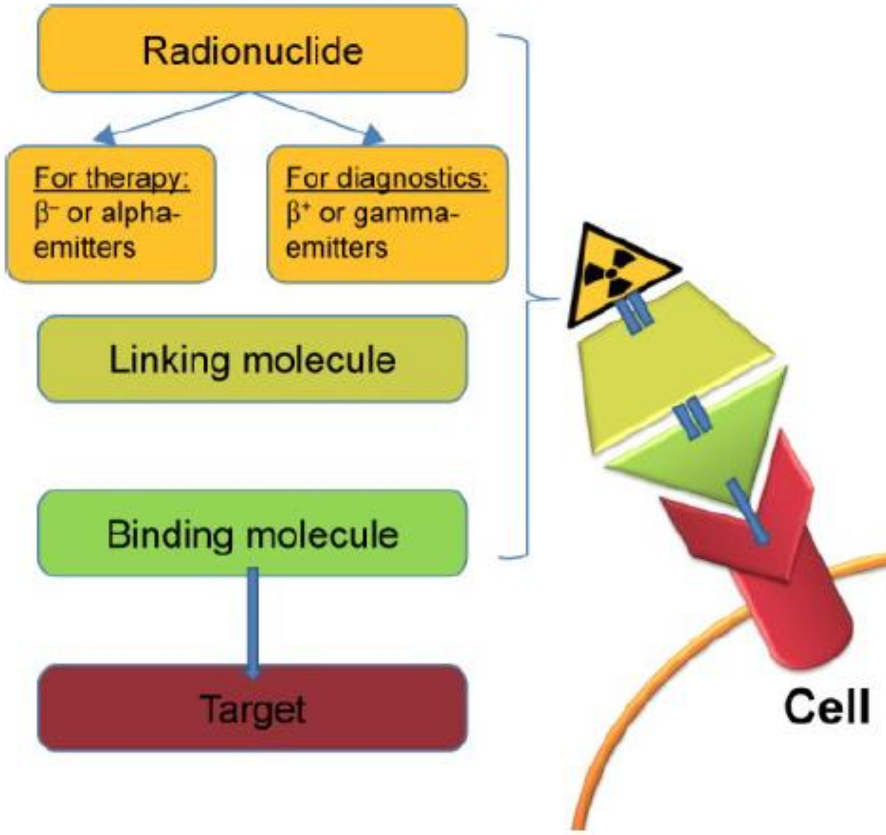
Isotopes that decay by the emission of β-, alpha, and Auger electrons can be used to kill/damage tumor cells

Challenge is in the delivery of the radioisotope

Must be highly selective and targeting the tumor (antibodies)

Examples: ^{90}Y or ^{131}I do not need targeting since they naturally accumulate

Theranostic Approach



The theranostic approach in nuclear medicine couples diagnostic imaging and therapy using the same molecule or at least very similar molecules, which are either radiolabeled differently or given in different dosages.

Example 1: iodine-131 and lutetium-177 are gamma and beta emitters; thus, these agents can be used for both imaging and therapy.

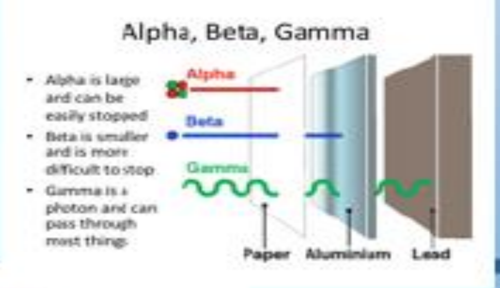
Example 2: iodine-123 (gamma emitter) and iodine-131 (gamma and beta emitters)

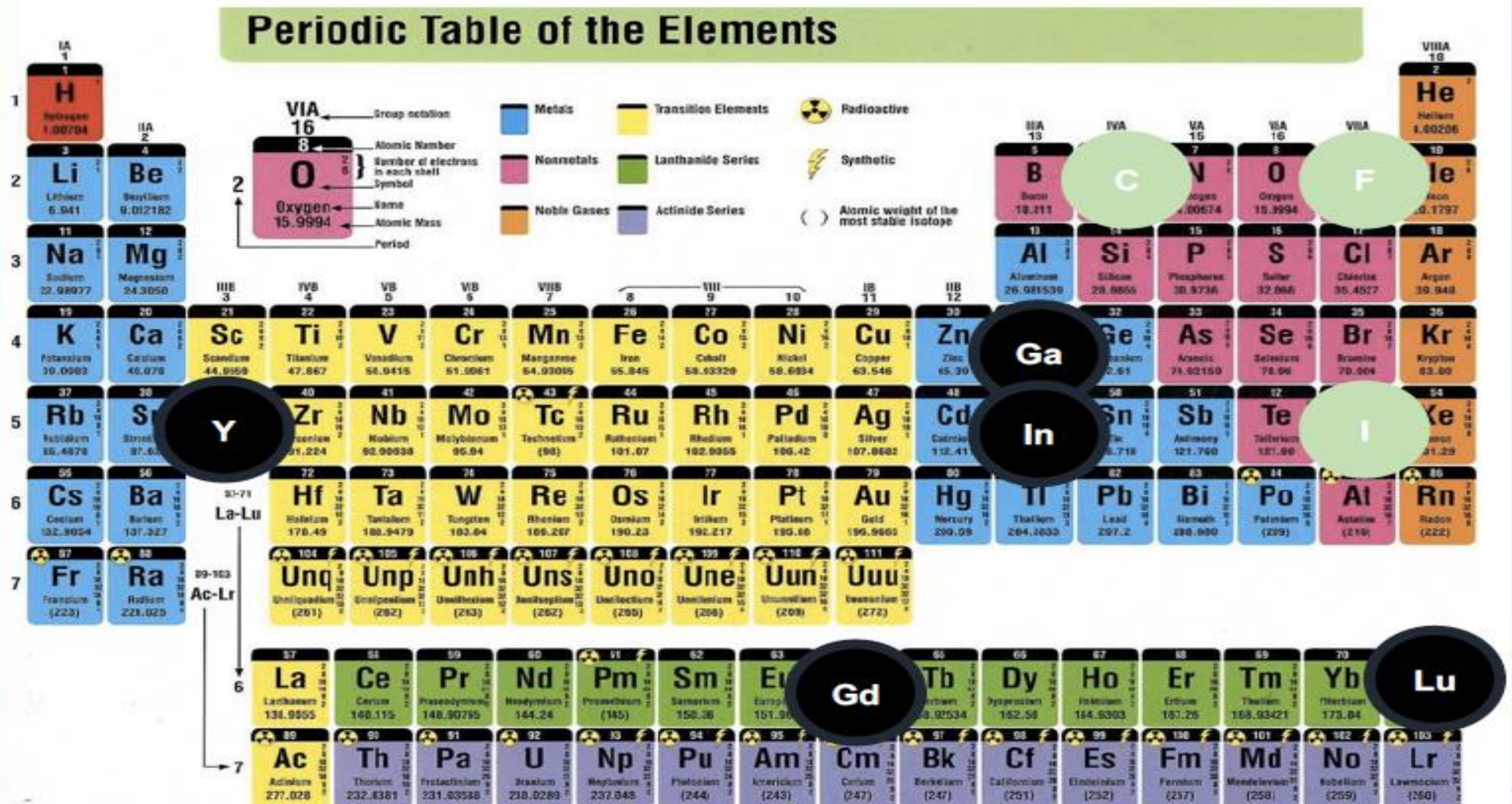
Example 3: yttrium-86/yttrium-90

Example 4: terbium isotopes (Tb): ^{152}Tb (beta plus emitter), ^{155}Tb (gamma emitter), ^{149}Tb (alpha emitter), and ^{161}Tb (beta minus particle).

Dr. Aboian

Radionuclide as a Therapeutic

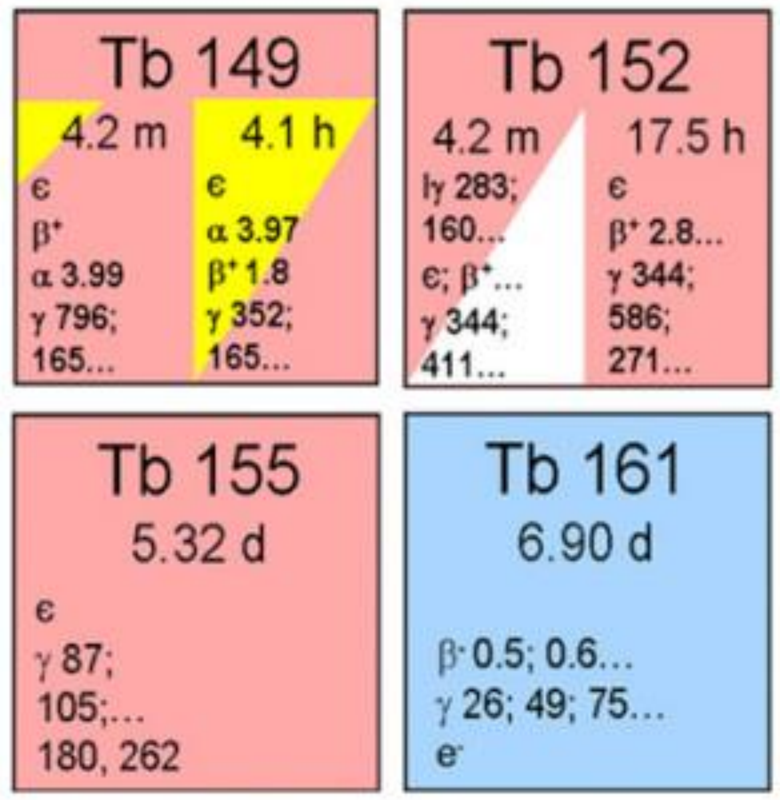




Radioisotope implanted **porous silicon nanoparticles** for theranostic applications

THERAPEUTIC USE OF RADIOACTIVE ISOTOPES

In December, researchers from ISOLDE-CERN, the Paul Scherrer Institute (PSI) and the Institut Laue-Langevin (ILL) published the results of an *in vivo* study which successfully proved the effectiveness of four terbium isotopes for diagnosing and treating cancerous tumors.



Potential cyclotron produced Isotopes

Collaboration with Materials Science to deliver the radioisotope

Collaboration with Pharmaceutical developments in Armenia

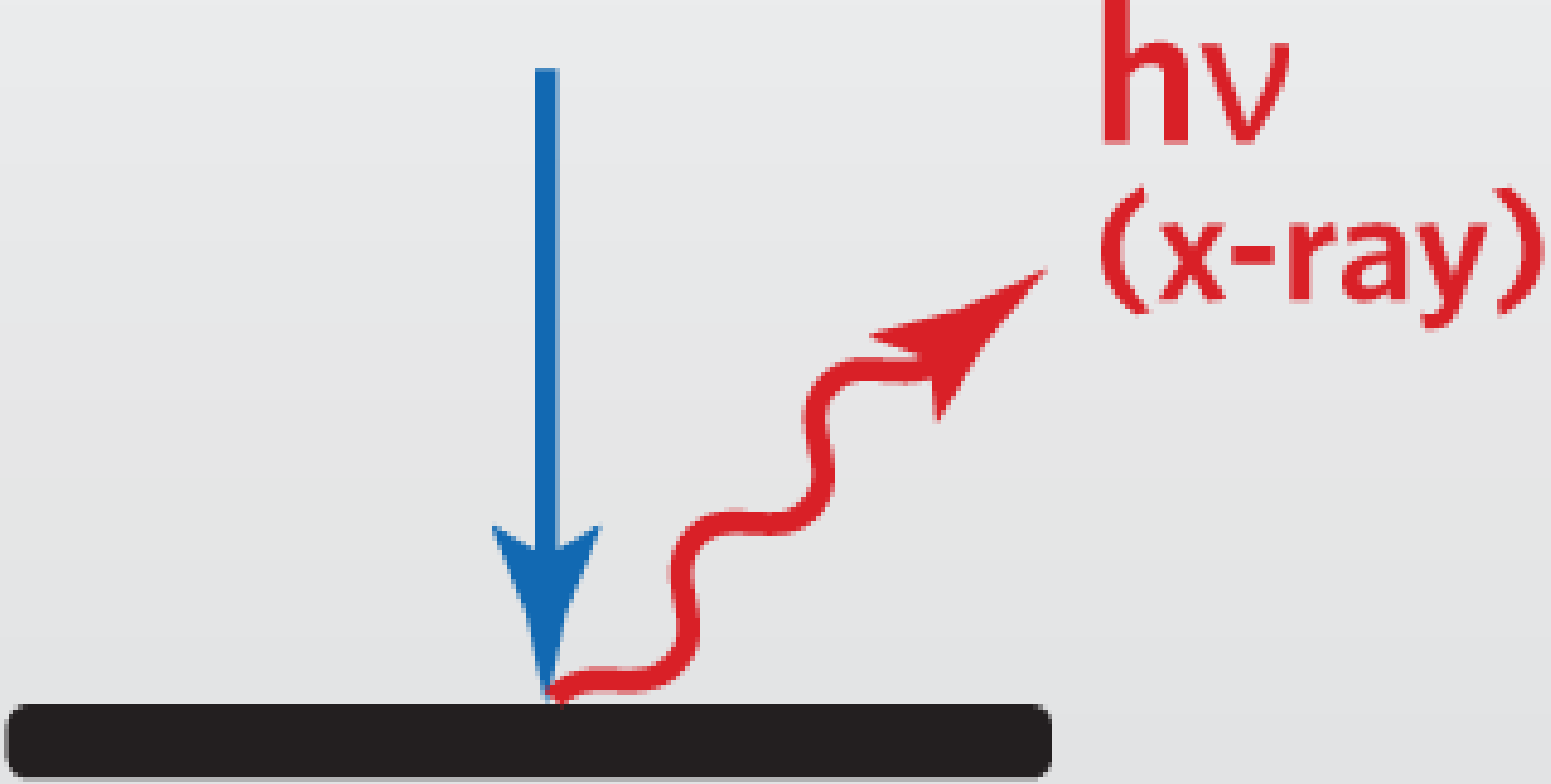
Collaborations with Biologists for in-vivo testing

^{11}C PET
^{18}F PET
^{44}Sc PET/ ^{47}Sc β^- therapy
^{45}Ti PET
$^{52,54}Mn$ PET
^{55}Co PET
^{64}Cu PET/ ^{67}Cu β^- therapy
^{68}Ga PET/ ^{67}Ga Auger therapy
^{86}Y PET/ ^{90}Y β^- therapy
^{89}Zr PET
^{90}Nb PET
^{99m}Tc SPECT/ ^{94m}Tc PET
^{103m}Rh Auger therapy
^{111}In SPECT
^{119}Sb Auger/^{118}Sb PET/^{117}Sb SPECT
^{124}I PET/ ^{125}I Auger therapy
^{149}Tb Alpha therapy/ ^{161}Tb β^- therapy
^{165}Er Auger therapy
^{177}Lu β^- therapy
^{203}Pb/ ^{212}Pb Alpha therapy
^{213}Bi Alpha therapy
$^{223,224}Ra$ Alpha therapy
^{225}Ac Alpha therapy
$^{227,228}Th$ Alpha therapy

Cyclotron: New Directions

Cultural Heritage

New Beginning in Armenia

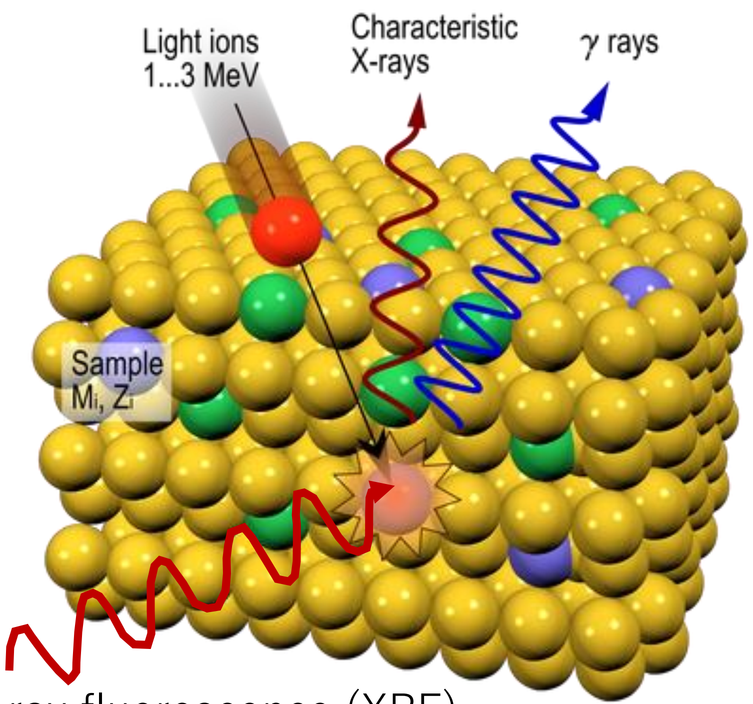


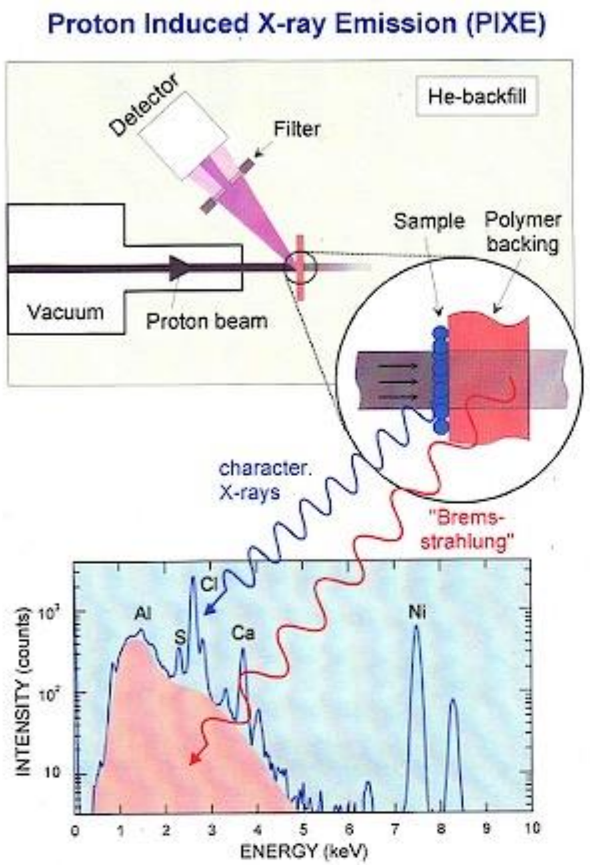
PIXE: Proton Induced X-ray Emission

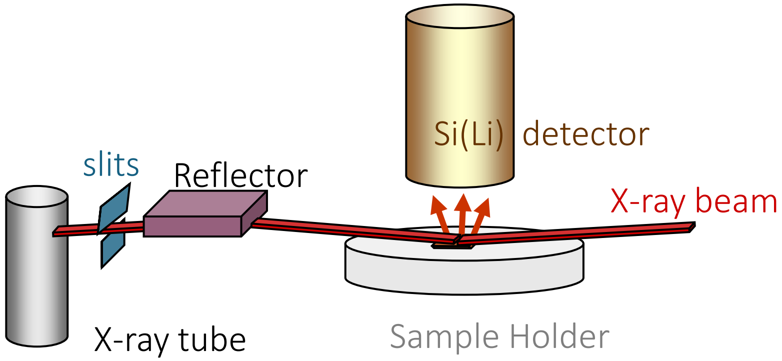
Material analysis with radiation

The analysis and imaging of material can be done by particle induced x-ray emission (PIXE) or x-ray fluorescence (XRF) or neutron activation techniques (NAA). These techniques allow punctual analysis or also the development of images for specific material components.

Particle induced X-ray/γ emission (PIXE/PIGE)

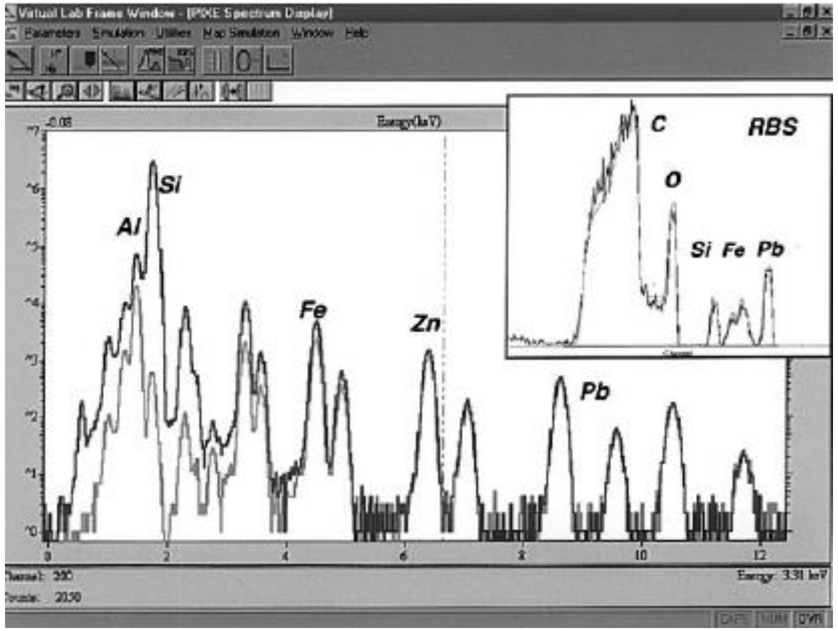


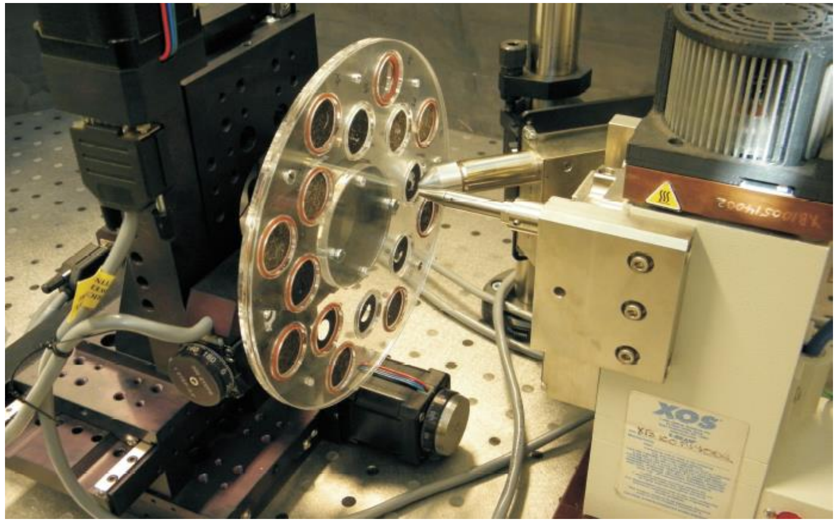


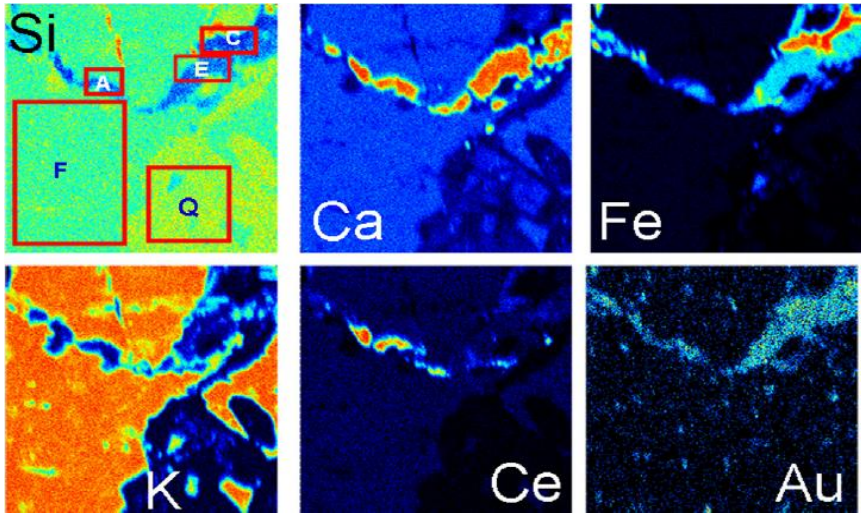


X-ray fluorescence (XRF)

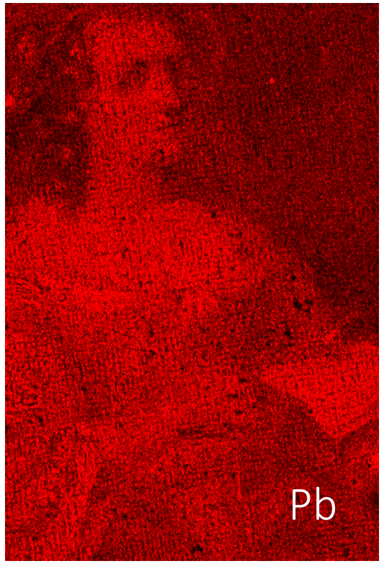
PIXE and XRF

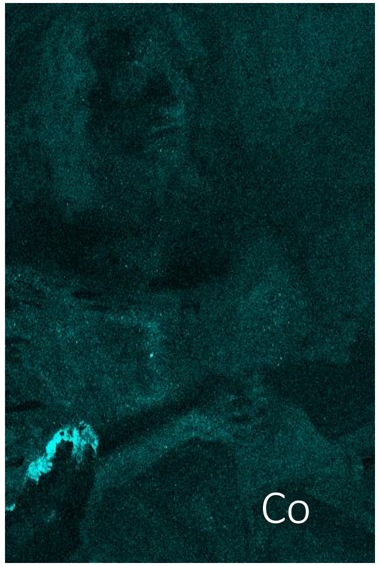


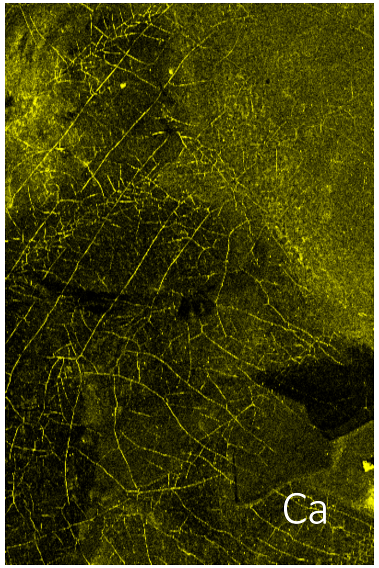


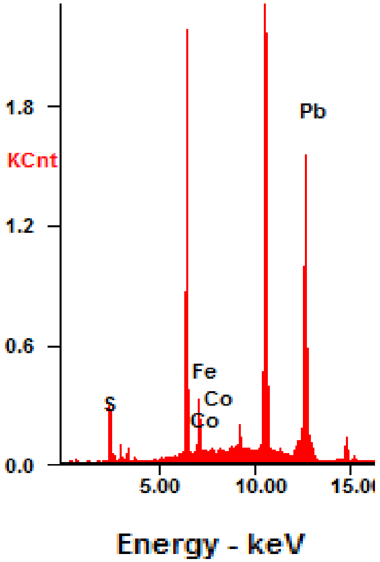


Art Analysis









$PbCO_3$ (lead-white) white pigment for preparing the backing (canvas, wood) and for highlighting bright areas, today TiO (titanium oxide)

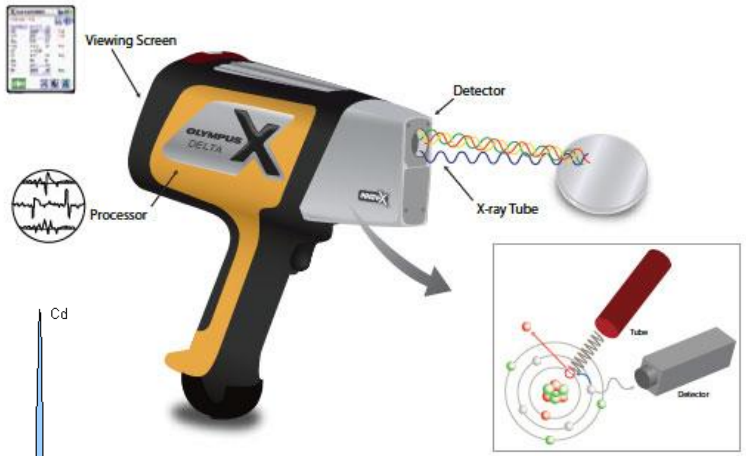
C_xH_y+ FeO + $CaC0_3$) (calcinated Van Dyke Brown) – a local product from the region near Cologne, which was used for the toning of darker brownish areas.

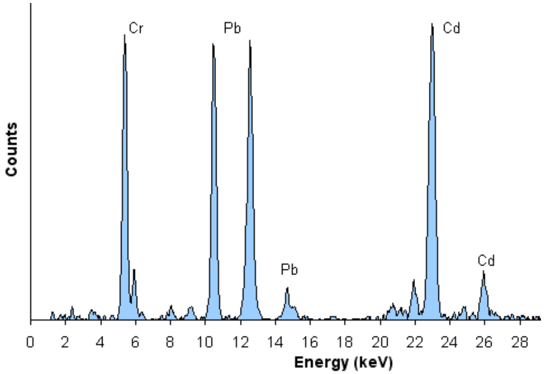
$(Fe_4[Fe(CN)_6])_3$ (Prussian Blue, based on Fe)- was used for the blue tones of broche – no Cu (Azurite) was observed. $CoAlO_4$ (Cobalt Blue or Smalt) was used for sleeve.

C_xH_y+ FeO + $CaC0_3$) (calcinated Van Dyke Brown) – a local product from the region near Cologne, which was used for the toning of darker brownish areas.

XRF for consumer goods

Easy approach for quick analysis of elemental composition of materials

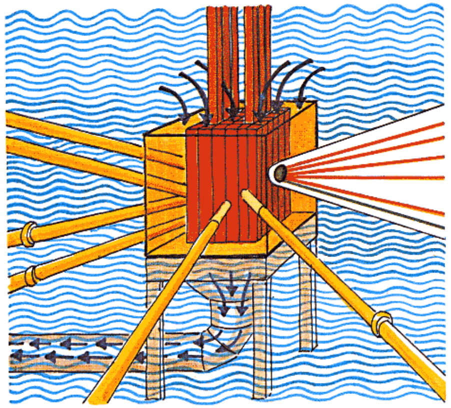


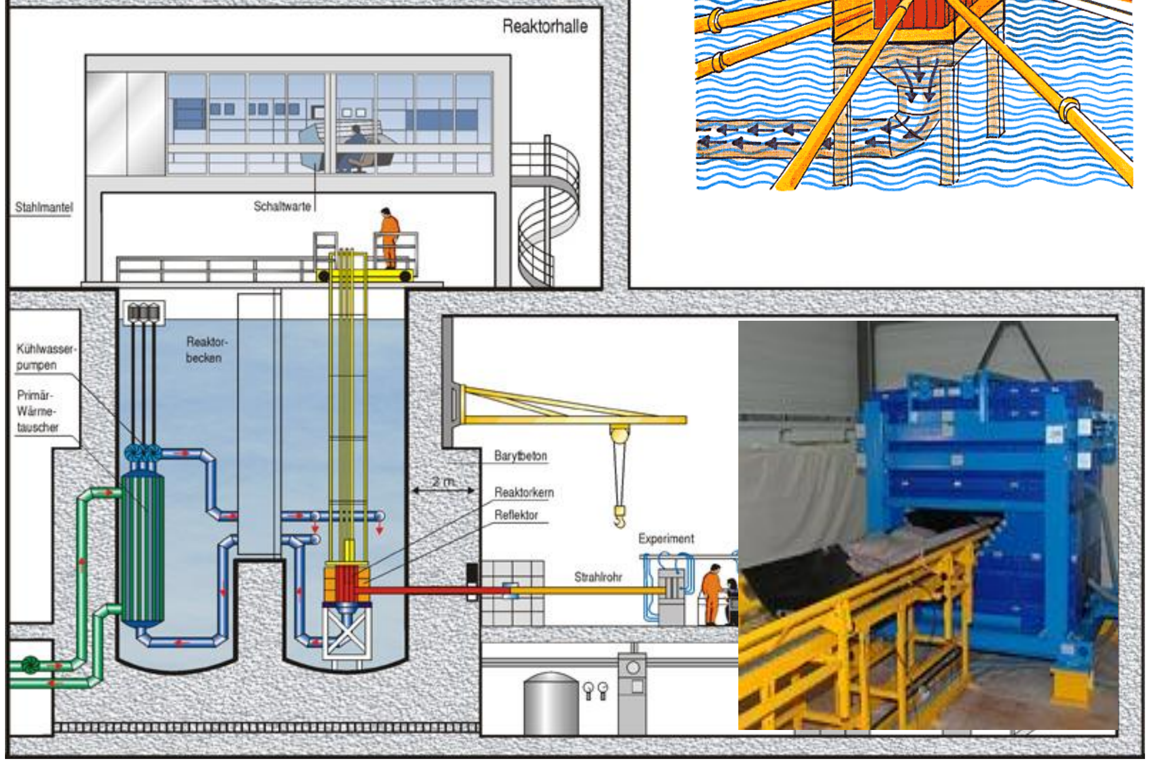


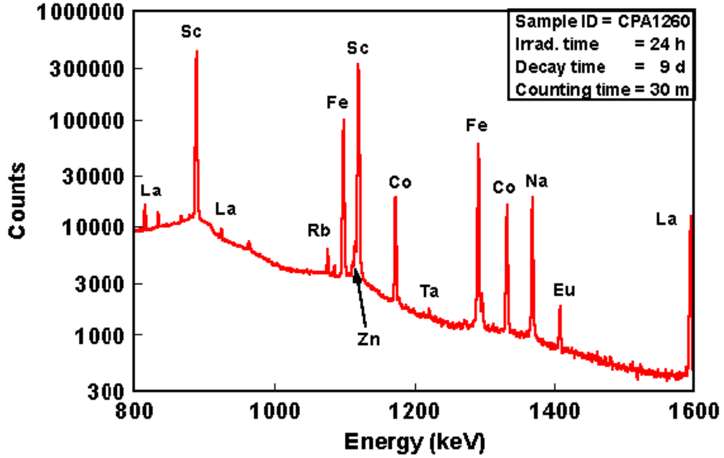
Multiple applications in analysis of merchandise (Chinese toys) to scrap metal, food, & environment

Neutron Activation Analysis (NAA)

Expose material to high neutron flux and add neutrons to nuclei to produce a radioactive isotope with subsequent analysis of elemental components for its characteristic radioactive decay pattern.



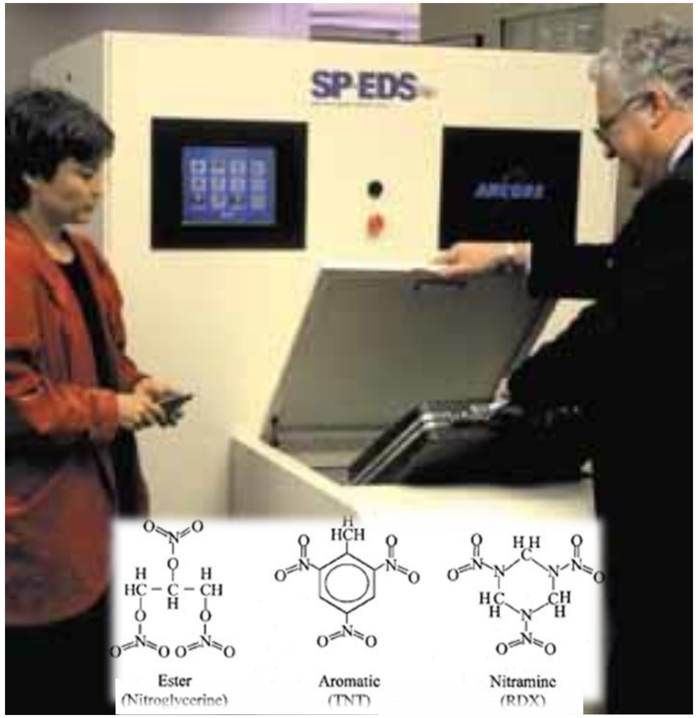




Prompt Neutron Activation Analysis

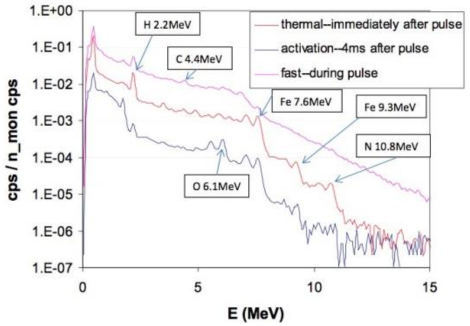
with Am-Be neutron sources

Sorting of security issues at airports

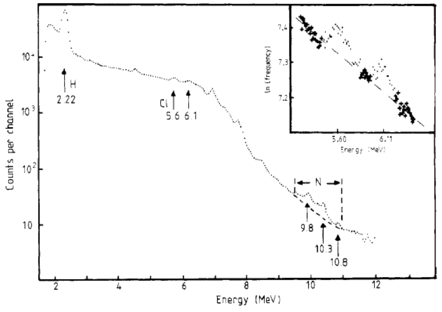


Sorting of waste components by activity analysis

$^{14}N(n,\gamma)^{15}N$ ejecting prompt 10.8 MeV γ-rays



$^{37}Cl(n,\gamma)^{38}Cl$ ejecting prompt 5.6 and 6.11 MeV γ-rays.



Nuclear Batteries

Nuclear batteries get their energy from the decay of radioactive material. The lifetime of a battery is associated with the lifetime **τ** or the half life $T_{1/2}$ of its radioactive fuel:

$$\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{\ln 2} = 1.44 \cdot T_{1/2}$$

Example: radioactive fuel ^3H: τ = 17.8 y, ^{63}Ni: τ = 144 y, ^{210}Po: τ = 200d.

The power ***P*** **(Watt=Joule/s)** generated by the battery depends on the **decay energy** ***Q*** and the **activity** ***A*** of the radioactive fuel at any given time ***t***:

$$P = Q \cdot A = Q \cdot \lambda \cdot N(t) = Q \cdot \frac{N(t)}{\tau} = Q \cdot \frac{N_0 \cdot e^{-\lambda \cdot t}}{\tau}$$

Example: energy release ^3H: ***Q***=5.7 keV, ^{63}Ni: ***Q*** = 66.9 keV, ^{210}Po: ***Q*** = 5304 keV.

$$A = \frac{P}{Q} \qquad 1eV = 1.6022 \cdot 10^{-19} J$$

Example: activity of a 12W battery ^3H: ***A***=$1.3 \cdot 10^{16}$Bq, ^{63}Ni: ***A***=$1.1 \cdot 10^{15}$Bq, ^{210}Po: ***A***=$1.4 \cdot 10^{13}$Bq. The use is pretty much restricted to micro-batteries with nano-Watt or micro-Watt power output with Giga- to Mega-Becquerel activities (Micro-electronic-mechanical systems MEMS)

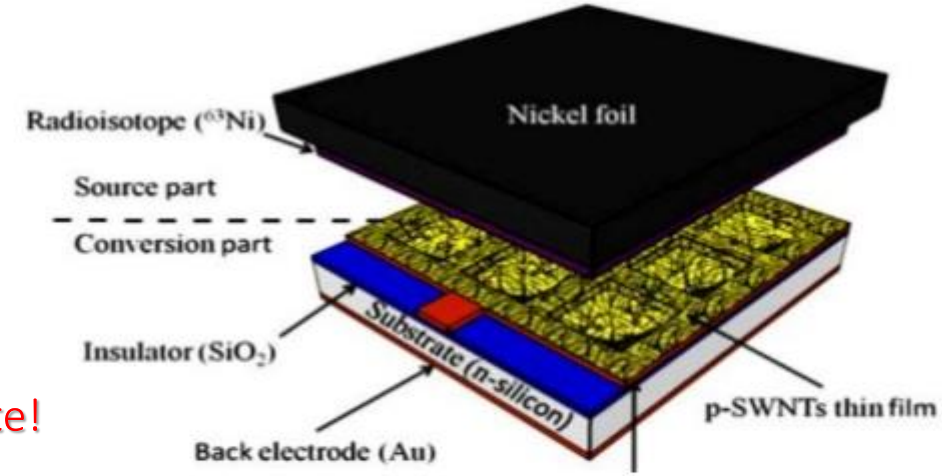
Beta-voltaics

Micro-batteries use electric diode techniques to convert the nuclear decay energy into electrical energies for micro-electronic devices. Small scale nuclear batteries expand the longevity compared to micro-batteries based on electro-chemical processes. Batteries powered by nuclear decay have a lifespan of decades and are up to 200 times more efficient

β articles (electrons) from decay of a radioactive sample generate electron-hole pair in semi-conductor material generating voltage between the electrodes.

Radioactive samples should be free from γ radiation to avoid external activity.

Used up-batteries are considered nuclear waste!



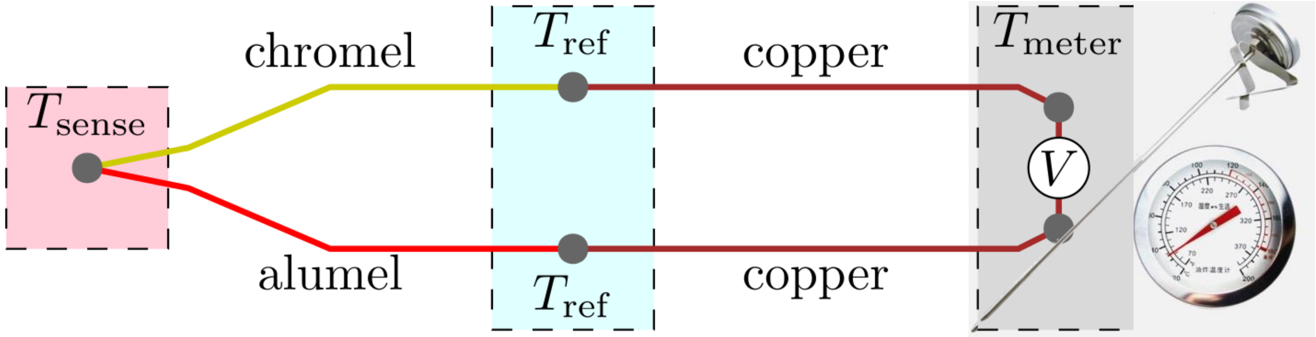
Applications for electronic units in long-term space missions, nuclear powered pacemakers. The nuclear-powered laptop battery Xcell-N has a 150-day life-time!

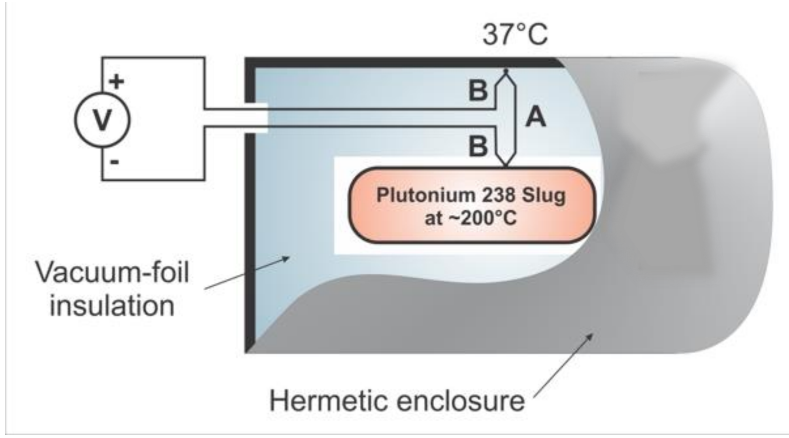
Future Applications: car batteries, deep-sea water probes, and long-term sensors

Radioisotope Thermoelectric Generator (RTG)

A RTG is an instrument that uses an array of thermocouples to convert the heat released by the decay of a suitable radioactive material into electrical voltage.

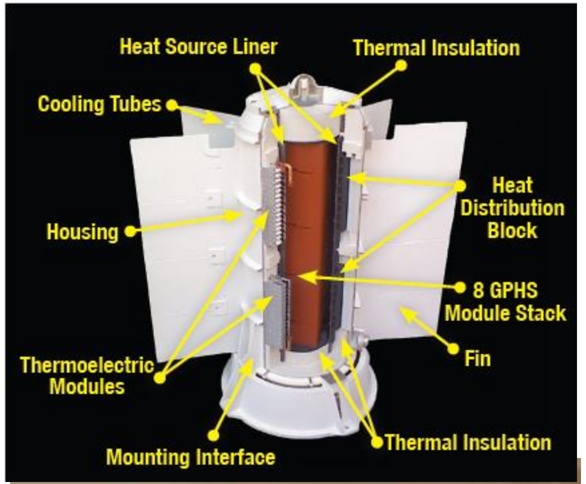
Thermocouples consist of two wire legs made from different metals. The wires legs are welded together at one end, creating a junction. This junction is where the temperature is measured. When the junction experiences a change in temperature, a voltage is created that generates an electrical current.

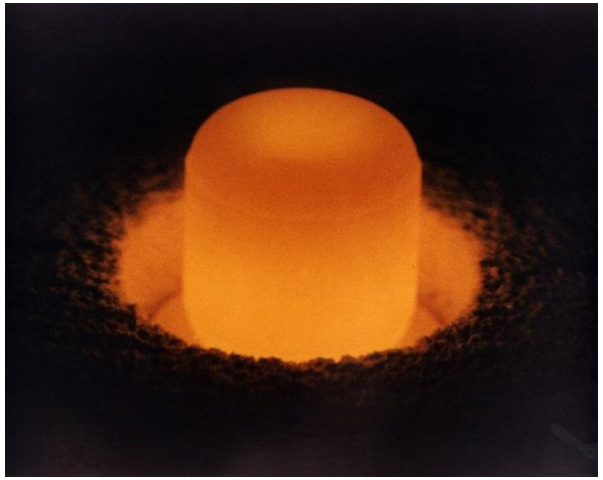




Space craft applications

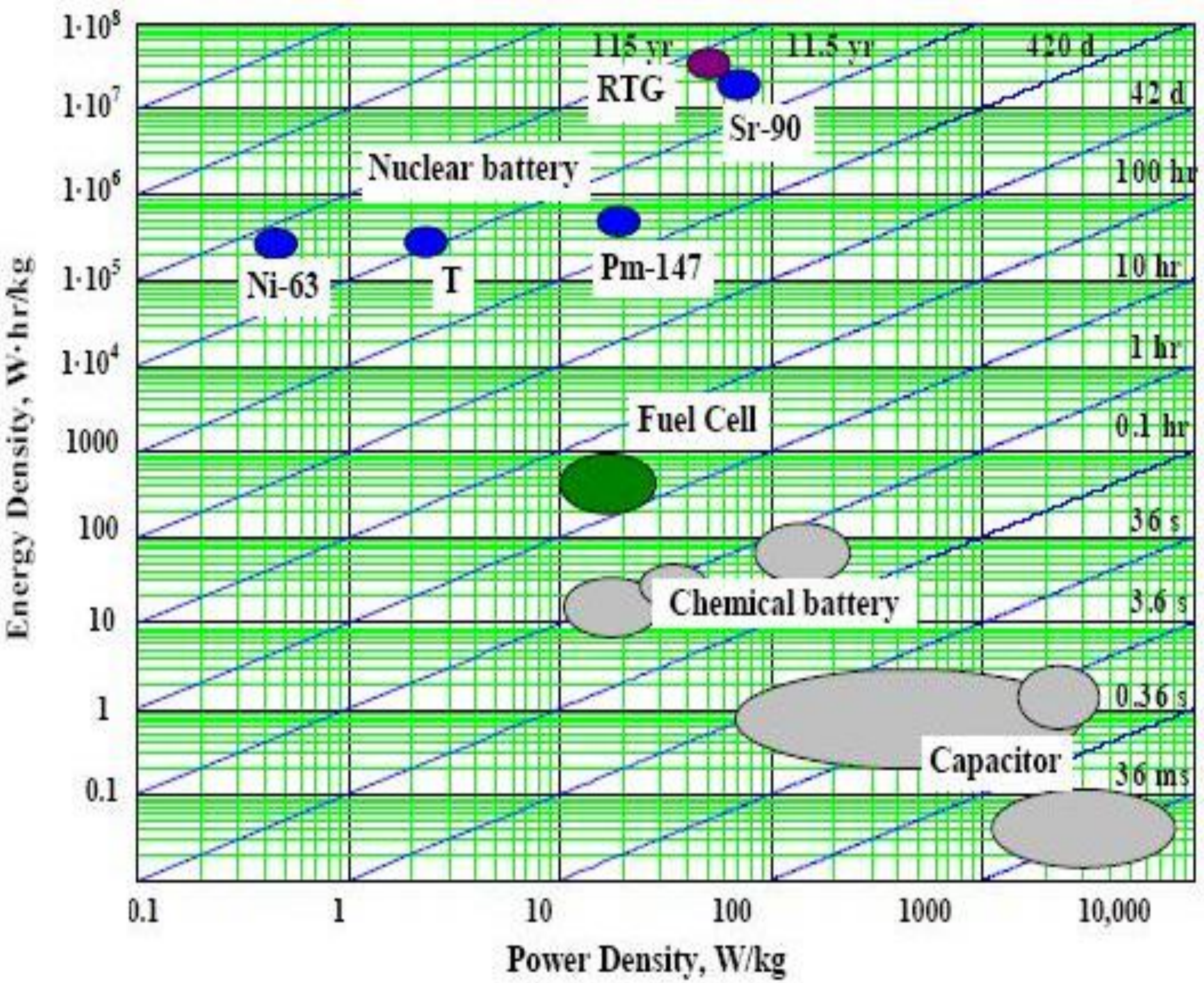
The Multi-Mission RTG (MMRTG) contains a total of **10.6 pounds (4.8 kilograms) of plutonium dioxide** (including Pu-238) that initially provides approximately 2,000 watts of thermal power and 110 watts of electrical power when exposed to deep space environments. The thermoelectric materials (PbSnTe, TAGS, and PbTe) have extended lifetime and performance capabilities. The MMRTG generator is about 25 inches (64 centimeters) in diameter (fin-tip to fin-tip) by 26 inches (66 centimeters) tall and weighs about 94 pounds (45 kilograms).





A plutonium oxide pellet ($^{238}Pu^{16}O_2$), glowing from its own heat, generated by the energy release of 5.6 MeV in the α decay. One-gram ^{238}Pu generates thermal power of approximately 0.5 W.

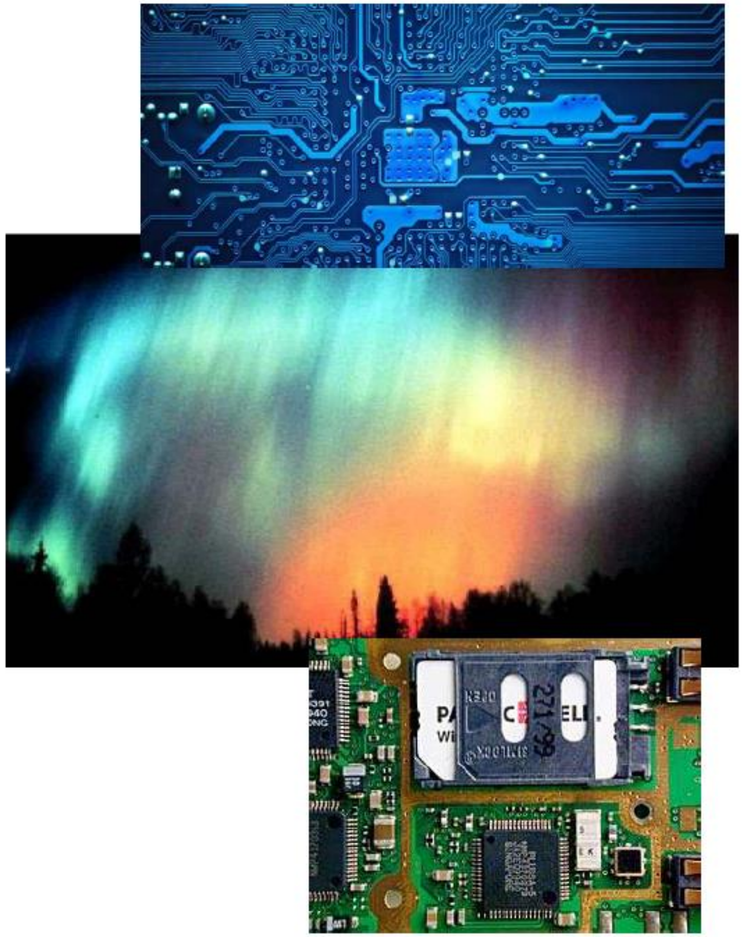
Nuclear battery efficiencies



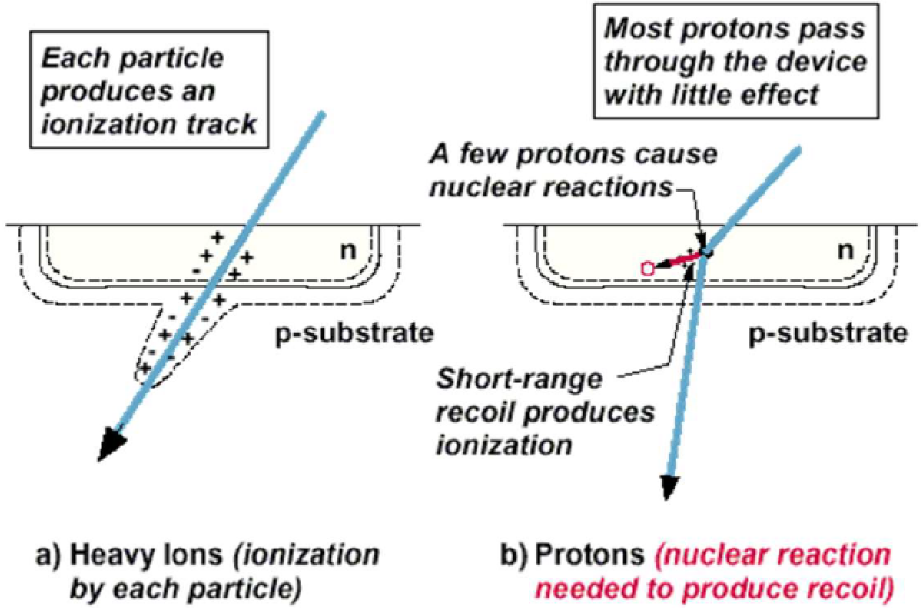
Radiation and microelectronics

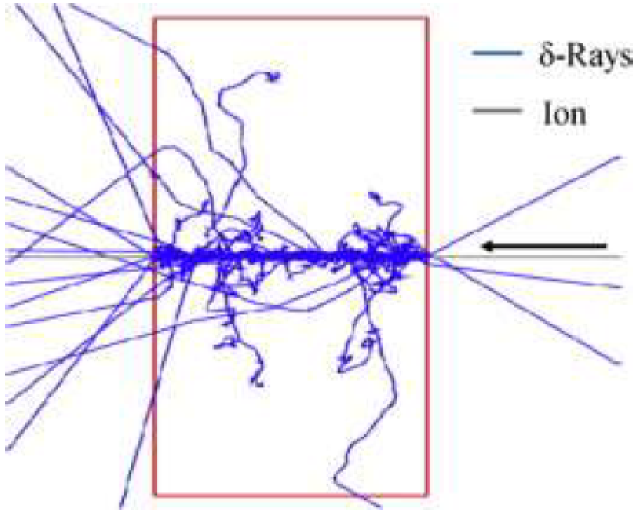
- Radiation damage on chips and/or micro-electronics in integrated circuits
- Affects as Single Event Effect SEE
- Satellite and airplane control
- Computer and cell phone operation
- Remote and computer controlled car and other traffic units

Everything is computer controlled. Through the miniaturization of electronics, everything is vulnerable!



Single Event Effect, SEE





SEE effects are statistical; damage and response of an electronic unit are difficult to predict, because of the complexity of damage. But the higher radiation level, the higher the likelihood of electronic failure; space exploration units and airplane control electronic are particularly susceptible to damage due to the combination of high radiation environment and microelectronic complexity. But a single hit can also do substantial damage to ground-based electronic units, doing local damage in chip structure and performance, flipping bits, damaging memory and control.

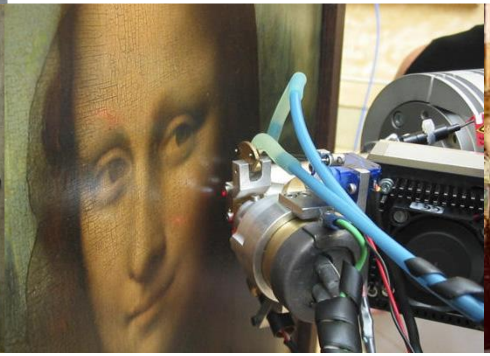
Endangered electronic systems

Malfunctions in integrated circuits (IC) due to radiation effects from high energy neutrons or alpha particles at ground level are now becoming a major concern; especially for life-critical and safety-critical applications such as aviation, industrial automation, medical devices, automotive electronics and for high-availability, revenue-critical applications such as communication infrastructure.

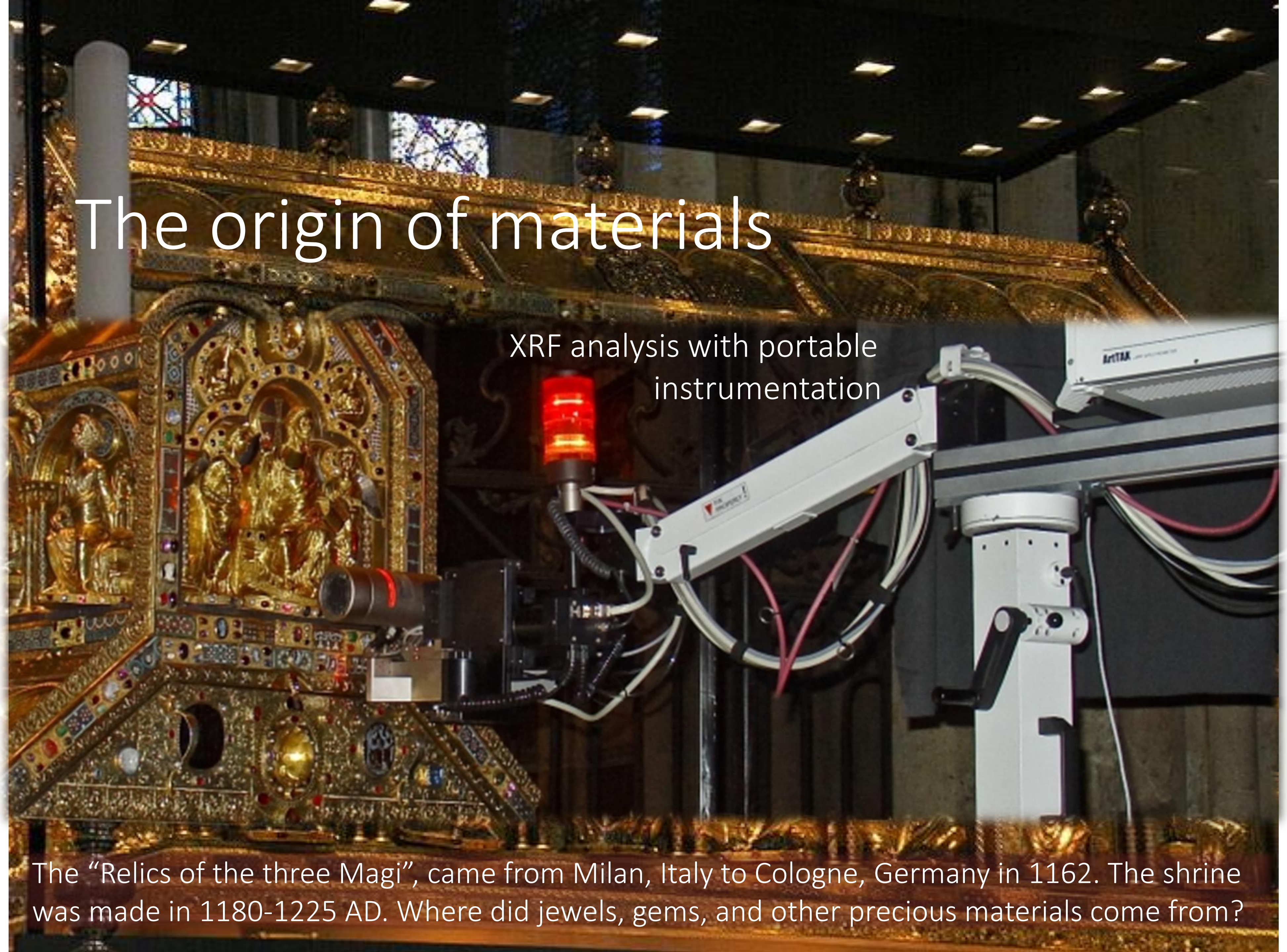
Modern Tools for Ancient Art

Modern art analysis techniques rely on the quantum nature of matter to determine providence, age, techniques, and forgeries.

The most frequently used methods are x-ray analysis such as PIXE and XRF, coupled with atomic analysis techniques such as Raman spectroscopy, and nuclear physics techniques such as Neutron activation analysis. This is complemented by radioactive dating taking the half-life as time scale.



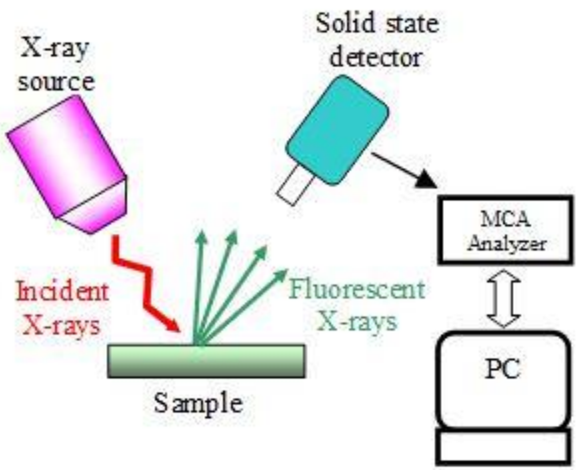
The origin of materials

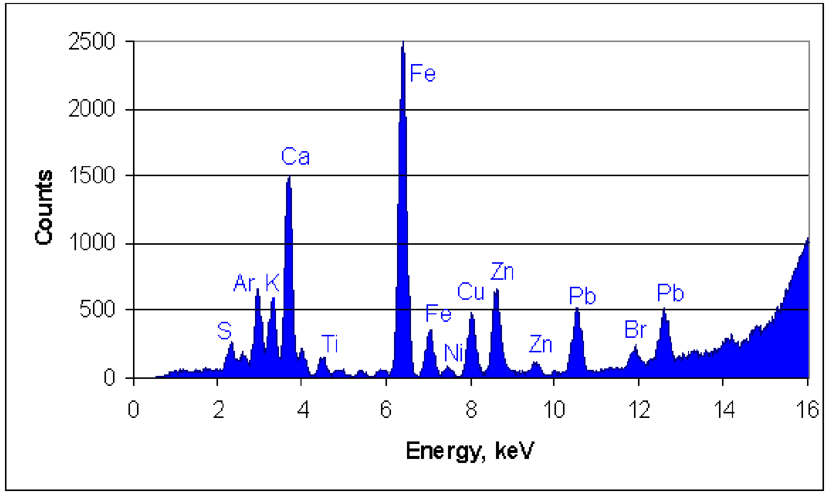


XRF analysis with portable instrumentation

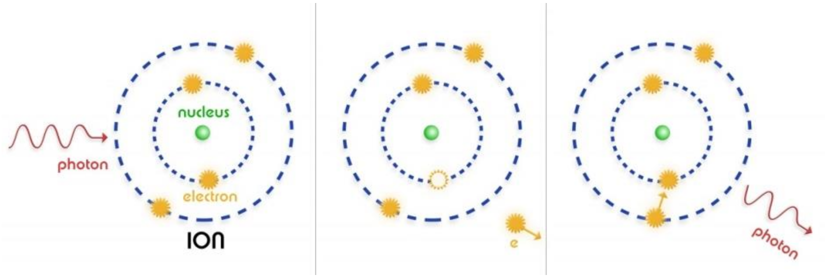
The “Relics of the three Magi”, came from Milan, Italy to Cologne, Germany in 1162. The shrine was made in 1180-1225 AD. Where did jewels, gems, and other precious materials come from?

X-ray Analysis by XRF and PIXE





Each element emits its own characteristic line due to the quantum transition of electrons to lower excited orbits in the atomic shell.



$$E_x = (Z-1)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right)$$

for S: $Z = 16;\ E_x = (15)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 2.29\,[eV]$

for Ca: $Z = 20;\ E_x = (19)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 3.68\,[eV]$

for Ti: $Z = 22;\ E_x = (21)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 4.50\,[eV]$

for Fe: $Z = 26;\ E_x = (25)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 6.37\,[eV]$

for Zn: $Z = 30;\ E_x = (29)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 8.58\,[eV]$

Analysis of paint pigments

Pre 1800 oil paintings contained specific pigments prepared from naturally available materials to achieve color effects. After 1850 these pigments were gradually replaced by organic (Carbon based) pigments provided by the chemical industry.

White pigments

Antimony white	Sb_2O_3
Lithopone	$ZnO + BaSO_4$
Permanent white	$BaSO_4$
Titanium white	TiO_2
White lead	$2PbCO_3 \cdot Pb(OH)_2$
Zinc white	ZnO
Zirconium oxide	ZrO_2
Chalk	$CaCO_3$
Gypsum	$CaSO_4 \cdot 2H_2O$

Yellow pigments

Auripigmentum	As_2S_3
Cadmium yellow	CdS
Chrome yellow	$2PbSO_4 \cdot PbCrO_4$
Cobalt yellow	$K_3[Co(NO_2)_6] \cdot 1.5H_2O$
Lead–tin yellow	$Pb_2SnO_4/PbSn_2SiO_7$
Massicot	PbO
Naples yellow	$Pb(SbO_3)_2/Pb_3(SbO_4)_2$
Strontium yellow	$SrCrO_4$
Titanium yellow	$NiO \cdot Sb_2O_3 \cdot 20TiO_2$
Yellow ochre	$Fe_2O_3 \cdot nH_2O$ (20–70%)
Zinc yellow	$K_2O \cdot 4ZnO \cdot 4CrO_3 \cdot 3H_2O$

Red pigments

Cadmium red	$CdS + CdSe$
Cadmium vermilion	$CdS + HgS$
Chrome red	$PbO \cdot PbCrO_4$
Molybdate red	$7PbCrO_4 \cdot 2PbSO_4 \cdot PbMoO_4$
Realgar	As_2S_3
Red lead	Pb_3O_4
Red ochre	Fe_2O_3 (up to 90%)
Vermilion	HgS

Green pigments

Basic copper sulfate	$Cu_x(SO_4)_y(OH)_z$
Chromium oxide	Cr_2O_3
Chrysocolla	$CuSiO_3 \cdot nH_2O$
Cobalt green	$CoO \cdot 5ZnO$
Emerald green	$Cu(CH_3COO)_2 \cdot 3Cu(AsO_2)_2$
Guignent green	$Cr_2O_3 \cdot nH_2O + H_3BO_3$
Malachite	$CuCO_3 \cdot Cu(OH)_2$
Verdigris	$Cu(CH_3COO)_2 \cdot nCu(OH)_2$

Blue pigments

Azurite	$2CuCO_3 \cdot Cu(OH)_2$
Cerulean blue	$CoO \cdot nSnO_2$
Cobalt blue	$CoO \cdot Al_2O_3$
Cobalt violet	$Co_3(PO_4)_2$
Egyptian blue	$CaO \cdot CuO \cdot 4SiO_2$
Manganese blue	$BaSO_4 \cdot Ba_3(MnO_4)_2$
Prussian blue	$Fe_4[Fe(CN)_6]_3$
Smalt	Co-glass ($K_2O + SiO_2 + CoO$)
Ultramarine	$Na_{8-10}Al_6Si_6O_{24}S_{2-4}$

Black pigments

Antimony black	Sb_2O_3
Black iron oxide	$FeO \cdot Fe_2O_3$
Carbon or charcoal black	C (95%)
Cobalt black	CoO
Ivory black	$C + Ca_3(PO_4)_2$
Manganese oxide	$Mno + Mn_2O_3$

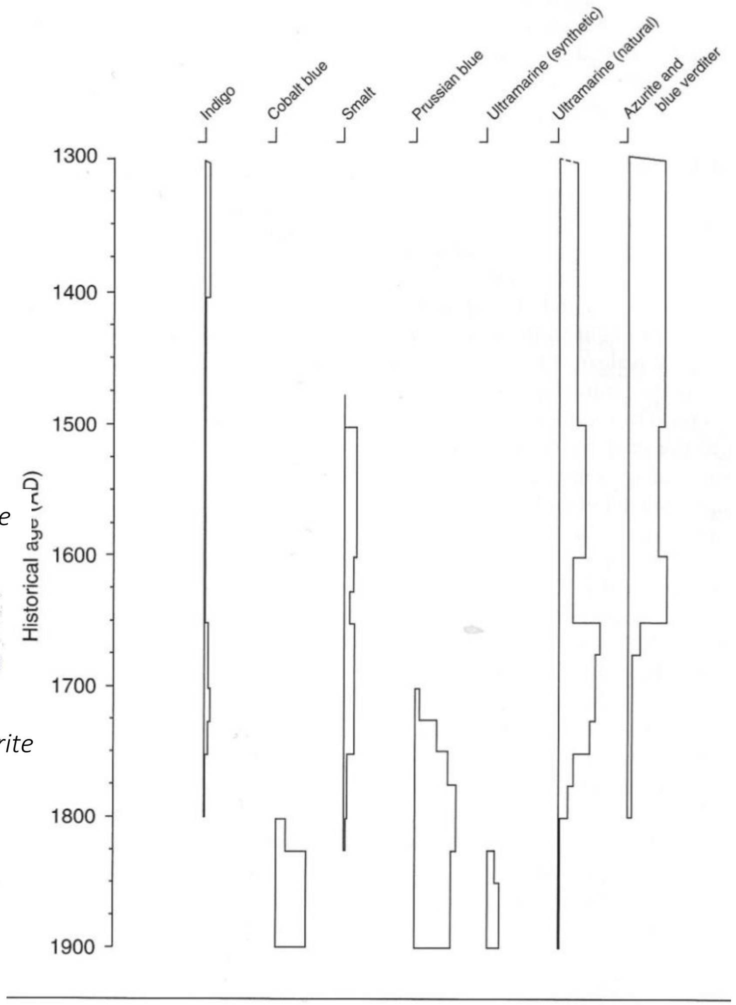
Pigments available until 1800 AD

Paint is composed of a colored pigment and a binder substance

Pigment: colored powdered substance grinded from minerals salts, or dyes

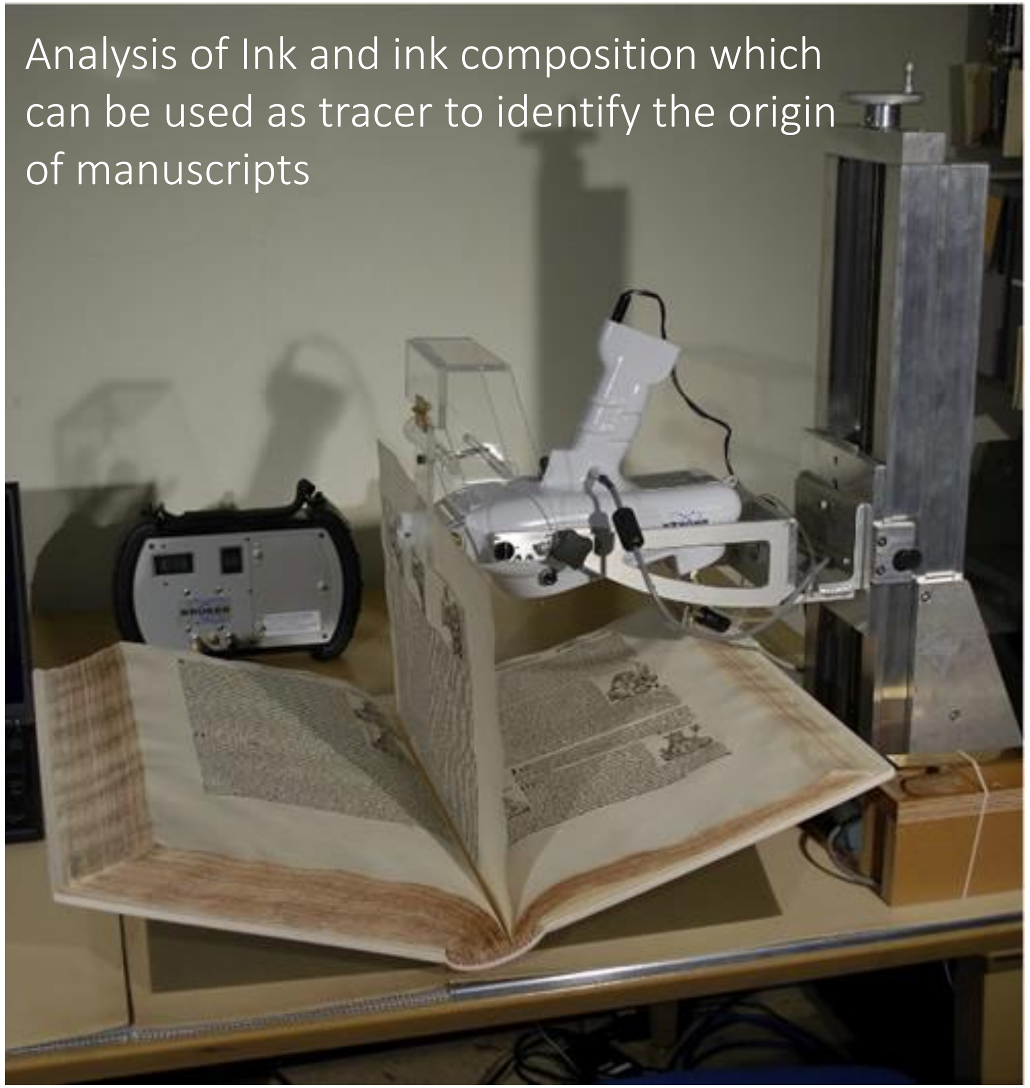
Binder: Material that evenly disperses the pigment, adheres to surface when paint applied and then dries.

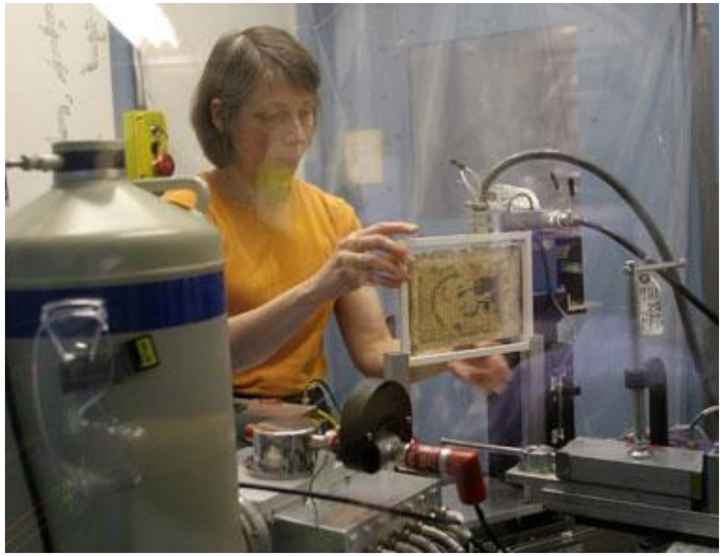
Paints are throughout uniform homogeneous mixtures.



X-Ray Fluorescence of Manuscripts

Analysis of Ink and ink composition which can be used as tracer to identify the origin of manuscripts

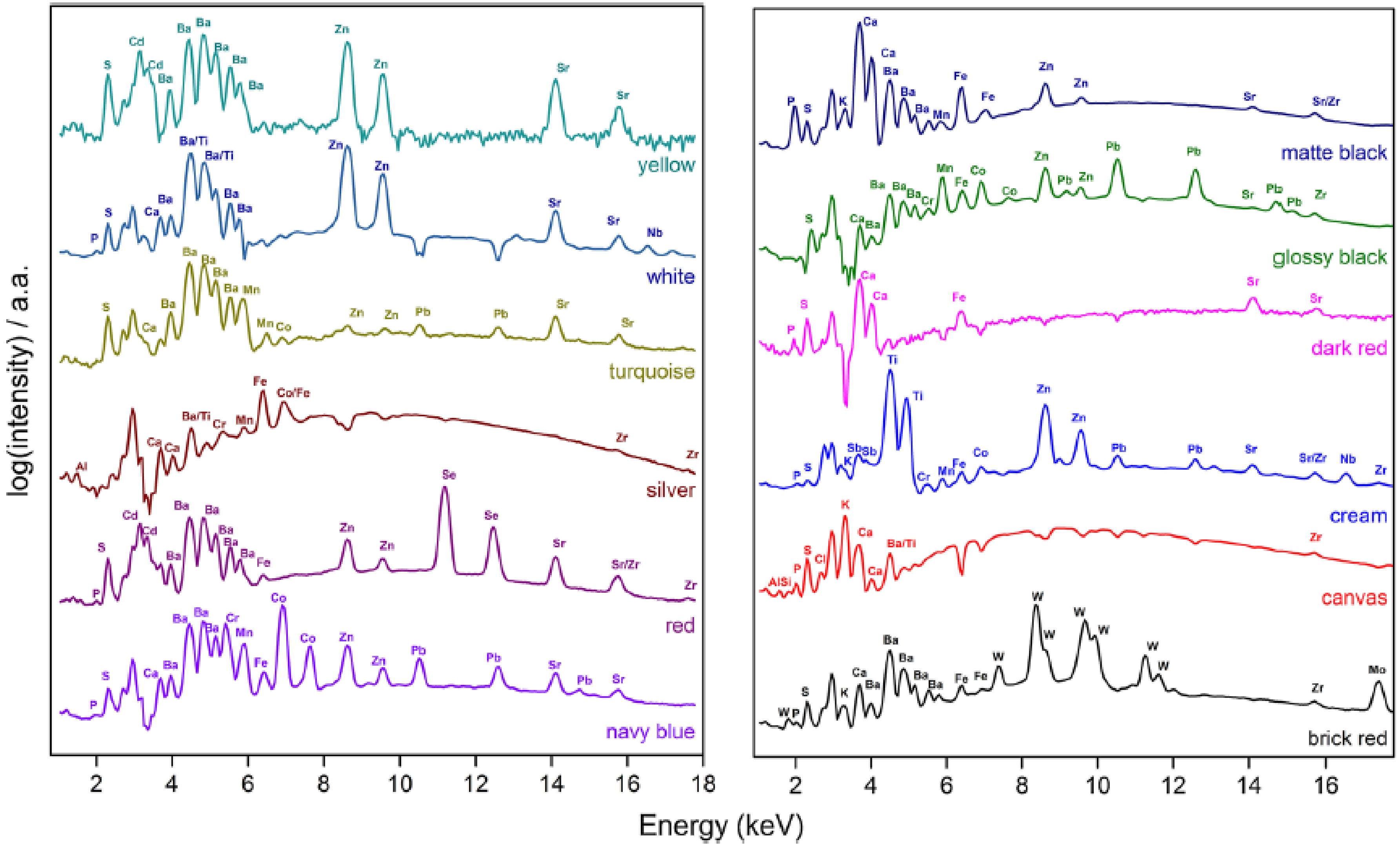




Painting techniques on the example of Pollock

Jackson Pollock’s Number 1A (1948)

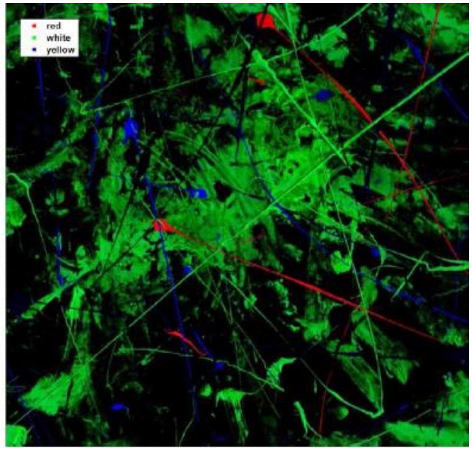
XRF spectra for different color combinations



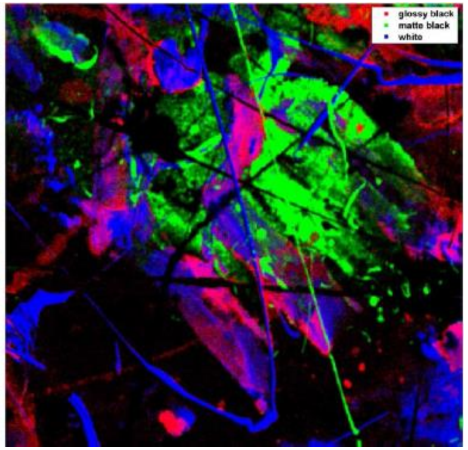
Signature spectra for the twelve components (11 paints and canvas) identifying the characteristic x-ray *lines* for the elements present.

XRF analysis of use of overlaying colors

Overlapped distribution maps of the *white*, *red* and *yellow* paints for area (1) and image of that area. The sequence in which they were applied can be established by examining how the paints overlap: *white*, *red*, *yellow* and *white* again.



Overlapped distribution maps of the *white*, *glossy* and *matte black* paints for a section in area (1) showing that the gray paint was made by mixing the *white* paint and the *black glossy* paint and not the *matte black*



Pollock mostly applied each paint straight out of the tube or can, and with a specific gesture, brushstroke (matte black and white), dripping (cream, glossy black and silver gray), thrusting (turquoise, matte black and white), squeezing the tube (red and yellow) or splattering (cream and silver gray), and using a specific tool, brush or stick. Some of the paints were applied wet on wet like the thinner cream and glossy black house paints creating a marbling look by overlapping the corresponding distribution maps for the area . He used his hands to apply the red brick and matte black paints leaving clear handprints, or creating large stains by dragging his hands or pressing his palms against the canvas.

Identification of Art Forgeries

Science techniques are an emerging tool for:

- Forgery analysis by nuclear forensic techniques in a competitive art market (Vermeer, Van Gogh, Modigliani, Rothko, etc)

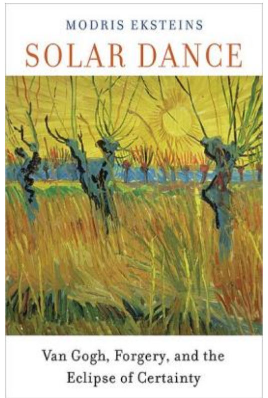
e.g. Vermeer forgeries by Hans van Meegeren

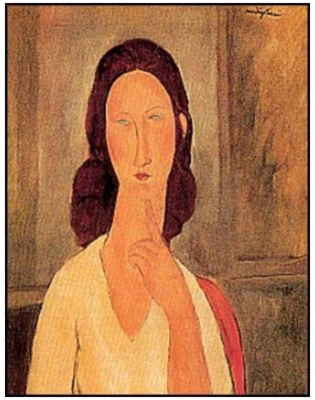
Van Gogh forgeries by Otto Wacker

>1000 Modigliani fakes by Elmyr de Hory

New York galleries sold Mark Rothko, Jackson Pollock and Willem de Kooning forgeries; damage unknown

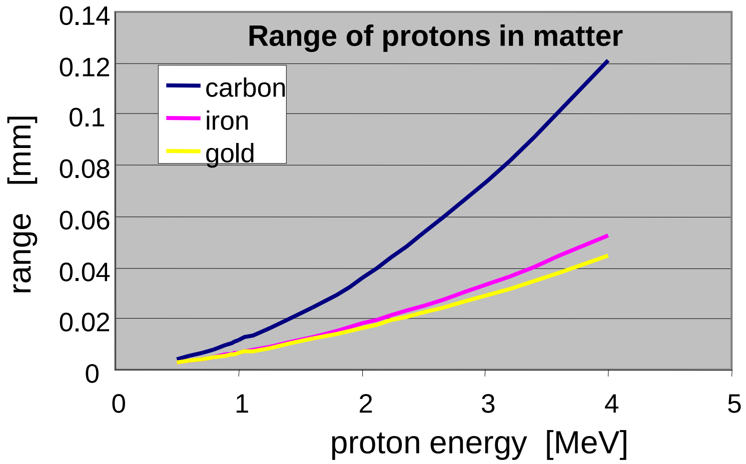
Recent forgeries by Wolfgang Beltracchi of German expressionists such as Heinrich Campendonk and Max Ernst caused a major art scandal in Europe.





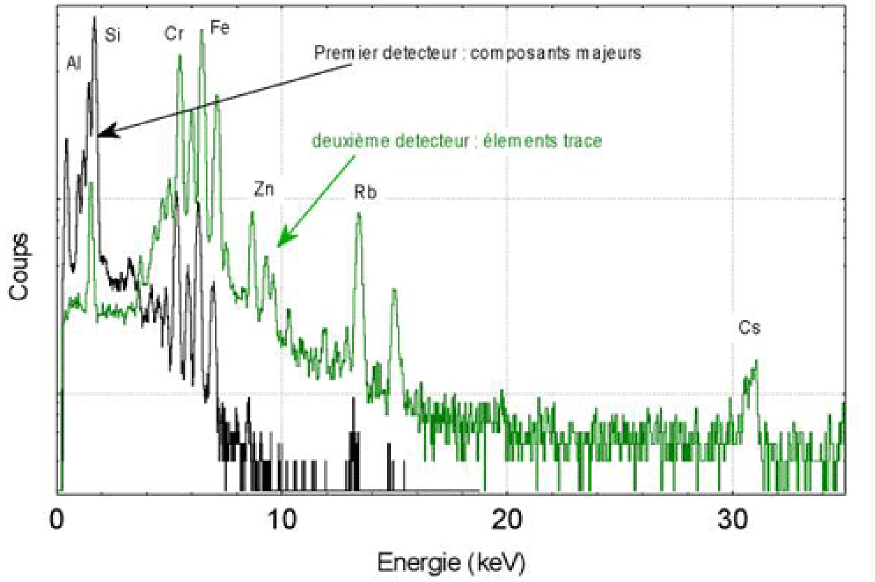
Proton Induced X-ray Emission (PIXE)

Accelerated particles like protons penetrate deeper into material, which reduces distorting surface effects that handicap XRF analysis. Depending on energy the composition of deeper material layers can be explored. That provides an additional insight in chemical decomposition processes important for restoration procedures.



Tracing Material Origins

The red stone eyes of the statue of the Parthian goddess of love Ishtar were originally thought by Louvre curators to be made of colored glass



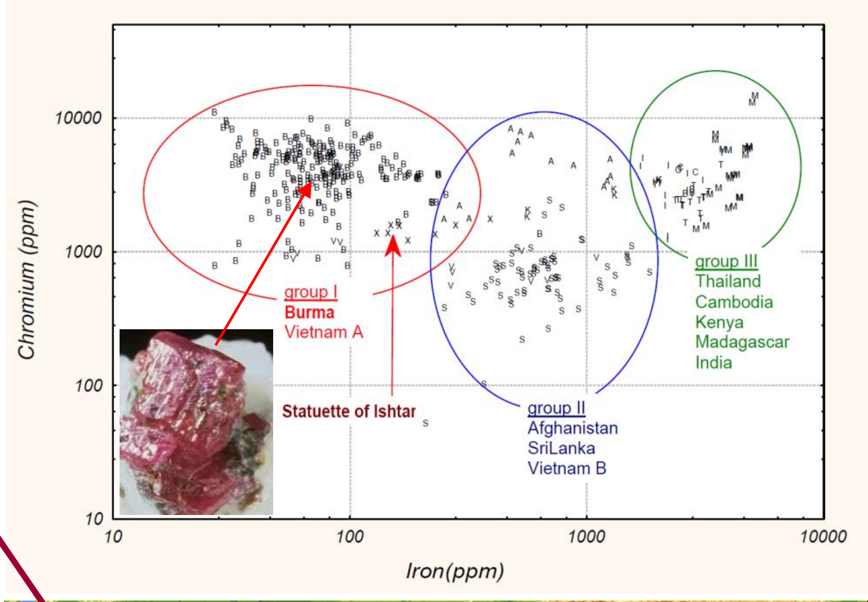
PIXE analysis showed that the inlays were rubies. AL_2 SIO_4 $(F,OH)_2$+(Cr,Fe rich)

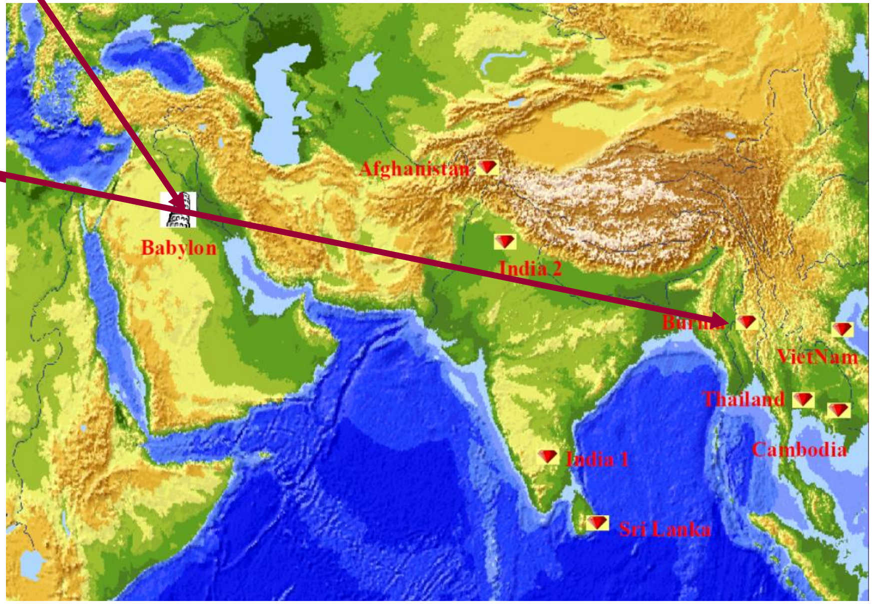
T. Calligaro et al. Nucl. Instr. Meth. B 136 (1998) 846-850

Provenance, or where did the rubies come from?

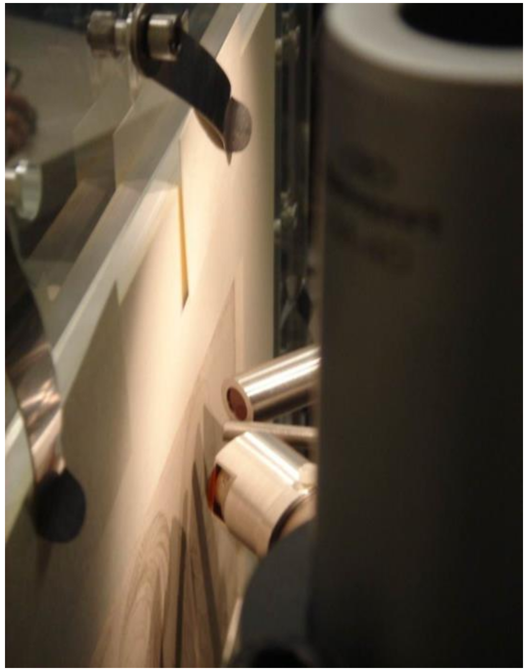
The trace element content provides the fingerprint of provenance in archaeology

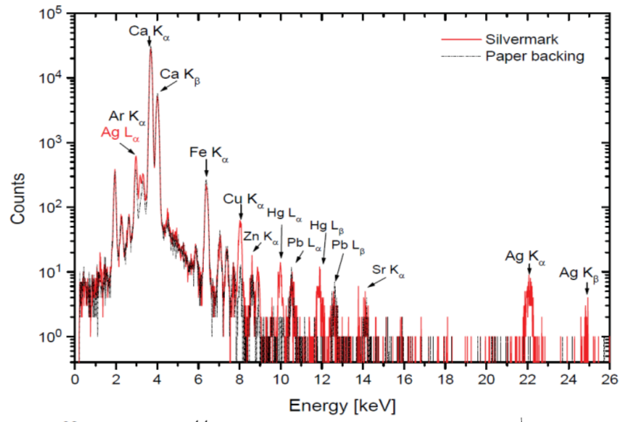
Comparison of Fe versus Cr content in the Ishtar rubies found in Mesopotamia with rubies from various provenances shows strong indication that rubies did originate from Burma. Ancient trade connections (silk road) between near and far east empires!

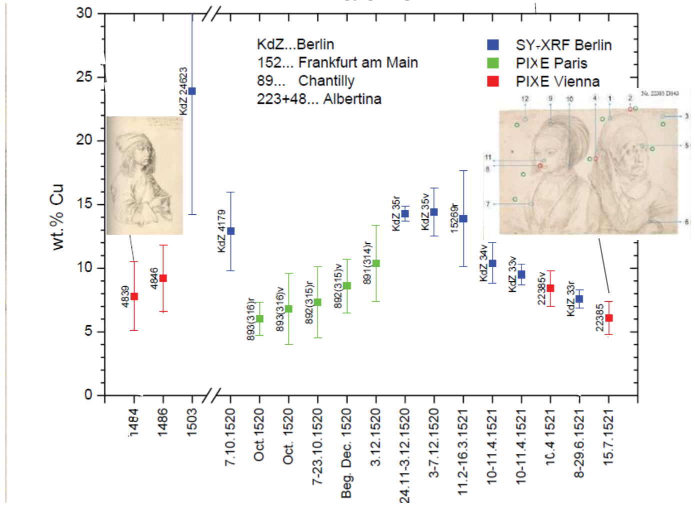


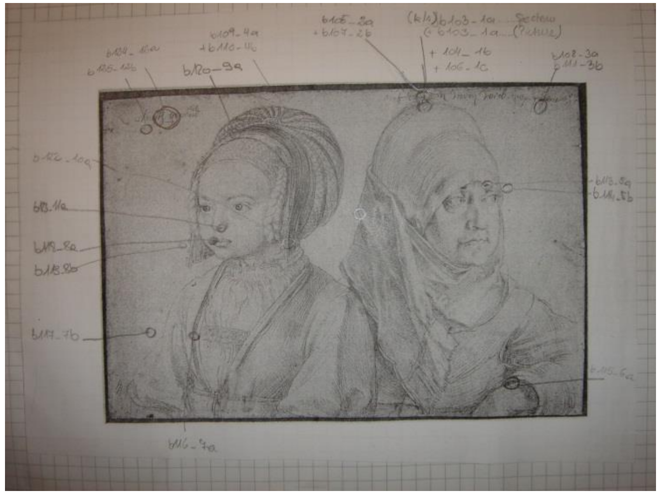


PIXE and Dürer travels





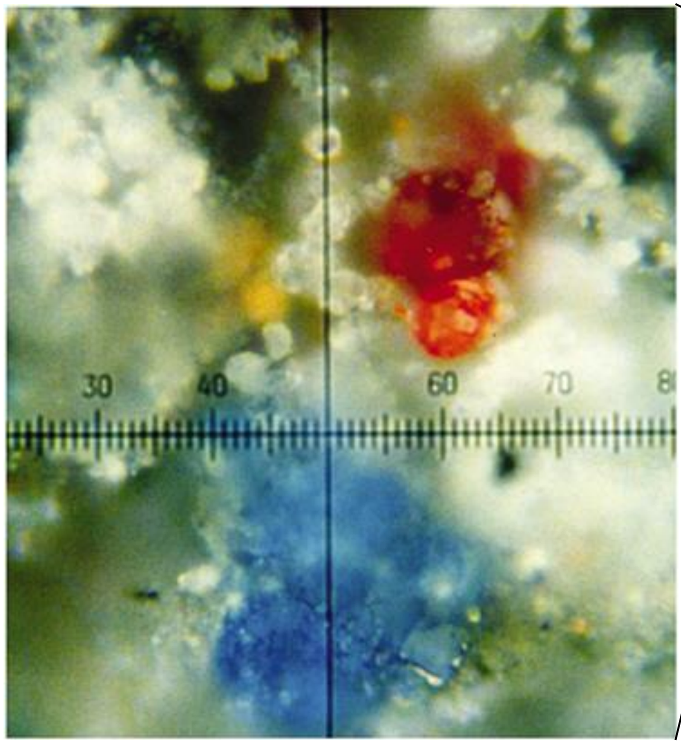


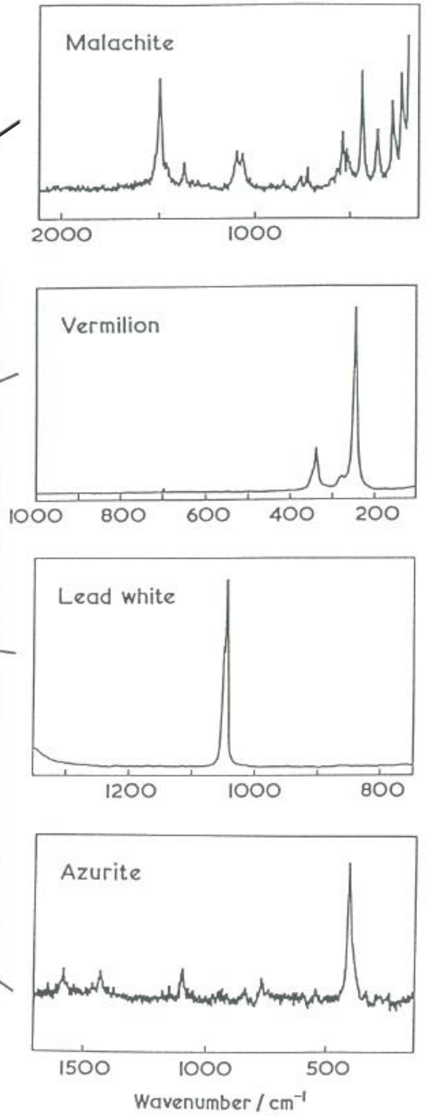


Albrecht Dürer silverpoint drawings

Testing ink pigments of medieval monastery handwriting of letter ℜ

Lead white: k=1050 cm^{-1} ($PbCO_3$)
Malachite: ($Cu^{2+}{}_2(CO_3)(OH)_2$)
Azurite: ($Cu^{2+}{}_3(CO_3)_2(OH)_2$)
Vermillion: k= 253 cm^{-1} 285 cm^{-1}, 343 cm^{-1} (HgS) (cinnabar)
Minium: k=226 cm^{-1}, 313 cm^{-1}, 390 cm^{-1}, 549 cm^{-1} (Pb_2O_3)



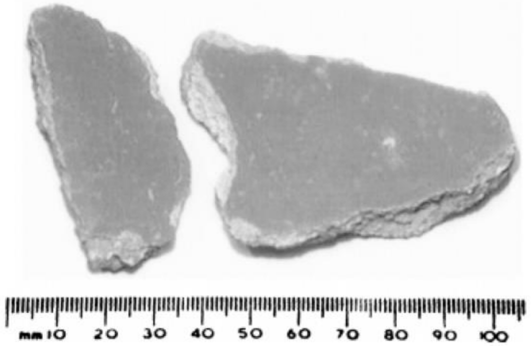


Best et al. Endeavour, New Series 16 (1992) 66-73

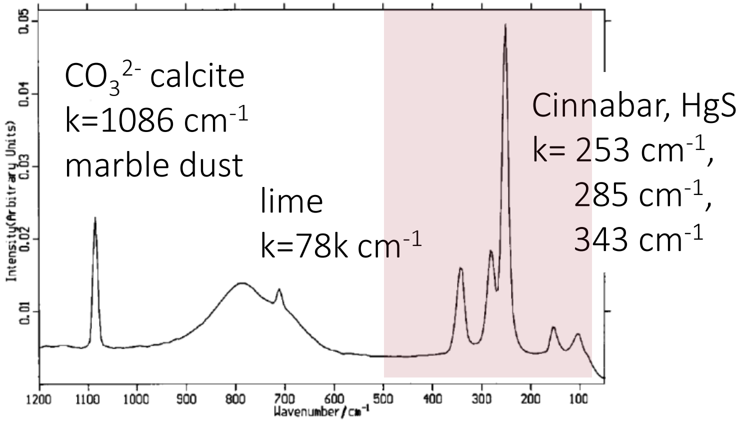
Frescoes in Herod’s Tomb in Jericho

Roman fresco technique: lime wash, followed by pigment application

Analysis of fragments with Raman spectroscopy

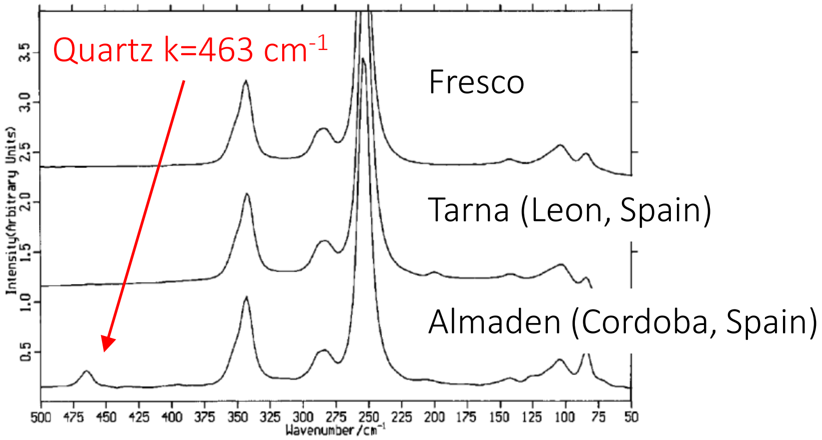


Cinnabar (Persian Dragon’s blood):
HgS (vermilion)



1064 nm excitation

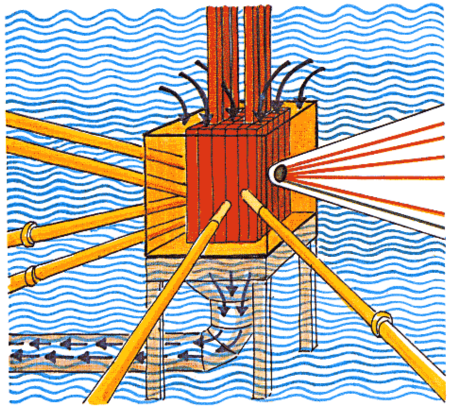
Provenance of HgS pigment
(Pliny & Vitruvius claim Spain)

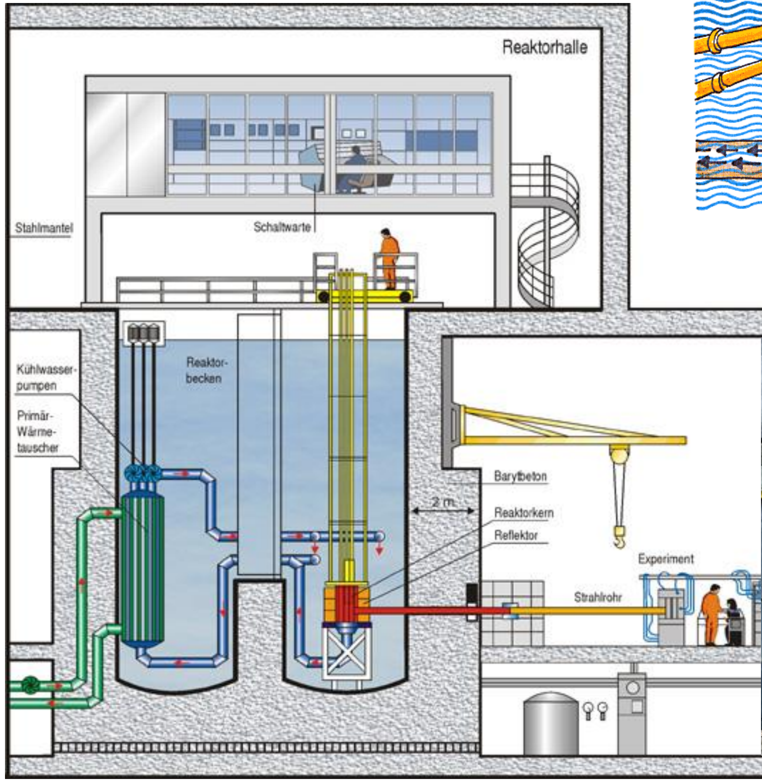


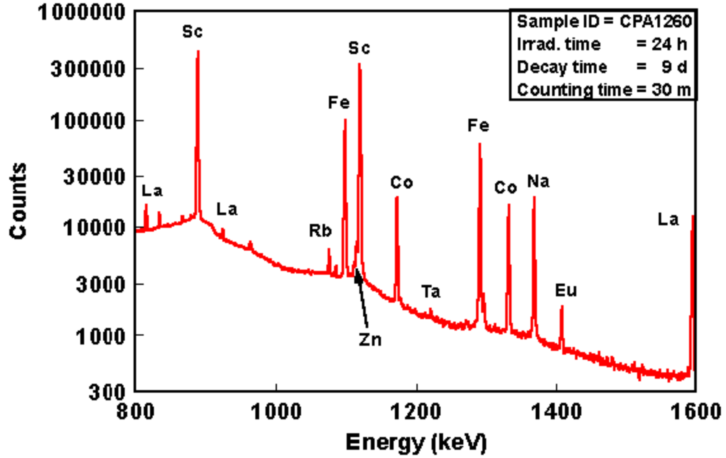
H. G. M. Edwards et al. J. Raman Spectrosc. 30 (1999) 361-377

Neutron Activation (NA)

Expose material to high neutron flux and add neutrons to nuclei to produce an radioactive isotope with subsequent analysis of its characteristic radioactive decay pattern.

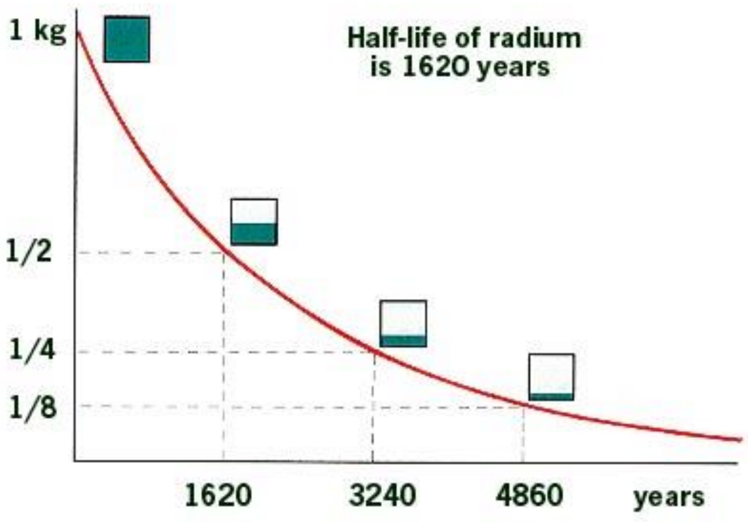






Timescale and Radiation Sensitivity

Signatures are either characteristic radiation or characteristic decay time, which is different for each radioactive isotope



Taking advantage of radioactive decay

Chemical element	Associated pigment	Radioactive isotope formed during activation and its half-life	Time period after activation during which best images in autoradiographs are produced
manganese	umber, dark ocher	Mn^{56}, 2.6 hours	0–24 hours
copper	malachite, azurite, verdigris	Cu^{66}, 5.1 minutes Cu^{64}, 12.8 hours	0–20 minutes 1–3 days
sodium	glue, medium, canvas, ultramarine	Na^{24}, 15.0 hours	1–3 days
arsenic	smalt, glass	As^{76}, 26.5 hours	2–8 days
phosphorus	bone black	P^{32}, 14.3 days	8–30 days
mercury	vermilion	Hg^{203}, 48 days	more than 25 days
cobalt	smalt, glass	Co^{60}, 5.3 years	more than 25 days

Table 1. Chemical elements and associated pigments most frequently observed in autoradiography of seventeenth-century Dutch and Flemish paintings.
The following pigments generally do not cause distinct images in autoradiographs: chalk, lead white, ocher, lead-tin yellow, lakes, madders, and indigo.

The Man with the Gold Helmet

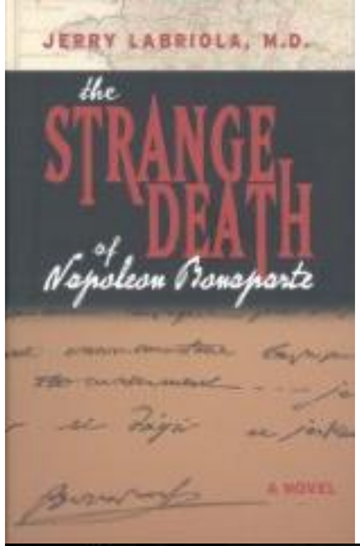
by Rembrandt van Rijn?

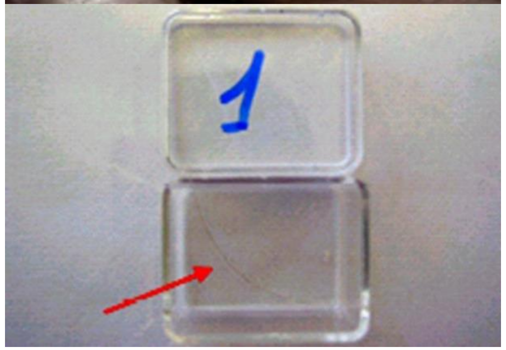
Was Napoleon murdered by the British?

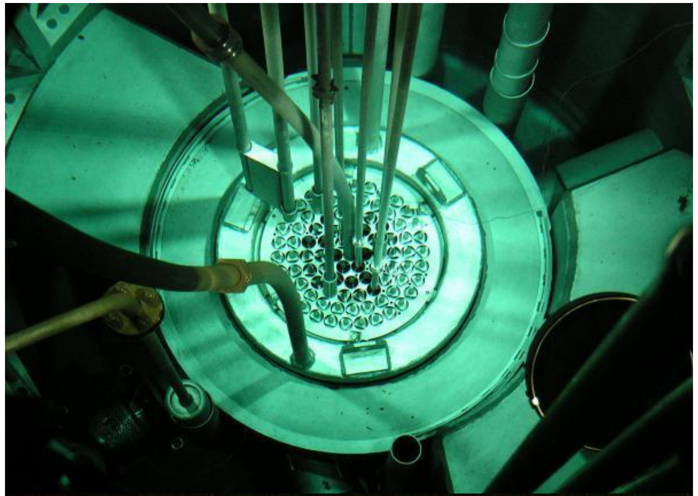
Neutron activation comes handy

Napoleon's Death,

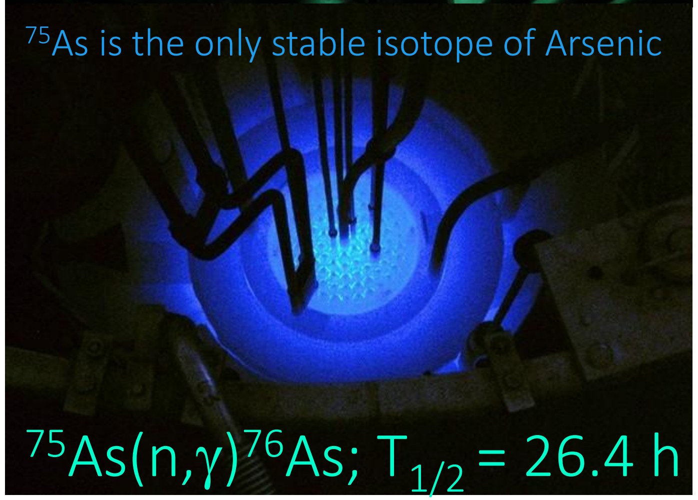
poisoned by Arsenic?????







^{75}As is the only stable isotope of Arsenic



$^{75}As(n,\gamma)^{76}As; T_{1/2} = 26.4$ h

The Emperor's hair had an average arsenic level of around 10-15 ppm, whereas the arsenic level in the hair samples from currently living persons is around 0.1 ppm. But surviving relatives had similar levels!

May 5 1821

Napoleon has declared in his will that 'I die before my time, murdered by the English oligarchy and its hired assassin'.

Stable Isotope Analysis (SIA),
the King of Stonehenge at 2300 BC

Chemophysical fractionation of isotopes cause local changes in abundance ratio.
Climate and rain pattern influence the ^{18}O to ^{16}O isotope ratio from sea to land.

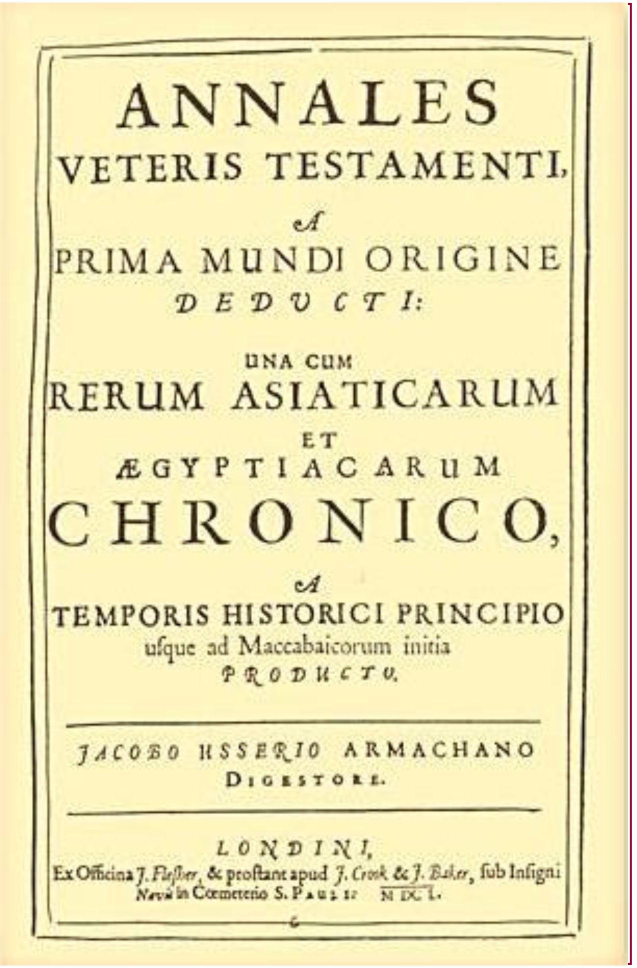
The Daily Express expressed the opinion
"This is as shocking as the discovery that the first cricket players wore leather pants and ate Bratwurst with their tea".

Archaeological Dating the past

"Everything which has come down to us from heathendom is wrapped in a thick fog; it belongs to a space of time we cannot measure. We know that it is older than Christendom, but whether by a couple of years or a couple of centuries, or even by more than a millennium, we can do no more than guess"

Rasmus Nyerup, 1802

Archaeological clocks



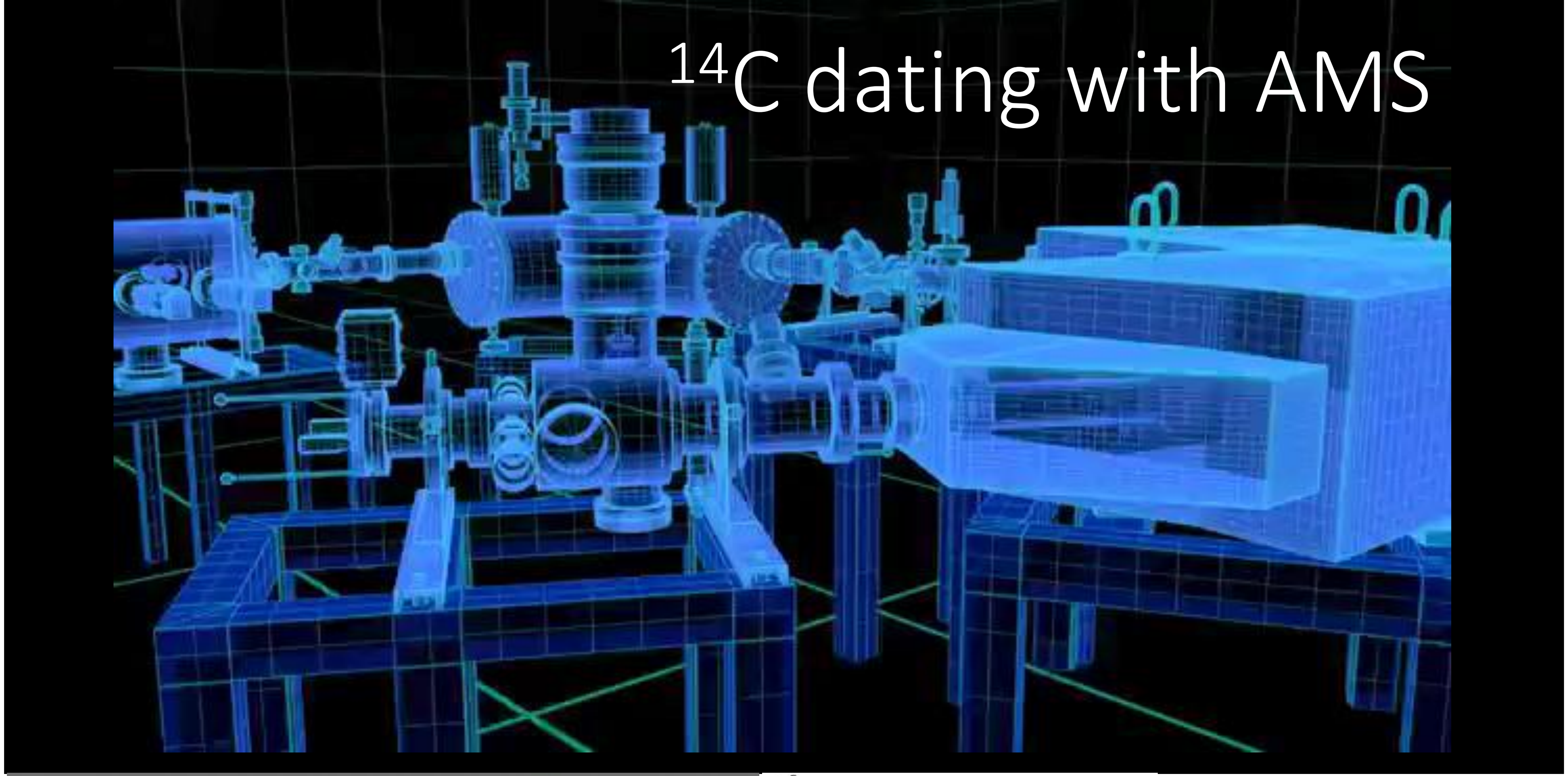
ANNALES
VETERIS TESTAMENTI,
A
PRIMA MUNDI ORIGINE
DEDUCTI:
UNA CUM
RERUM ASIATICARUM
ET
ÆGYPTIACARUM
CHRONICO,
A
TEMPORIS HISTORICI PRINCIPIO
usque ad Maccabaicorum initia
PRODUCTO.

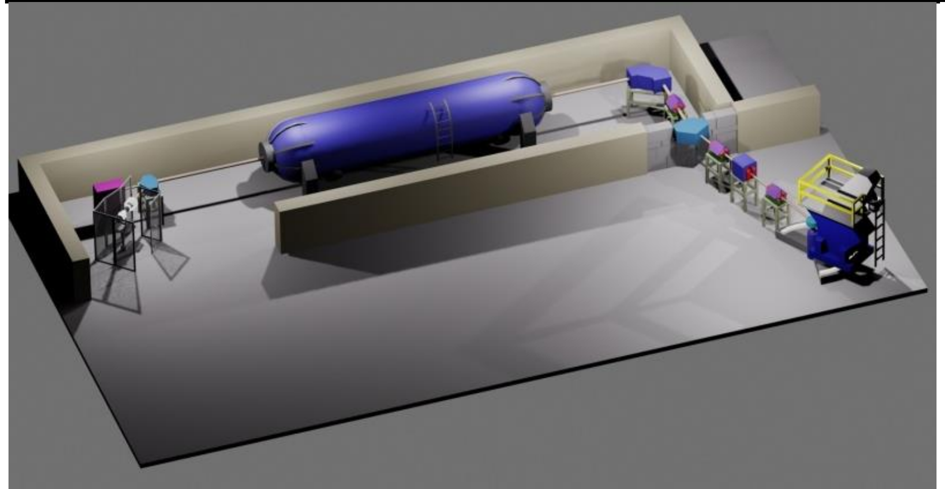
JACOBO USSERIO ARMACHANO
DIGESTORE.

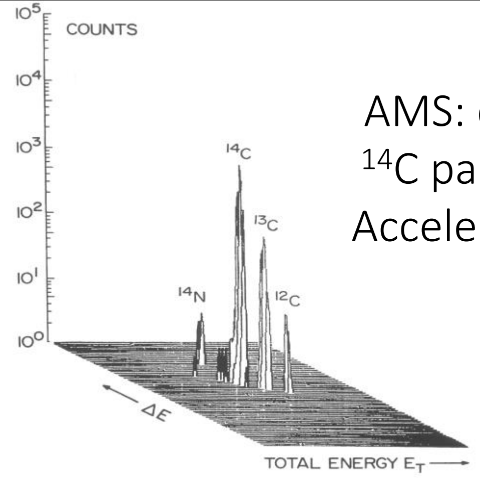
LONDINI,
Ex Officina J. Flesher, & prostant apud J. Crook & J. Baker, sub Insigni Navis in Cœmeterio S. Pauli. M DC L.

How to measure the time and age of things?

^{14}C dating with AMS



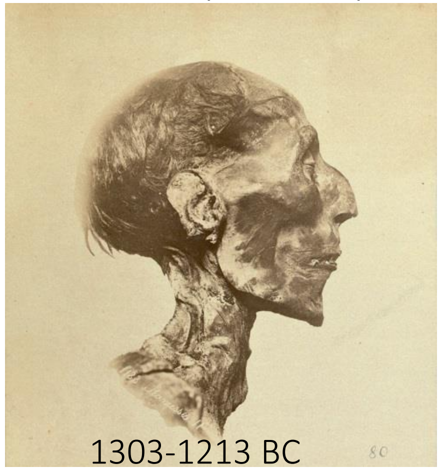


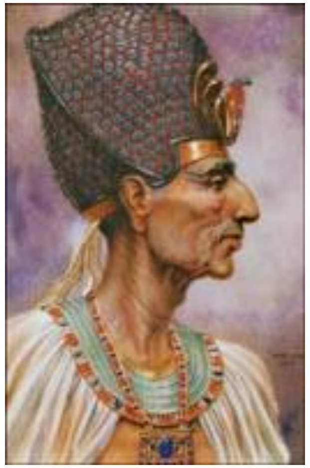


AMS: counting the radioactive ^{14}C particles with accelerators: Accelerator Mass Spectrometry

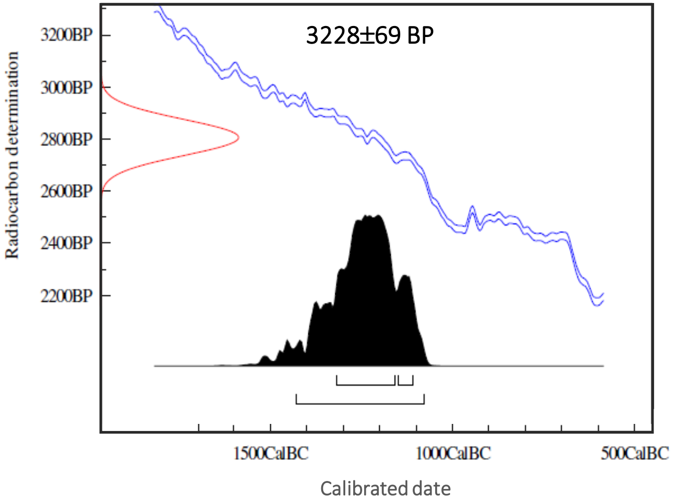
Dating Mummies

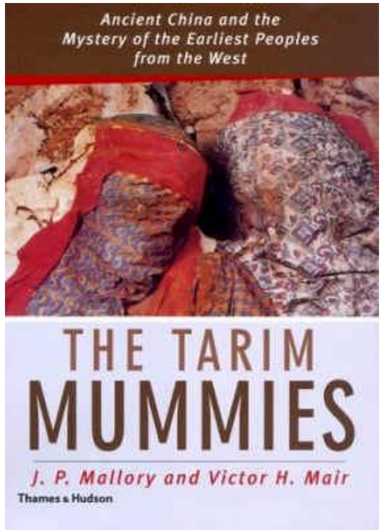
'My name is Ozymandias, king of kings:
Look on my works, ye Mighty, and despair!'

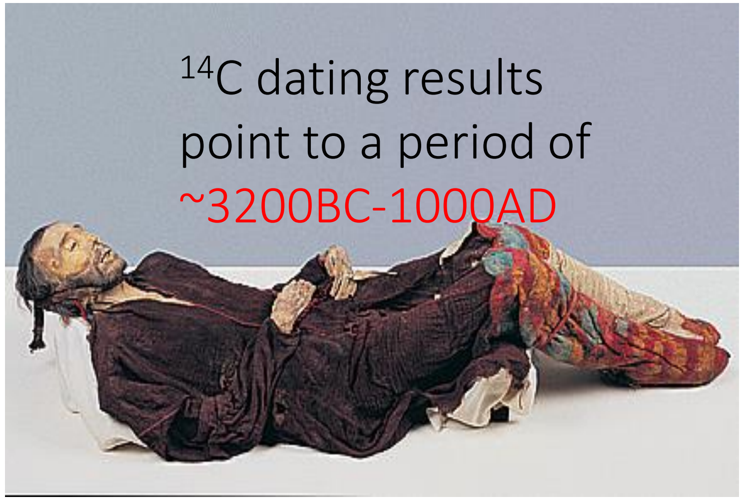




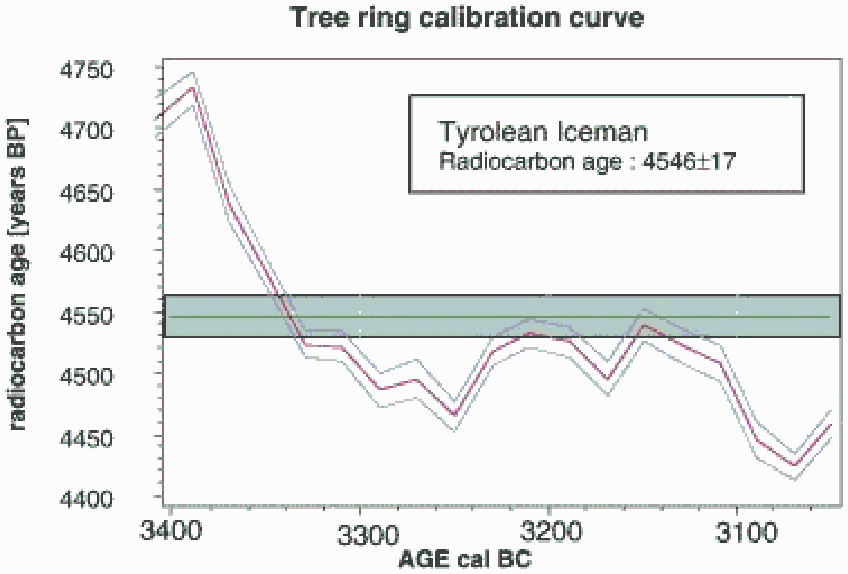
The mummy of Ramses II was one of the first samples tested by the new ^{14}C radiocarbon method to check the reliability of Egyptian dynasty counting versus biblical counting.

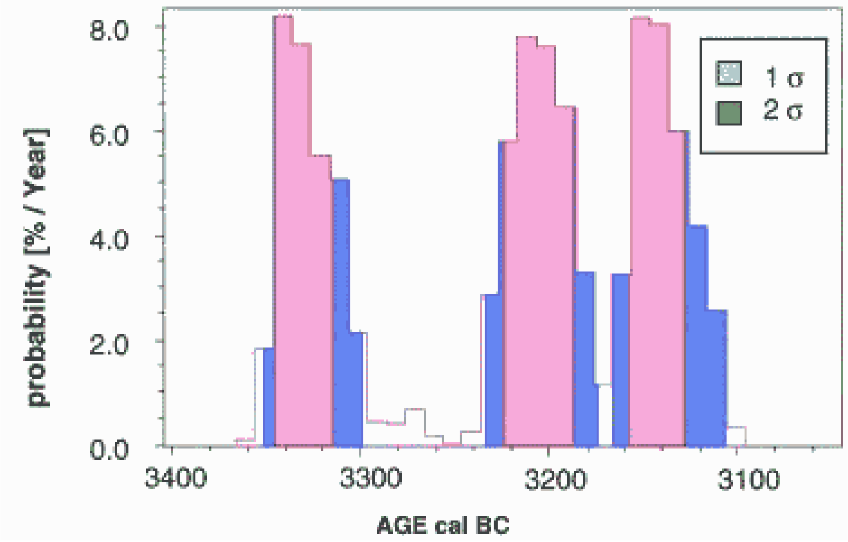




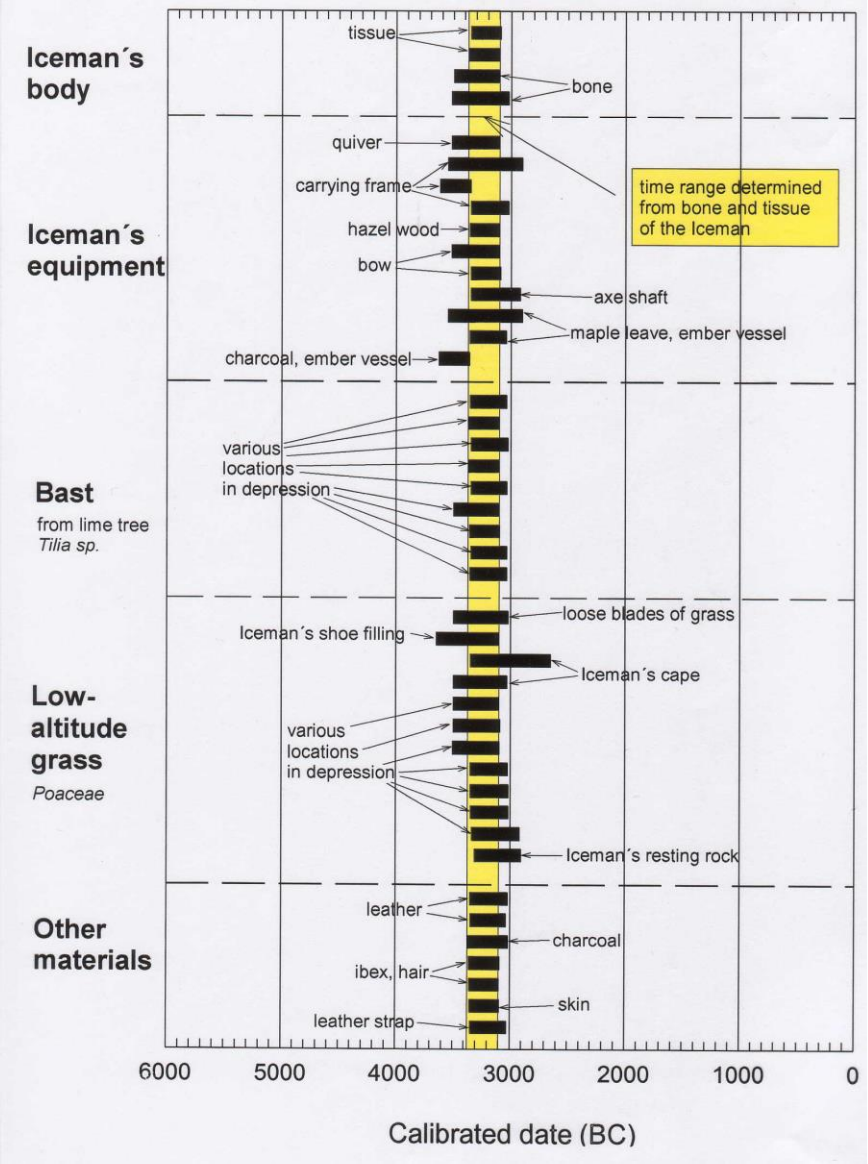


Conserved by ice - Oetzi, the iceman





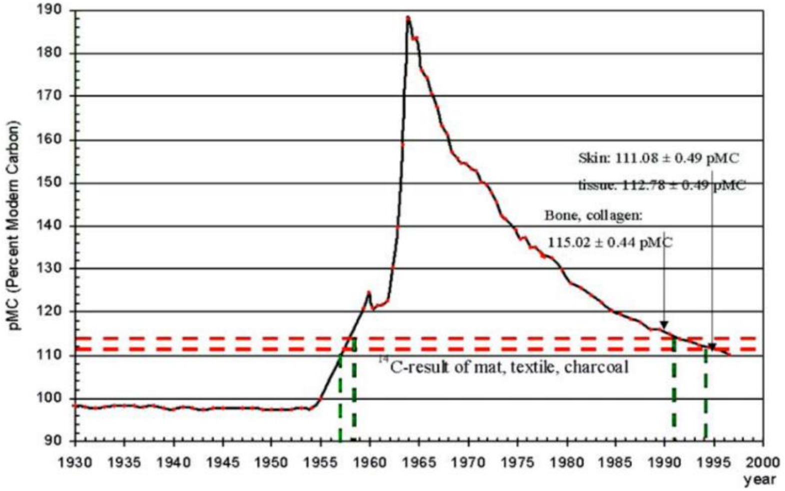
Murder 5000 years ago



The big business with (false) artifacts

Police raid of an art dealer in Karachi, Pakistan in October 2000 found a mummy, supposedly the daughter of Cyrus the Great (576-530 BC). The asking price of the dealer was US $ 11 Million.

Owner claims were filed by the governments of Pakistan, Iran, Afghanistan (Taliban).



AMS analysis determined a large ^{14}C amount in the mummy and dated her death to ~1993 !

Tracking
Illegal Ivory Trade

❖Increasing slaughter of elephants since 1970 with increased use of automatic weapons.

❖Ivory trade ban in 1989 to protect elephants from becoming extinct

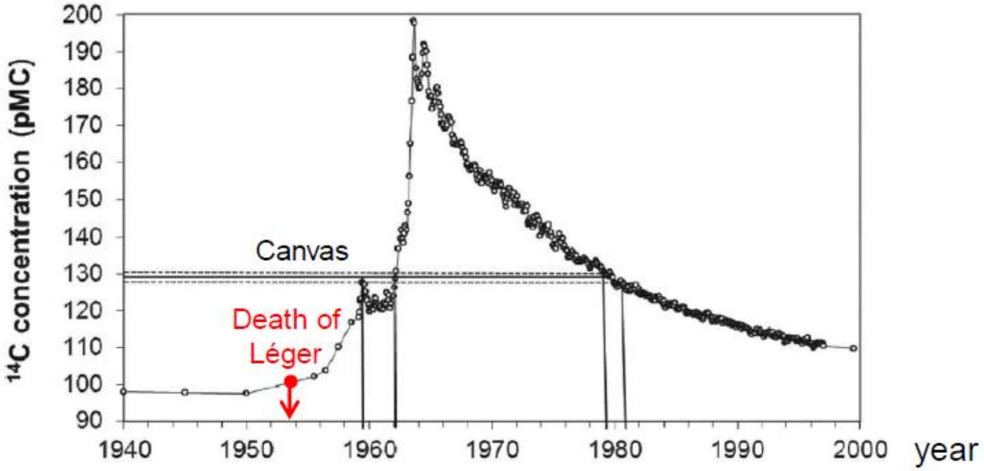
❖Growth in poaching and smuggle leading to local decline of elephant population as high as 90%

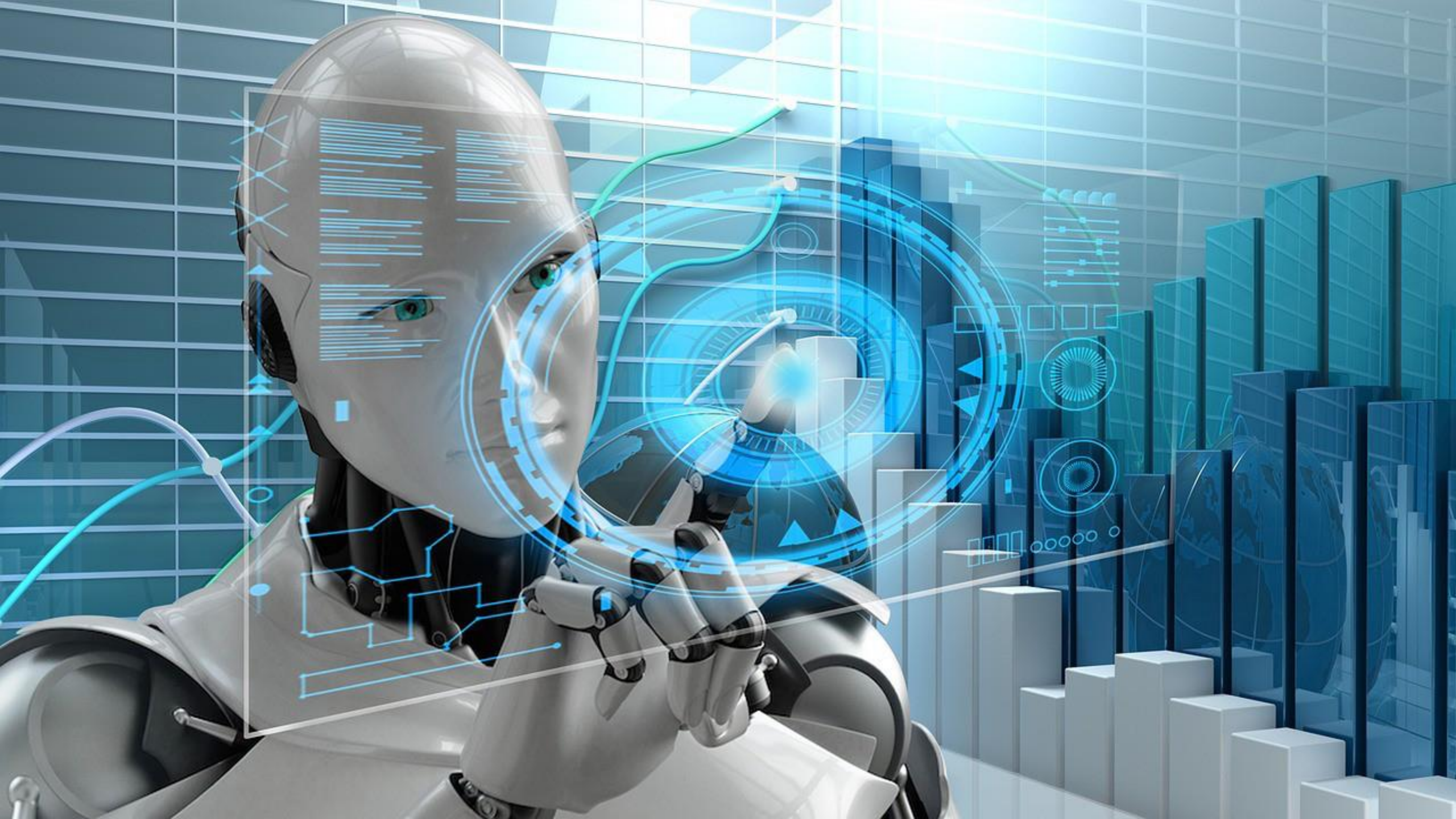
Fernand Léger purchased by Guggenheim Collections

Contraste de formes, Fernand Léger (?)
Peggy Guggenheim Collection, Venice

Contraste de formes, Fernand Léger (1881-1955), 1913,
Solomon G. Guggenheim Foundation, New York

Detail of the canvas sample





Aerial view: section of the loop, displaying hovering over the vegetation.

Aerial view:
Loop smoothly continuing inside
second floor of the proposed cafe building.

DRAFT
INVIVIA


DRAFT
INVIVIA

Phasing

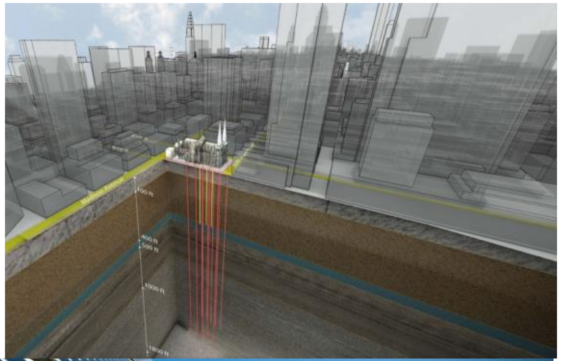
Landscape

Renovating Buildings + Loop

New Buildings

Renewable Energies

- Fossil fuel is bad (CO_2 emission, climate change)
- Nuclear fuel is bad (radioactivity)
- Are Renewable energy sources th solution?



Rare Earth Metal Needed

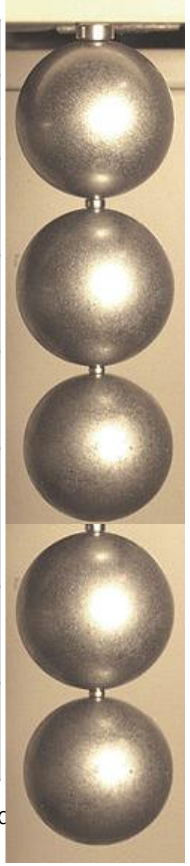
Atomic Number	Element	Symbol
21	Scandium**	Sc
39	Yttrium	Y
57	Lanthanum	La
58	Cerium	Ce
59	Praseodymium	Pr
60	Neodymium	Nd
61	Promethium*	Pm
62	Samarium	Sm
63	Europium	Eu
64	Gadolinium	Gd
65	Terbium	Tb
66	Dysprosium	Dy
67	Holmium	Ho
68	Erbium	Er
69	Thulium	Tm
70	Ytterbium	Yb
71	Lutetium	Lu

Rare earth metals, yttrium, lanthanum or cerium are formed from 17 chemically similar elements and are extremely rare. Because of their strong magnetic properties and high electrical conductivity, they are light in weight and efficient, making them critical to the clean energy industry.

Wind turbines, energy-efficient light bulbs, electric car batteries, and efficiency motors or generators all depend on dysprosium, neodymium etc to generate the magnets that make them work. No substitute has been found that can match rare earths in weight and efficiency.

Magnetic Materials

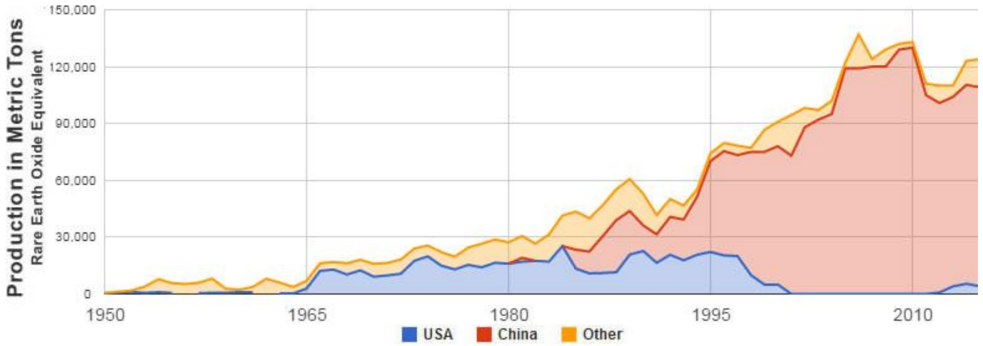
Magnet	Magnetic field (T)	Resistance to demagnetize (kA/m)	Energy Density (kJ/m^3)	Temperature Range	
				(°C)	(°F)
$Nd_2Fe_{14}B$ (sintered)	1.0–1.4	750–2000	200–440	310–400	590–752
$Nd_2Fe_{14}B$ (bonded)	0.6–0.7	600–1200	60–100	310–400	590–752
$SmCo_5$ (sintered)	0.8–1.1	600–2000	120–200	720	1328
$Sm(Co, Fe, Cu, Zr)_7$ (sintered)	0.9–1.15	450–1300	150–240	800	1472
Alnico (sintered)	0.6–1.4	275	10–88	700–860	1292–1580
Sr-ferrite (sintered)	0.2–0.78	100–300	10–40	450	842



Multiple applications of Rare Earth based materials in computer, information, transportation and energy industries.

Rare Earth Economy

In 2000 China's low prices forced US producers out of business; 2013 China dominated the production with 90%. With increase in prices and demands US and other countries created new mining initiatives!



United States Usage (2015 data from USGS)	
Chemical Catalysts	60%
Metallurgy & Alloys	10%
Ceramics and Glass Making	10%
Glass Polishing	10%
Other	10%

World Mine Production and Reserves (2015 Estimates)		
Country	**Production (Metric Ton)**	**Reserves (Metric Ton)**
United States	4,100	1,800,000
Australia	10,000	3,200,000
Brazil	--	22,000,000
China	105,000	55,000,000
India	--	3,100,000
Russia	2,500	?
Thailand	2,100	not available
World total (rounded)	110,000	140,000,000

Clockwise from top center: praseodymium, cerium, lanthanum, neodymium, samarium, and gadolinium.

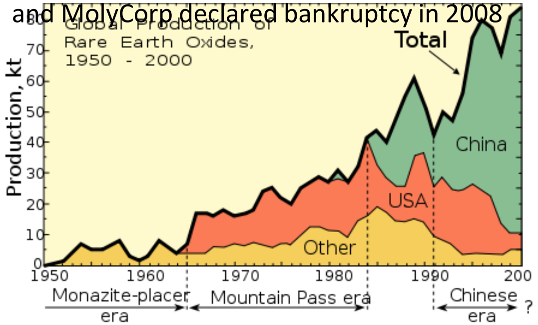
Rare Earth Element Harvesting

Rare earths are often located within minerals such as Bastnaesite, Monazite, Xenotime, and Thorite

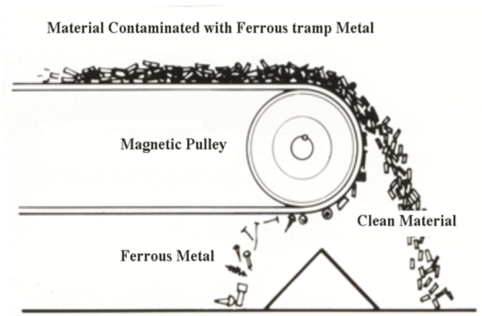
The four Rare Earth containing minerals, Bastnaesite, Monazite, Xenotime, and Thorite, require special chemical treatment with acids to dissolve, extract and separate their basic elements.

Biggest (and only) US Rare Earth Mining Facility

The deposit was mined in a larger scale between 1965 and 1995 supplying most of the worldwide rare earth metals.
The mine closed in 2002, in response to both environmental restrictions and dropping prices.
The mine has been mostly inactive since 2002. and MolyCorp declared bankruptcy in 2008



Magnetic Separation

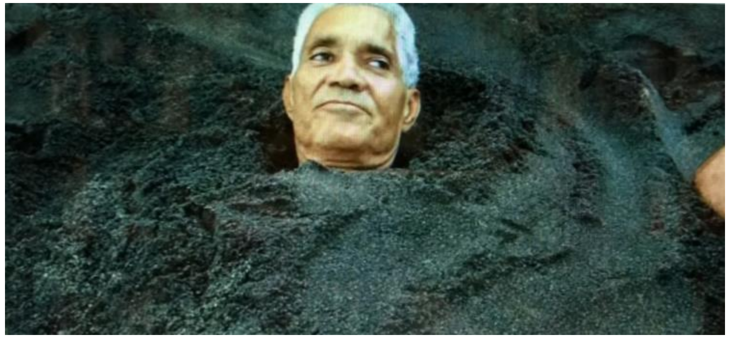


Magnetic ore (rare earth particles) stick to drum, and are separated into an extra container, the non-magnetic tailings are being removed. This can be a multi-step process with increasing purity

Beaches of Brazil

Monazite enriched black sand washed down from the mountains along the shore lines contains significant amounts of Thorium! The reading is μSv/h.

The locals believe in the healing powers of the Monazite black sands!



The radioactive foot print of windmills

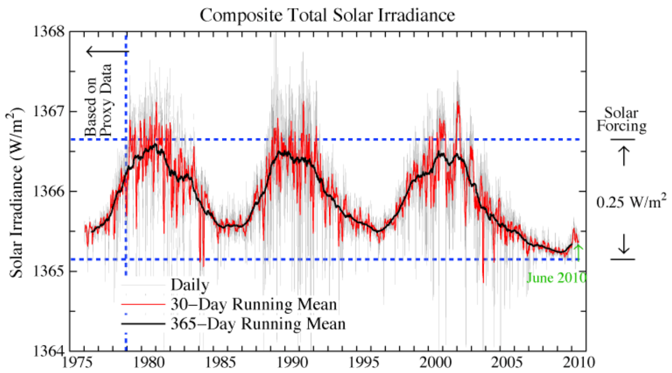
A 2 megawatt (MW) wind turbine contains about 800 pounds of neodymium and 130 pounds of dysprosium, which is mostly harvested and processed in China.

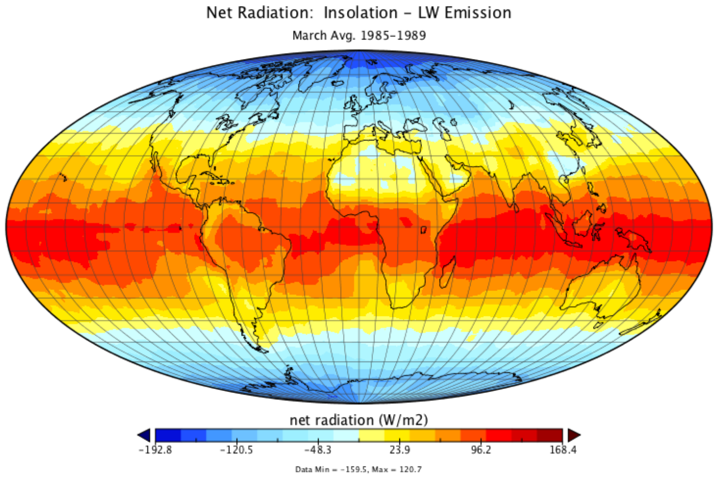
- ➢ The mining of one ton of rare earth minerals produces about one ton of radioactive waste.
- ➢ Each year, the U.S. adds a record 10 – 15 GW of wind generating capacity.
- ➢ That translates to about 5 million pounds of rare earths in newly installed wind turbines.
- ➢ Consequently 5 million pounds of radioactive waste were created in the harvesting process.
- ➢ In comparison, America's nuclear industry produces around 5 million pounds of spent nuclear fuel each year.
- ➢ Nuclear energy provides about 20% of America's energy needs, wind accounts for just 4%.

Solar Energy

Solar thermals systems:	convert sunlight into heat
Solar photovoltaic systems:	convert sunlight into electricity

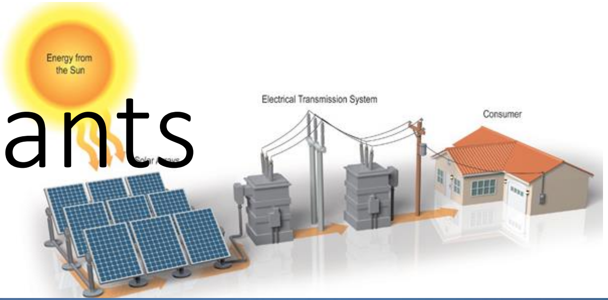
Power production by solar energy



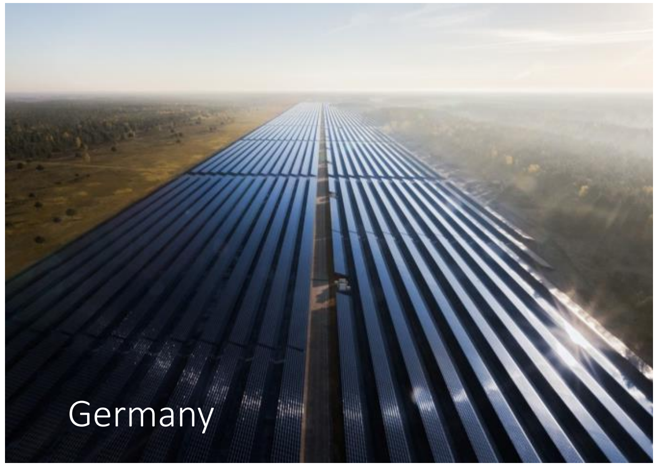


High power generation requires large areas; 1 GW of total irradiance requires an area 732,000m^2 or 0.73 km^2 if all the sunlight is converted to energy. Irradiance in the US is typically near 50-60% of total irradiance. The photovoltaic efficiency of conversion is 20%. This ten folds the required area to 7.3 km^2 or 3 square-mile, an order of magnitude improvement over wind power.

Photovoltaic plants

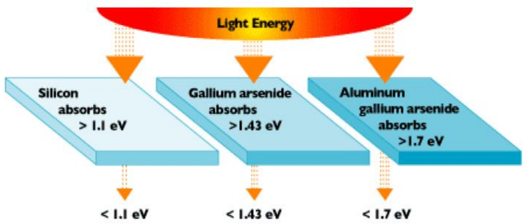


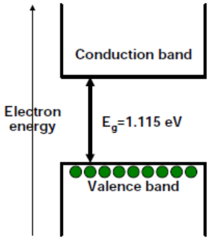
Require a lot of space and a lot of sun-light



The photovoltaic effect

A photovoltaic (PV) cell corresponds to two semi-conductor materials n (negative) and p (positive type are sandwiched together. The photovoltaic effect occurs when photons release electrons near the np-junction from the valence band to the conducting band in the lattice of a semi-conductor material Si, Ge, GaAs , etc. The electric charges are moved by an internal electrical potential at the semi-conductor junction, creating an electric current that is proportional to the amount of absorbed light energy. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. For producing energy for a 60 W light bulb, about 100 PV cells need to be matched together.





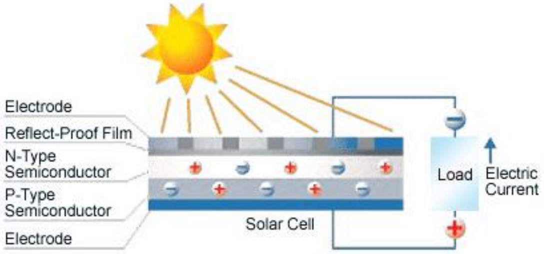
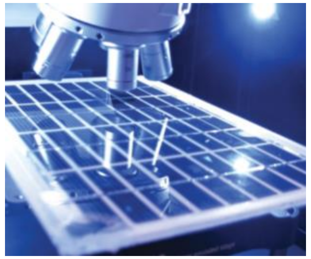


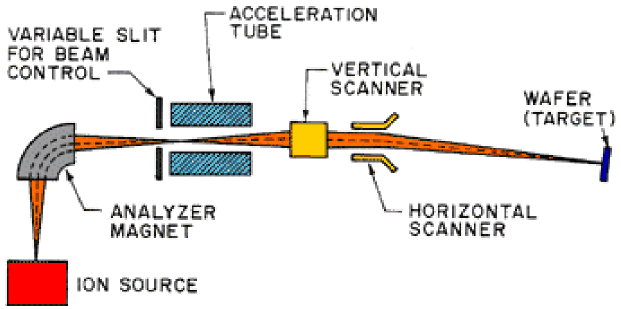
Table II. Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at a cell temperature of 25 °C (IEC 60904-3: 2008, ASTM G-173-03 global).

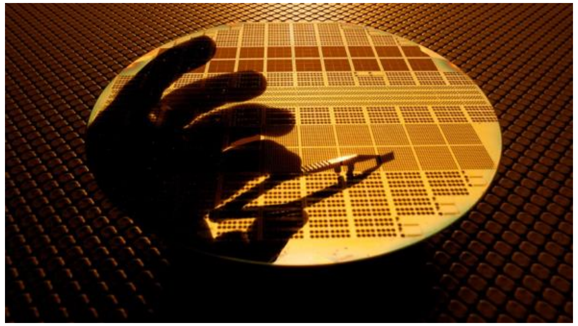
Classification	Effic. (%)	Area (cm^2)	V_{oc} (V)	I_{sc} (A)	FF (%)	Test centre (date)	Description
Si (crystalline)	22.9 ± 0.6	778 (da)	5.60	3.97	80.3	Sandia (9/96)[a]	UNSW/Gochermann [32]
Si (large crystalline)	22.4 ± 0.6	15 775 (ap)	69.57	6.341[b]	80.1	NREL (8/12)	SunPower [33]
Si (multicrystalline)	18.5 ± 0.4	14 661 (ap)	38.97	9.149[c]	76.2	FhG-ISE (1/12)	Q-Cells (60 serial cells) [34]
GaAs (thin film)	24.1 ± 1.0	858.5 (ap)	10.89	2.255[d]	84.2	NREL (11/12)	Alta Devices [35]



Ion Implantation

The ion beam is produced in an ion source by plasma ionization of sputtering, extracted and separated by mass and charge in a magnetic field, accelerated and implanted in Si wafers. This approach is not for mass production!

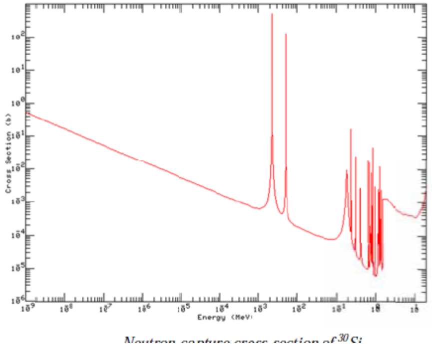




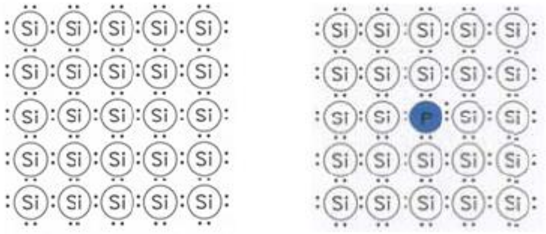
Neutron activation of rare isotope components with subsequent decay to doping material

$$^{30}Si(n,\gamma)^{31}Si(\beta^-)\,^{31}P \qquad ^{30}Si\text{: } 3.1\%$$

Similar neutron activation processes at other semiconductor materials



Reaction probability or cross section requires thermal neutron energies!

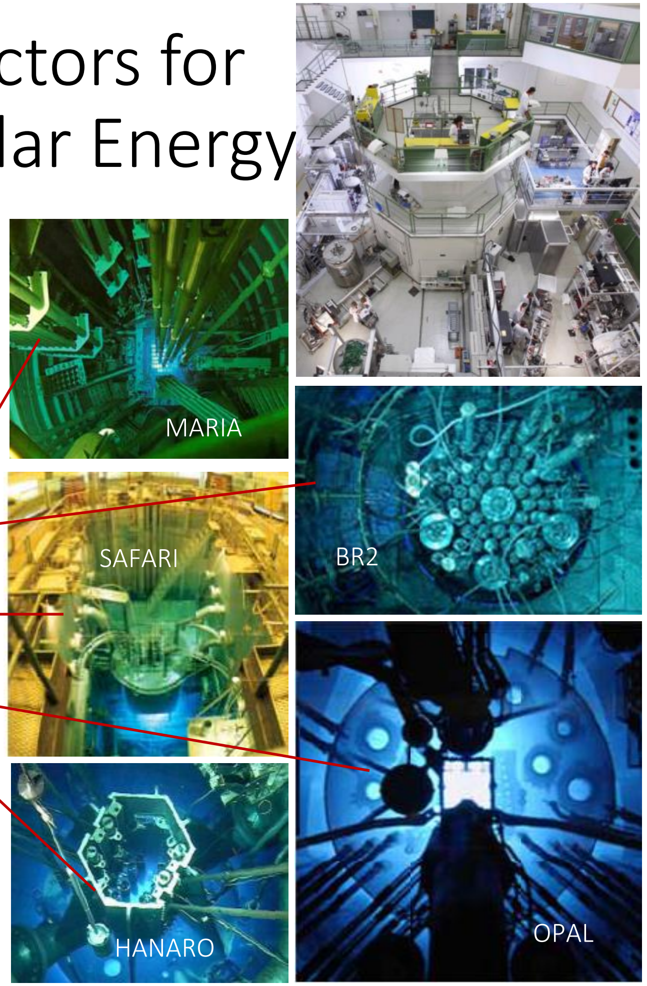


^{30}Si isotope in Si lattice is converted to ^{31}P

Utilization of Nuclear Reactors for efficient production of Solar Energy

Reactor	Thermal power	Irradiation rig	Neutron flux [$cm^{-2}s^{-1}$]	Gamma ray heating or temperature
MARIA in Poland	30 MW		2.1×10^{13}, (thermal), Fast (>1 MeV)/thermal=0.02	0.5 W/g
BR2 in Belgium	56 MW (Nominal: 85 MW)		1.74×10^{14} (thermal), 1.9×10^{13} (fast),	< 200°C Si core temp.
SAFARI-1 in South Africa	20 MW	4 inch SILIRAD	2.5×10^{13}-8×10^{13} (thermal)	Measured temperature at Si: ~80°C
FRM II in Germany	20 MW	8 inch	1.6×10^{13} (thermal) Thermal/fast=1700	Max. temp.: 110°C (Si core temp.) [44]
OPAL in Australia	20 MW	5, 6, 8 inch	2.5×10^{12}–1.5×10^{13} (thermal) Thermal/fast=900	
HANARO in the Republic of Korea	30 MW	5,6 inch NTD2	Thermal/fast=400 Cd ratio for gold: 16~22	0.2–0.9 W/cm^3

Smaller scale reactors (TRIGA type) that don't generate much energy, but a relatively high neutron flux between 10^{12} and 10^{14} neutrons/cm^2/s!



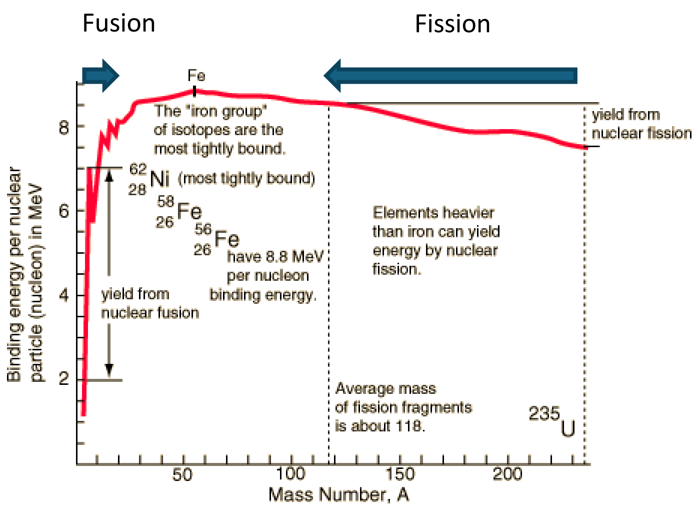
First man splitted the atom,

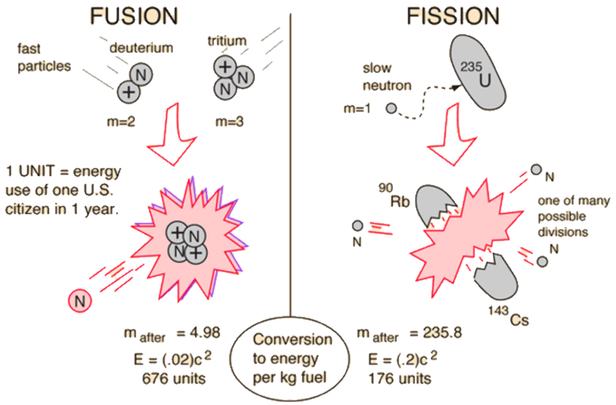
now the atom

splits man.

Gerhard Uhlenbruck

Nuclear Energy Production





The energy release per atomic mass unit is 0.7MeV for fission and 6.2MeV for fusion, fusion is the more effective nuclear reaction!

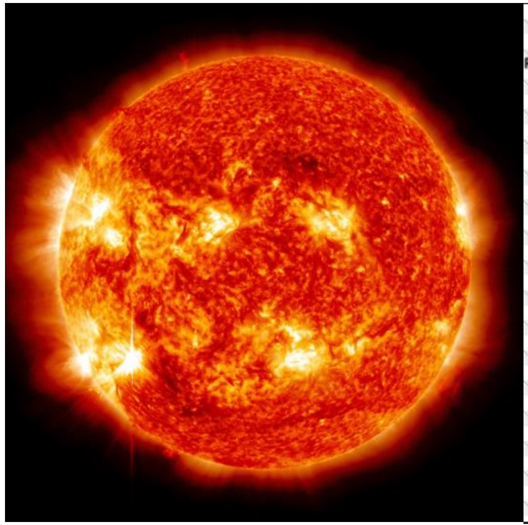
Fusion occurs by the nuclear reaction between two light hydrogen isotopes, such as d+d ($^{2}H+^{2}H$), or d+t ($^{2}H+^{3}H$), while fission is the neutron induced splitting of ^{235}U or ^{239}Pu into two lower mass isotopes between mass 100 and mass 130.

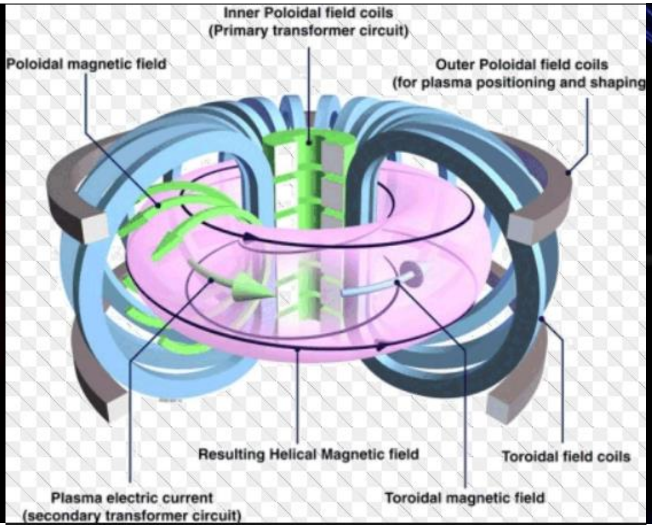
Confinement of hot Plasmas

Gravitational confinement

Magnetic confinement

Inertial confinement





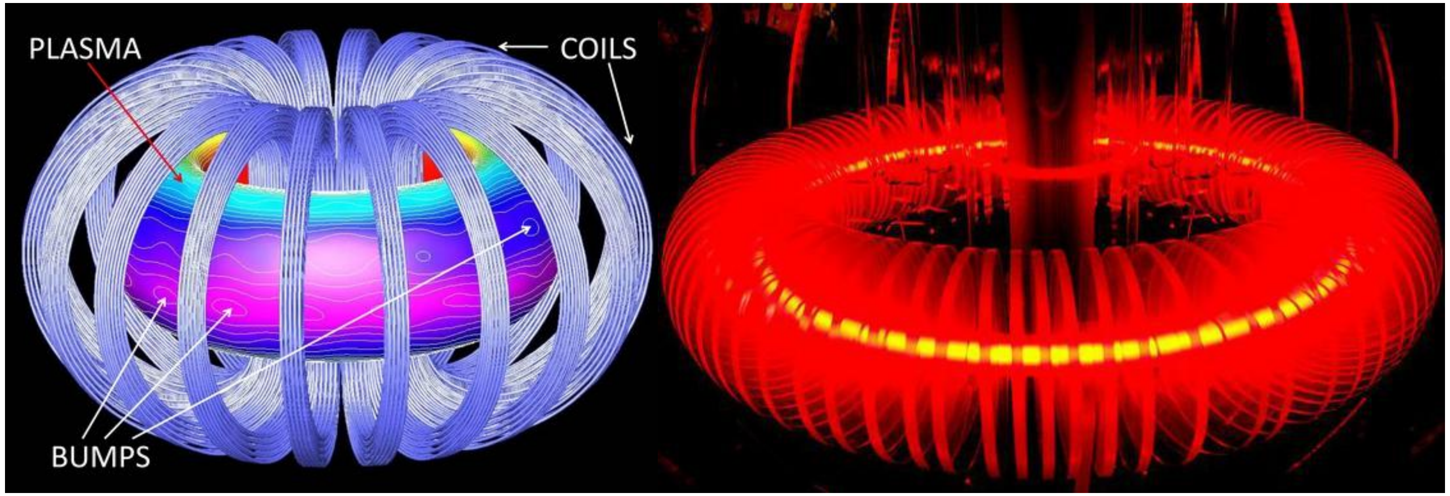
Nature's approach

human approach

Plasma fusion

through magnetic confinement

A major advantage of fusion reactors is the small if not negligible amount long-lived radioactive decay products! Light radioactive isotopes are short-lived and produce additional energy through the decay heat.

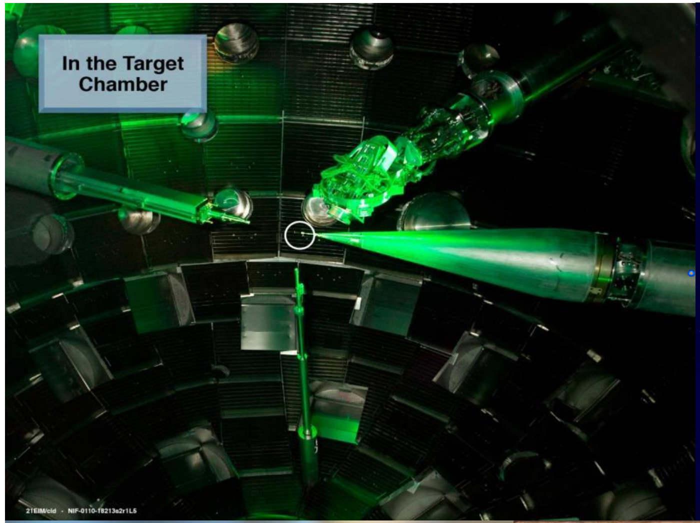


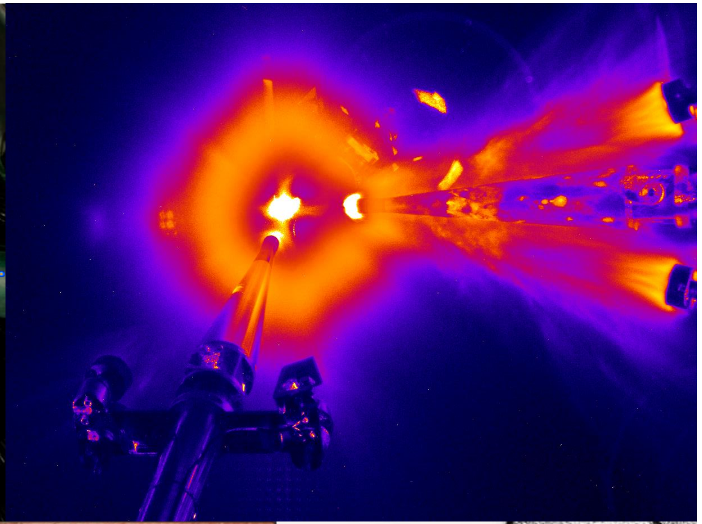
Plasma has to have temperatures of ten times the temperature in the core of the sun to generate the required energy output. The plasma is contained by magnetic fields 10,000 times that of the Earth's field. The shape of the fusion plasma is dictated by the magnetic field generation. These provides enormous technical challenges that have not been achieved yet. The main project towards the goal is the international ITER project in France, but there are still a number of smaller projects in the US, CHINA, and Germany.

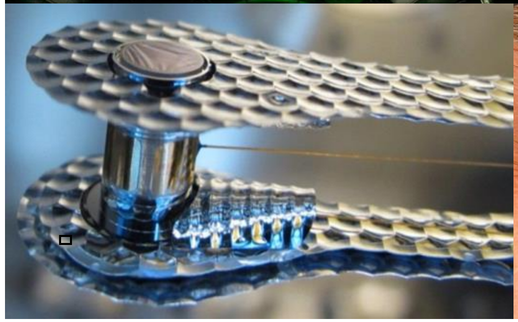
Laser Induced Fusion

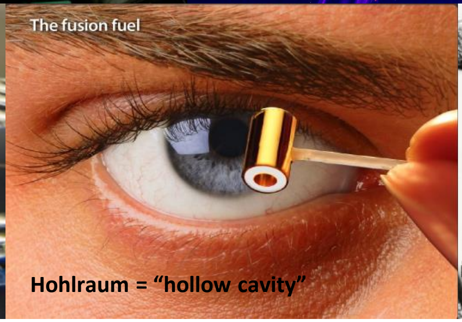
through inertial confinement

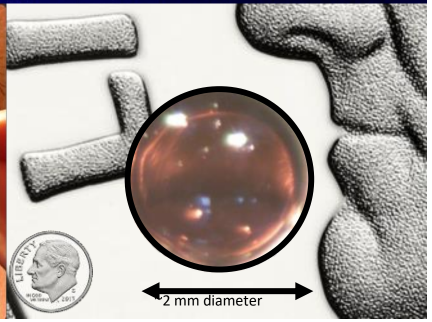
195 Peta-Watt Lasers aiming at one spot generating an implosion of capsule reaching temperatures and densities close or superseding solar values.



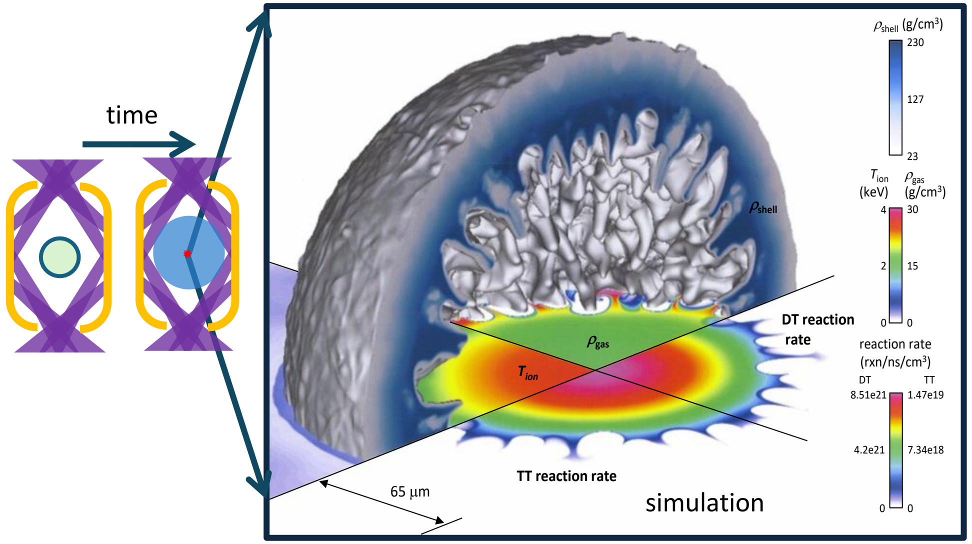


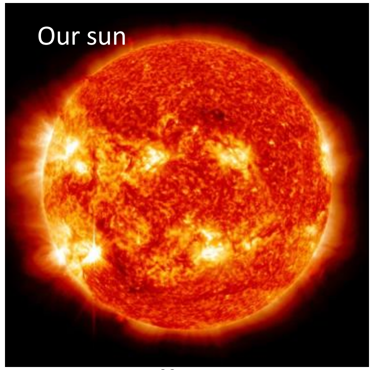




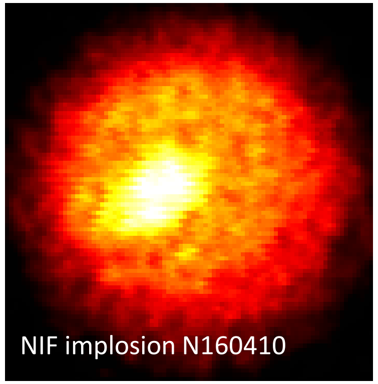


NIF shot conditions





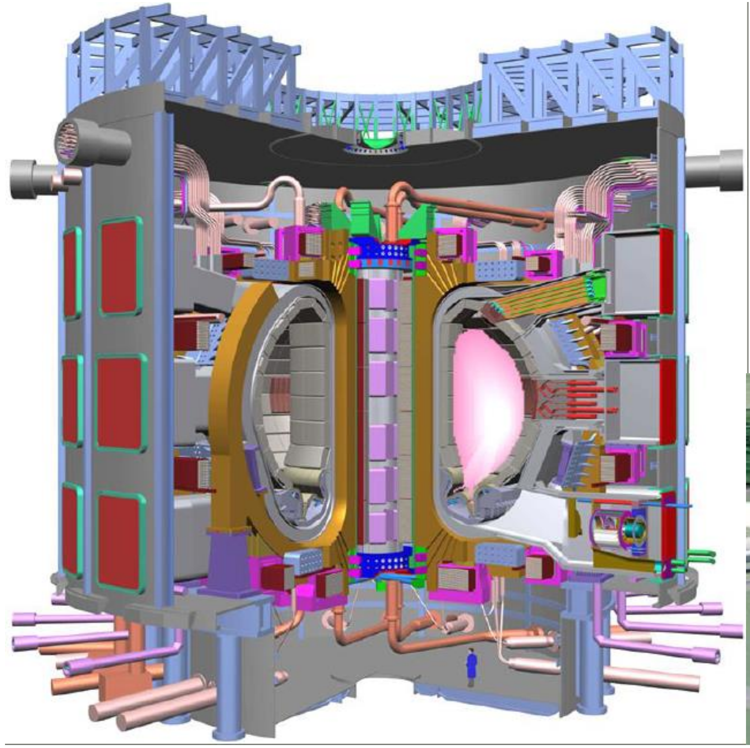
M_{Sun}~2×10^{33}g



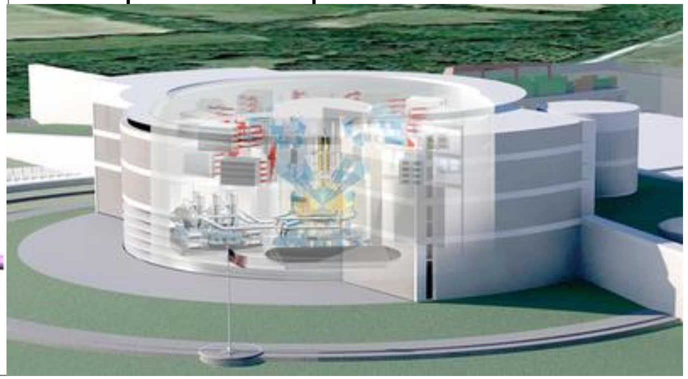
M_{impl}~6×10^{-6}g

Shot physics is not fully understood yet. Rapid convective processes seems to inhibit the production and release of positive net energy. A problem is the limited frequency or shot-rate, three shots/day, desired rate is 100 shots/second, a three million times improvement is necessary!

Time-line 30-50 years

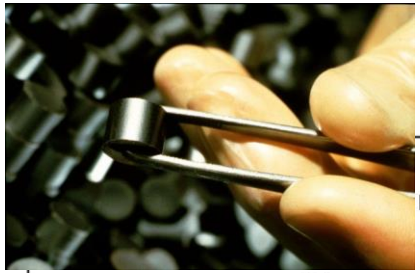


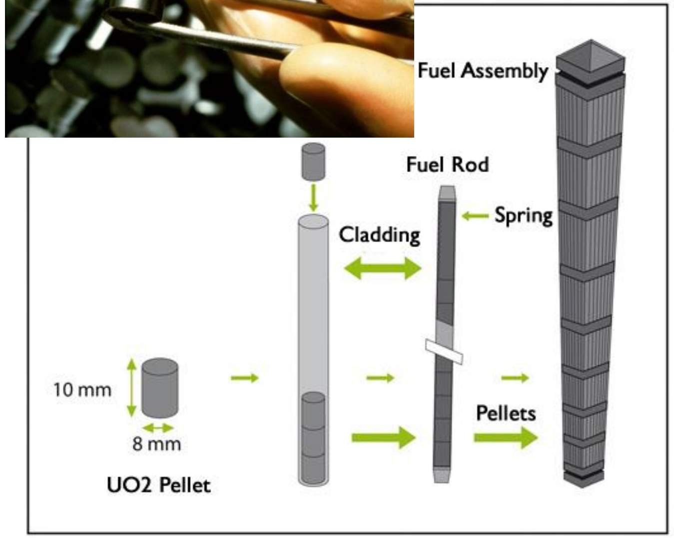
The general statement is that it takes 30-50 years towards reliable energy production by fusion, but the world cannot wait, the energy demand is growing exponentially! Nuclear fission is one of the existing options for bridging the time until a reliable fusion concept is developed!

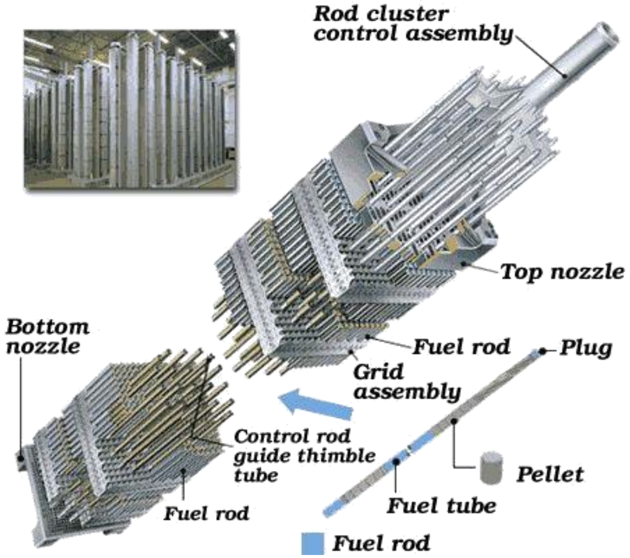


Present concepts: ITER LIFE

Fuel elements

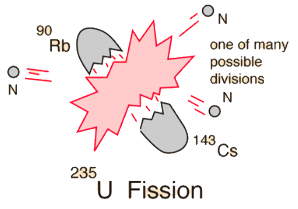


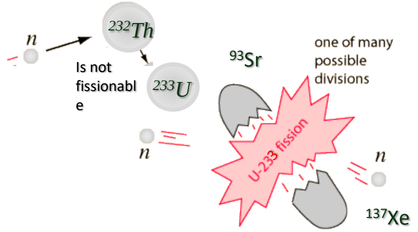


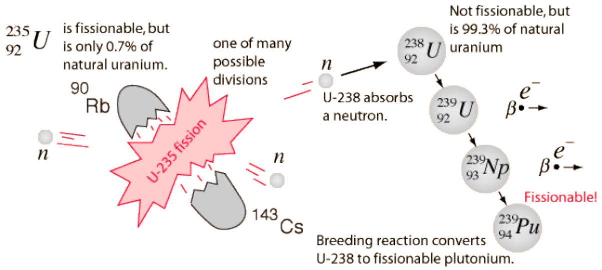


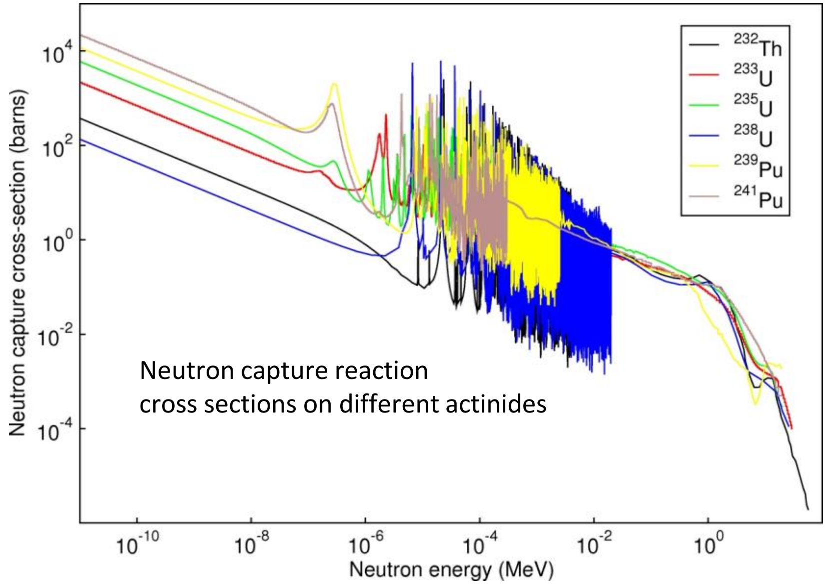
The assembly of fuel and moderator elements is an engineering problem towards optimized operation, safety, assembly, and disassembly for storage and recycling.

Alternative fission reactions Nuclear Fuel Breeder



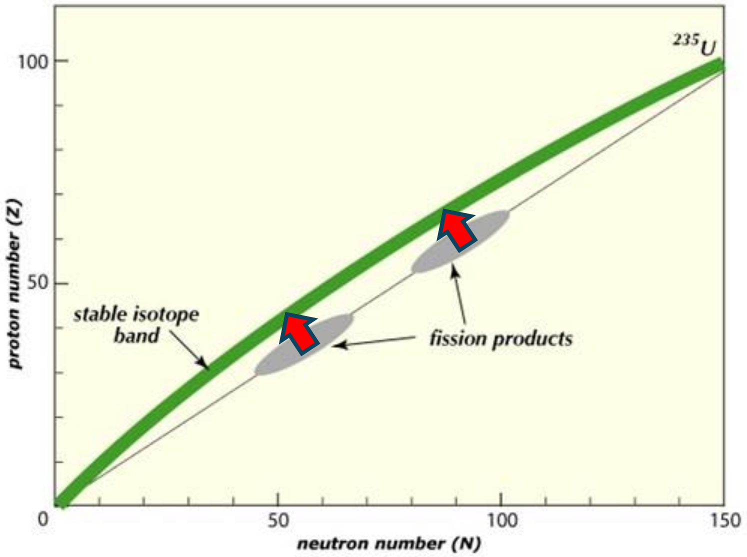


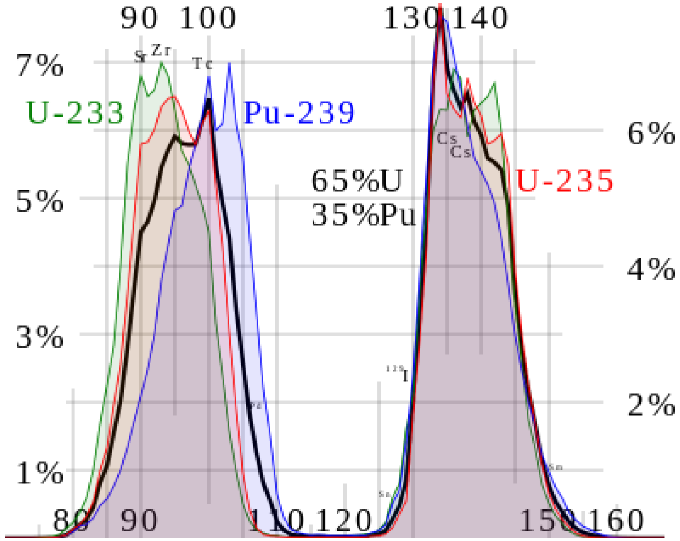




The breeding of nuclear fuel doesn't solve the issues associated with radioactive fission products but enhances the efficiency and reduced the fuel costs since ^{228}U and ^{232}Th is much more abundantly available than the rare ^{235}U. This removes and important costly aspect of fuel separation and preparation. Breeder also rely on fast neutrons and need no moderator materials.

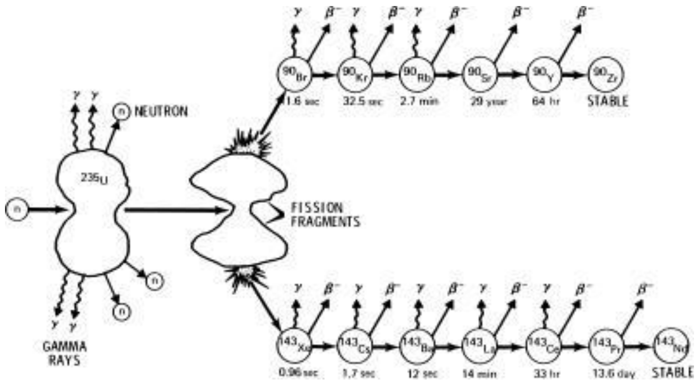
Fission Process



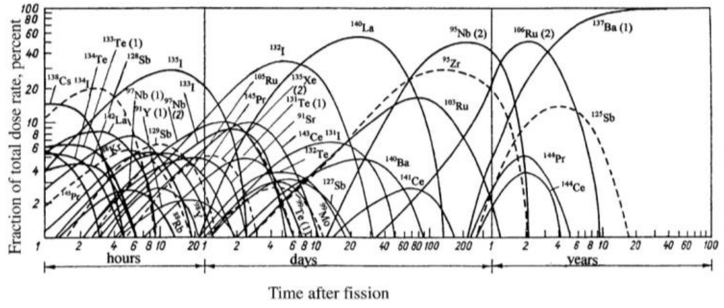


Fission product yields by mass for thermal neutron fission of ^{235}U, ^{239}Pu, a combination of the two typical of current nuclear power reactors, and ^{233}U used in the thorium cycle. The fission products are very neutron-rich and therefore highly radioactive and decay by β decay back to stability. Long-lived isotopes in the ^{233}U decay chains are: ^{93}Zr $T_{1/2}=1.5\cdot10^6$ y, ^{137}Cs $T_{1/2}=30$ y;

Fission products



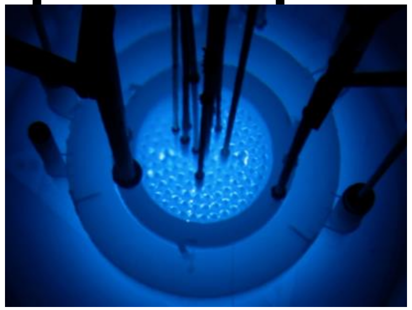
Uranium fission and possible fission products in subsequent β^- decay processes along the isobaric lines towards stability. These decay chains originate from the primary fission product distribution.

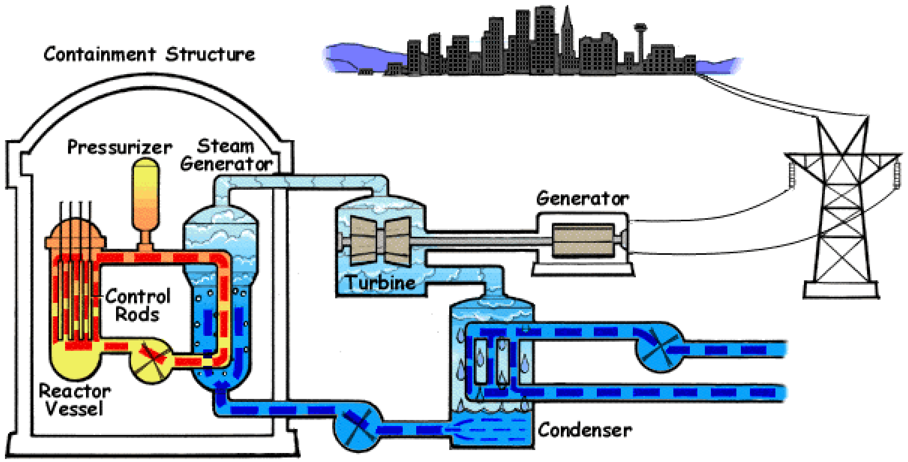


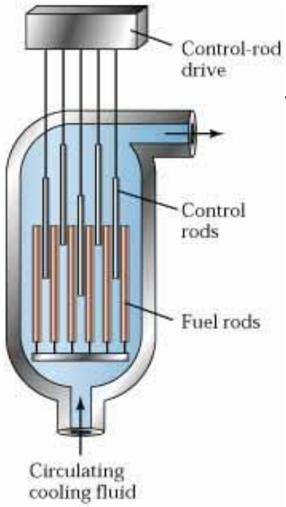
Medium-lived fission products				
Prop: Unit:	$t_{½}$ (a)	**Yield** (%)	**Heat** (keV)	βγ
^{155}Eu	4.76	0.0803	252	βγ
^{85}Kr	10.76	0.2180	687	βγ
^{113m}Cd	14.1	0.0008	316	β
^{90}Sr	28.9	4.505	2826	**β**
^{137}Cs	30.23	6.337	1176	β**γ**
^{121m}Sn	43.9	0.00005	390	βγ
^{151}Sm	96.6	0.5314	77	β

Long-lived fission products				
Prop: Unit:	$t_{½}$ (Ma)	**Yield** (%)	**Heat** (keV)	βγ
^{99}Tc	0.211	6.1385	294	β
^{126}Sn	0.230	0.1084	4050	β**γ**
^{79}Se	0.327	0.0447	151	β
^{93}Zr	1.53	5.4575	91	βγ
^{135}Cs	2.3	6.9110	269	β
^{107}Pd	6.5	1.2499	33	β
^{129}I	15.7	0.8410	194	β

The basic technical principles



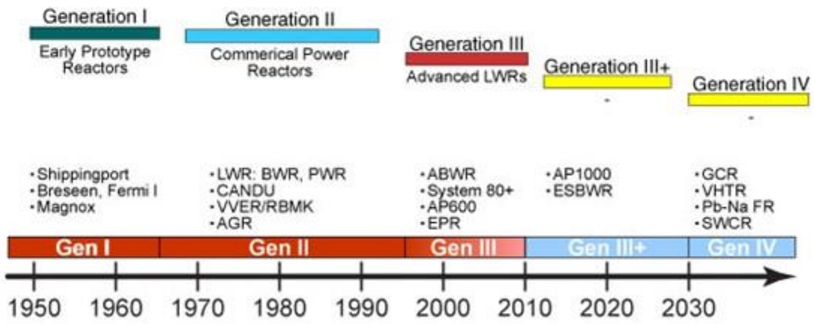




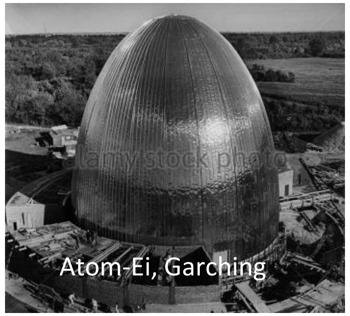
The cooling water that also functions as moderator for neutrons circulates through the reactor core and carries the heat that is generated by the fission process away in a closed water cycle, heating water in a secondary cycle. The water in the first cycle is radioactive from fission products the water in the second cycle should not be radioactive unless a leak has occurred. The hot water or steam in the second cycle drives the turbine. The control rods are made of Boron containing material since Boron has a large cross section for neutron capture. If in place the released fission neutrons are absorbed and the chain fission reactions stops. But there is still substantial decay heat being released, which requires continuous cooling!

Reactor Generations

Technical developments and safety concerns – sometimes even new physics results - drive the change in the different reactor generations from the early prototypes such as the pile to latest generation of reactors with high neutron flux to high energy out-put. A reactor life-time is 40-50 years, Public and political concerns often lead to administrative delays forcing the lifetime extension with consequences in aging and safety reduction.

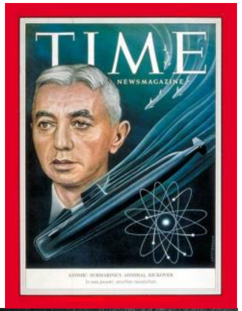



Pile, Chicago

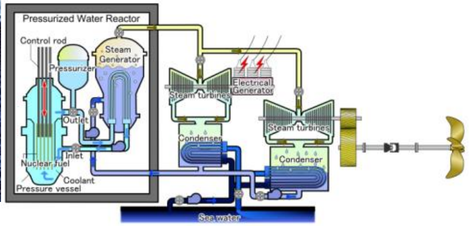

Atom-Ei, Garching


CANDU, Canada

The pressurized light water reactor



The PLWR is the present is the most used reactor type, developed at Oak Ridge and utilized for the nuclear submarine development under Admiral Rickover.

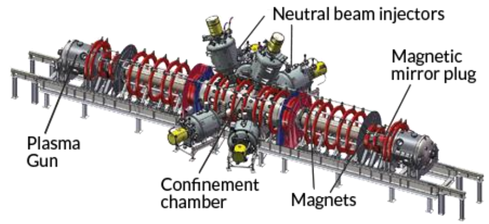


The **<u>Light Water Reactor (LWR)</u>** concept of water cooling seemed the obvious choice since water was available in large abundance. However, Rickover was also charged with the development of reactor types for peaceful applications (Atoms for Peace) and he continued with the same type despite the fact that it had more risk factors than other versions developed at Oak Ridge. The industrial military complex had started, since military requirements dictated the direction of civilian developments.

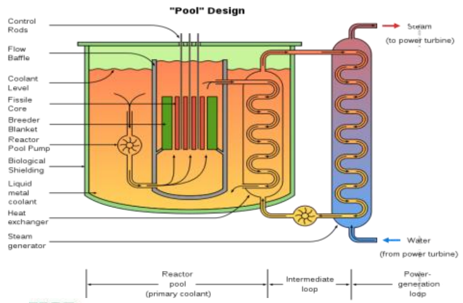
Other reactor types with potentially far advanced features

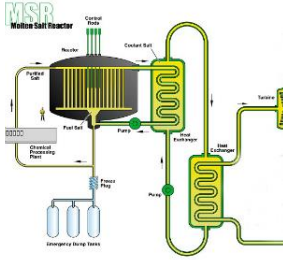
- **<u>Boron Reactor</u>**: a-neutronic fusion reactor device based on the $^{11}B(p,2\alpha)^{4}He$ reaction with little radioactive output from isotopic impurity $^{10}B(p,\alpha)^{7}Be(e^{-}\nu)^{7}Li$ ($T_{1/2}$=53 d). High intensity proton beam injected into a hot boron plasma in the magnetic confinement chamber
- **<u>Liquid Metal Reactor (LMR)</u>**: uses liquid sodium of lithium as coolant and uranium and/or thorium as fuel elements with a different distribution of fission products. Production of radioactive ^{24}Na occurs by neutron capture, but ^{24}Na has only 15 h half life. No stable ^{8}Li!
- **<u>Molten Salt Reactor (MSR)</u>** : the uranium fuel is dissolved in the sodium fluoride salt coolant which circulates through graphite core channels to achieve some moderation. Fission products are removed continuously and the actinides are fully recycled. A secondary coolant system is used for electricity generation.

Tri Alpha Energy model



Liquid Metal cooled Fast Breeder Reactors (LMFBR)





Thorium Reactor

Special version of Molten Salt Reactor (MSR)

The thorium reactor uses ^{232}Th as fuel converting it by neutron capture to ^{233}U, ^{232}Th(n,γ) ^{233}Pr($\beta^{-}\nu$)233U which a fissile material. It removes the costs for the production and possible enrichment of ^{235}U as fission source.

The salts concerned as primary coolant, mostly lithium-beryllium fluoride and lithium fluoride, remain liquid without pressurization from about 500°C up to about 1400°C, in marked contrast to a PWR which operates at about 315°C under 150 atmospheres pressure.

The main MSR concept is to have the fuel dissolved in the coolant as fuel salt, and ultimately to reprocess that online. Thorium, uranium, and plutonium all form suitable fluoride salts that readily dissolve in the LiF-BeF2 (FLiBe) mixture, and thorium and uranium can be easily separated from one another in fluoride form. Batch reprocessing is likely in the short term, and fuel life is quoted at 4-7 years, with high burn-up. Intermediate designs and the AHTR have fuel particles in solid graphite and have less potential for thorium use

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