DEPARTMENT OF ENERGY
Nuclear Engineering Division - CeSNEF
Integrated Laboratories of Nuclear Engineering

Applied Radiochemistry @ PoliMI

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May 2018

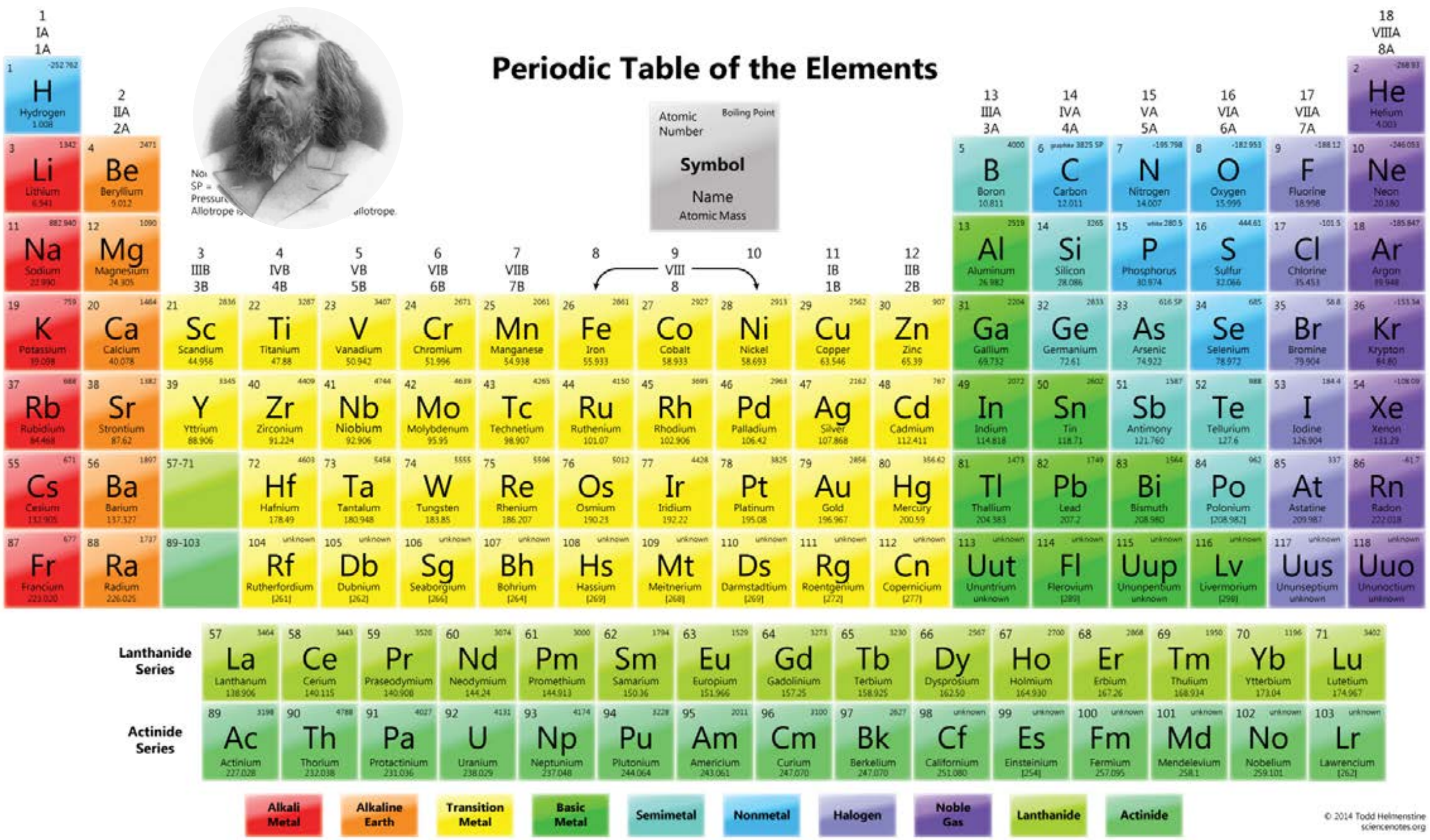
RADIOCHEMISTRY
&
RADIATION CHEMISTRY

@ NUCLEAR ENGINEERING

…why ?

Periodic Table of Elements

the existing elements can be organised into a periodic table



Of course, this is a domain of **CHEMISTRY!!!** **But**…

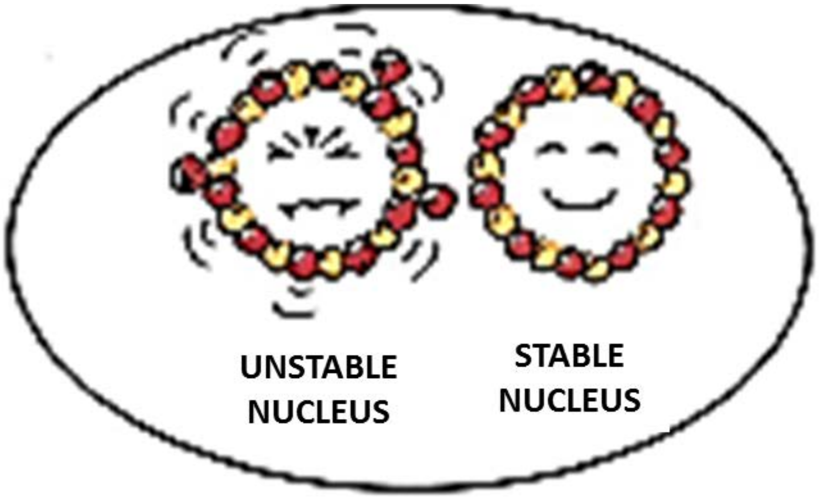
AS YOU WELL KNOW THE ATOMIC NUCLEI OF THE ELEMENTS CAN BE STABLE OR UNSTABLE

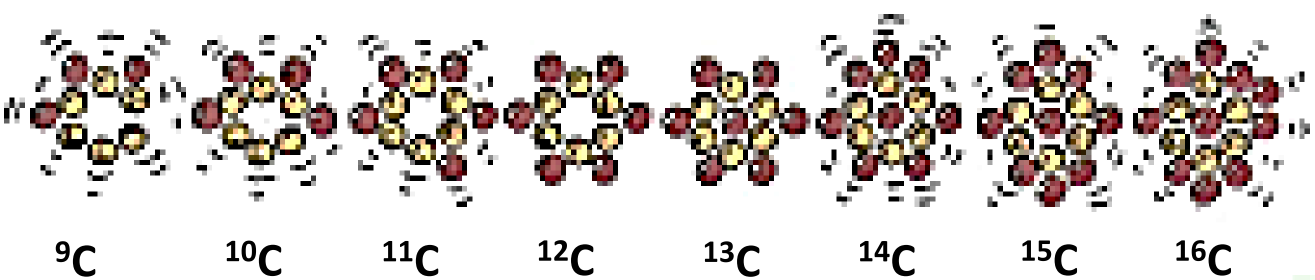
If neutron number is well balanced with respect to the proton number

- The atom is **STABLE**

If neutrons number is not well balanced with respect to the protons number

- The atom is **UNSTABLE**





A new way to organise the existing nuclides is needed

The **CHART OF NUCLIDES** by Soddy

Few nuclides are **WELL BALANCED** → They are **STABLE** (black boxes)

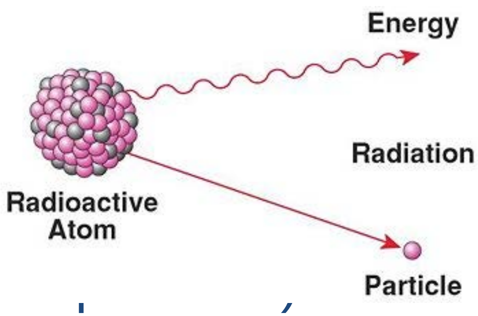
Some nuclides have **TOO MANY NEUTRON** → They are **β^- EMITTERS** (blue)

Some nuclides have **TOO FEW NEUTRON** → They are **β^+ or ELECTRON CAPTURE EMITTERS** (pink)

Some nuclides have **TOO MANY NUCLEONS** (protons and neutrons) → They are **α EMITTERS** (yellow)

Some nuclides are **TOTALLY UNSTABLE** → They give **FISSION** (green)

Some nuclides are in an **EXCITED STATE** → They are **γ EMITTERS** (white)



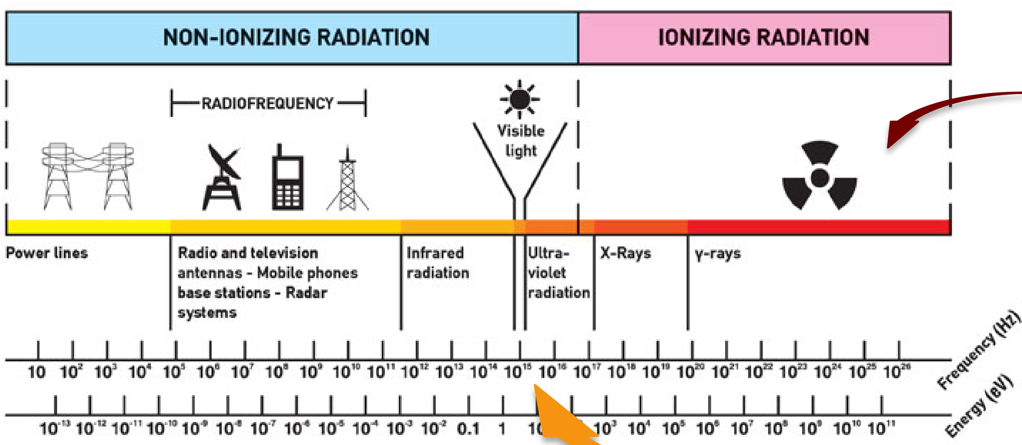
The products of this instability are the IONIZING RADIATIONS

HIGH ENERGY PARTICLES (α, β^-, β^+, n, fission

HIGH ENERGY PHOTONS (γ, x)

produced by

RADIOACTIVE DECAYS and/or NUCLEAR REACTIONS

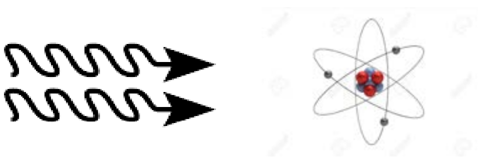


Typical energy of ionizing radiations

keV (10^3 eV) to MeV (10^6 eV)

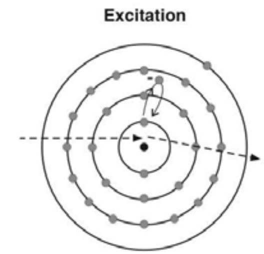
Typical energy in chemical processes

few eV

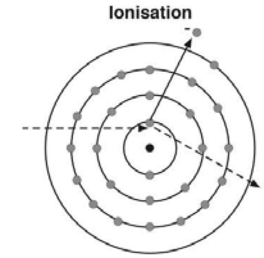


M

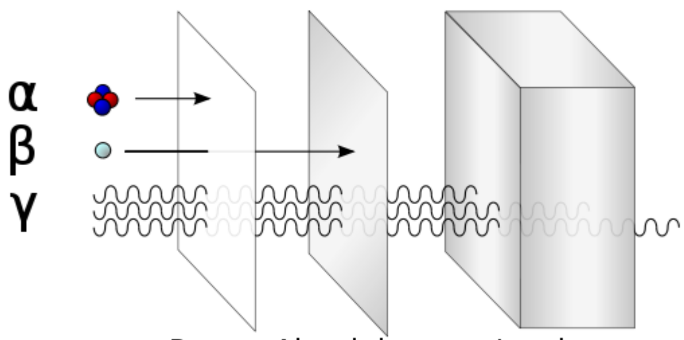
A lot of excited state
M*



A lot of ionization
$M^+ + e^-_{H.E.}$



different interactions for different ionizing radiations



<u>*a common concept:*</u>

the ABSORBED DOSE

mean energy released by ionizing radiation to matter per mass unit

Gray - [Gy] = joules per kilogram

Why radiation chemistry @ nuclear engineering?

We have the answer!

Ionizing Radiations can be a particular and uncommon reagent able to promote unexpected chemical reactions in materials

This is the domain of

RADIATION CHEMISTRY

in the Nuclear Engineering Field

Some examples:

$$H_2O \longrightarrow H_2,\ O_2,\ H_2O_2$$

H_2: Reducing agent; O_2, H_2O_2: Oxidating agents

$$n°(CH_2{=}CH_2) \longrightarrow -CH_2\text{-}CH_2\text{-})\text{-}$$ … Polymerization

Ethylene → Polyethylene

in general

$$A \longrightarrow B+C+D$$ … Degradations

$$A+B \longrightarrow C$$ . . . Syntheses

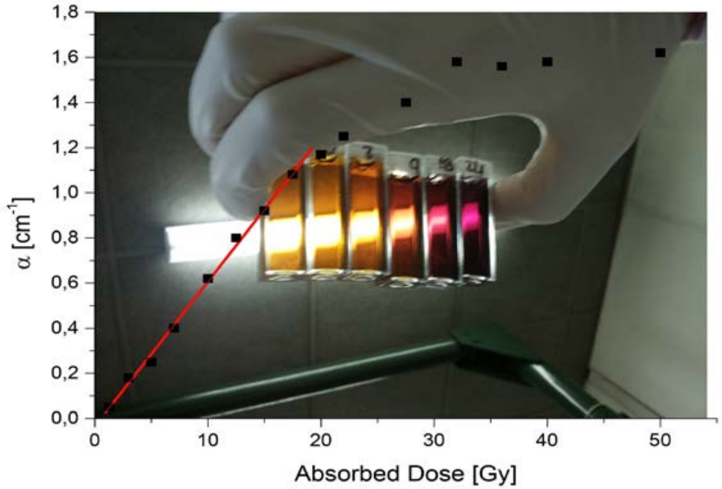
Generally, by means of Radiation Chemistry, we can study

Radio-induced modifications on materials and matrices:

- To improve their **properties**
- To modify their **structures**
- To study the **ageing** of materials
- To enhance the **degradation** for material recycling purposes
- To **sterylize** medical devices, cosmetics and pharmaceuticals
- To improve the **food shelf-life**
- To destroy tumur tissues (**radiotherapy**)
- To measure the dose of radiation (**CHEMICAL RADIATION DOSIMETERS**)

Some research topics @ PoliMi:

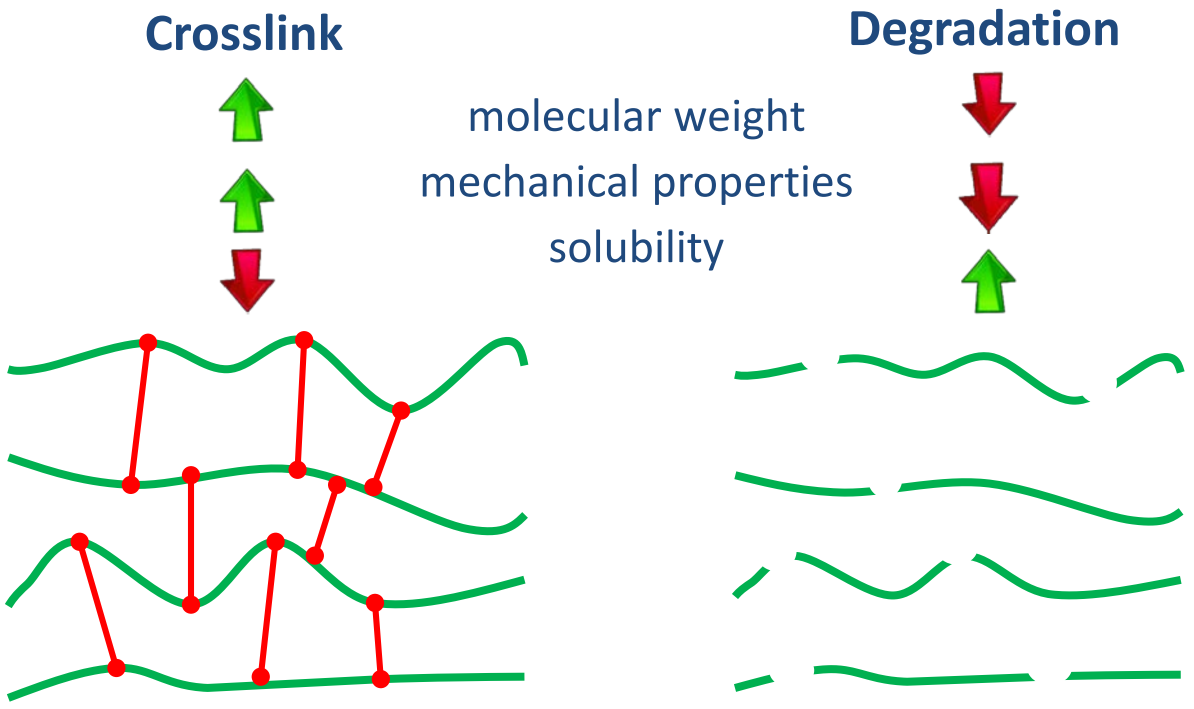
- Polymer irradiation
- Food irradiation
- Partitioning of spent nuclear fuel: radiolytic degradation of extractants and diluents
- Chemical dosimeters



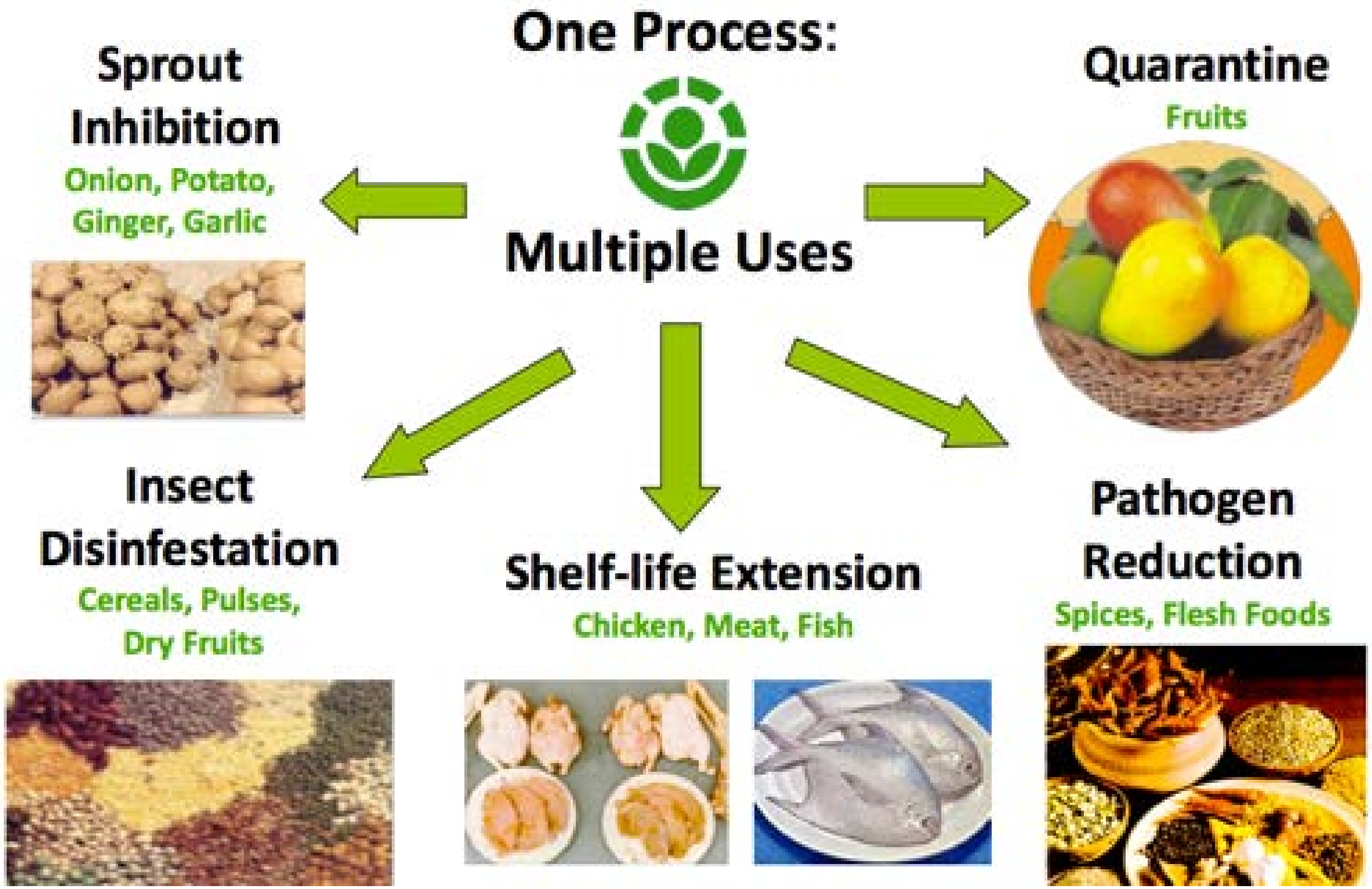
Plastics are extensively used in several applications, some involving ionizing radiations:

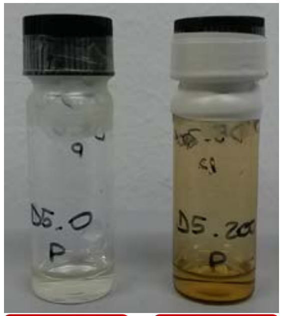
- ***Sterilization*** of medical supply
- ***Packaging*** for food irradiation
- ***Nuclear and aerospatial*** applications

Radiation processing of polymers



Food Irradiation



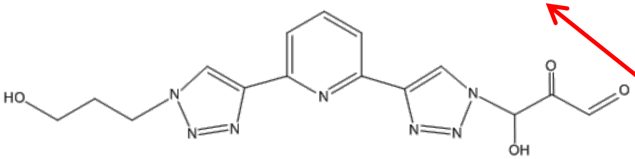


0 kGy 200 kGy

Irradiated by gamma radiation

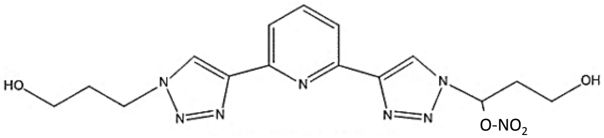
Peak 3 (2.7 - 2.9 min)

358.4(H⁺) 380.4(Na⁺)



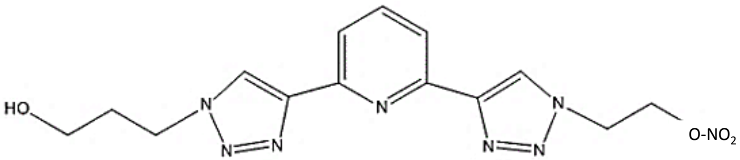
Chemical Formula: $C_{15}H_{15}N_7O_4$
Exact Mass: 357,12

391.3(H⁺) 413.3(Na⁺)

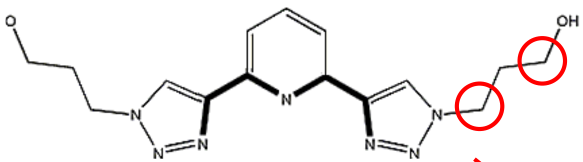


Peak 4 (4.1 - 4.2 min)

361.3(H⁺) 383.3(Na⁺)



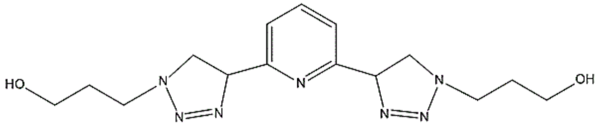
PyTri-Diol

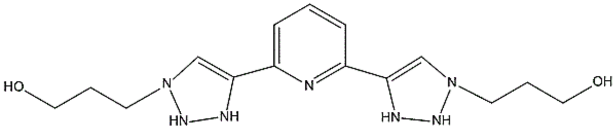


329.16

Peak 2 (1.4 - 1.5 min)

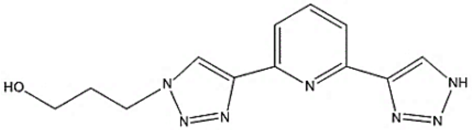
356.4(Na⁺)





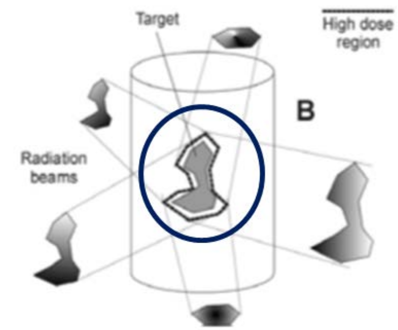
Peak 1 (1.3 - 1.4 min)

294.3(Na⁺)



Analysed by HPLC-MS

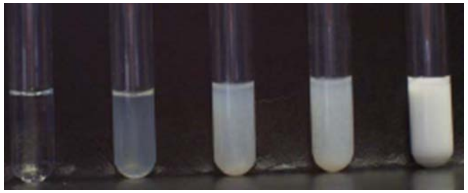
CONFORMATIONAL RADIOTHERAPY TREATMENTS

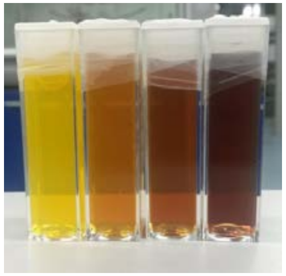


AIM: destroy cancer cells using radiation
OPEN ISSUE: accurate identification of target volume by advanced diagnostic imaging techniques

ACCURATE MEASUREMENTS OF THE 3D ABSORBED DOSE SPATIAL DISTRIBUTION

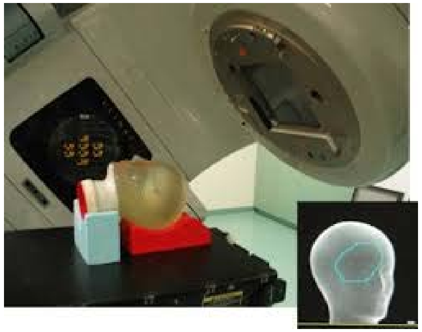
GEL CHEMICAL DOSIMETERS
(POLIMERIC GEL / FRICKE-XO GEL)
chemical change within the gel directly proportional with the absorbed dose

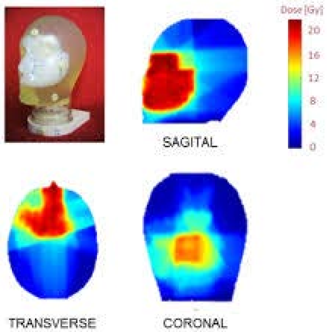




Increasing dose →

ANTROPOMORPHIC PHANTOM
simulating the patient during the radiotherapy treatment for the dose map verification



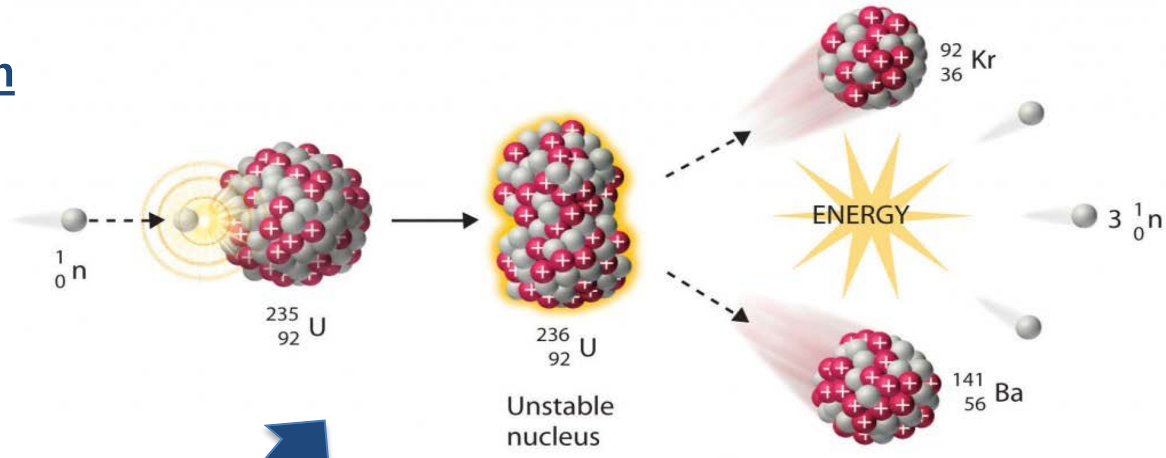


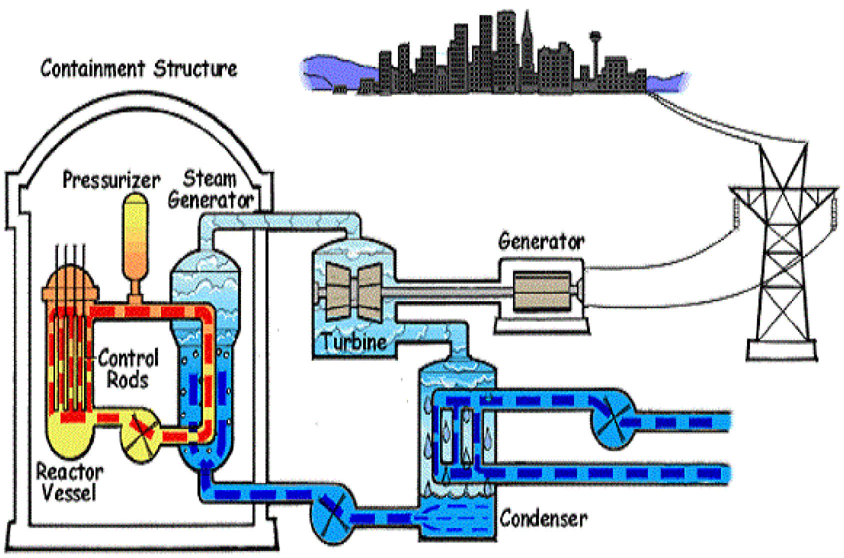
Why radiochemistry @ nuclear engineering?

We can find the answer !

FROM THE NUCLEAR ENGINEERING POINT OF VIEW…

Fission Reaction





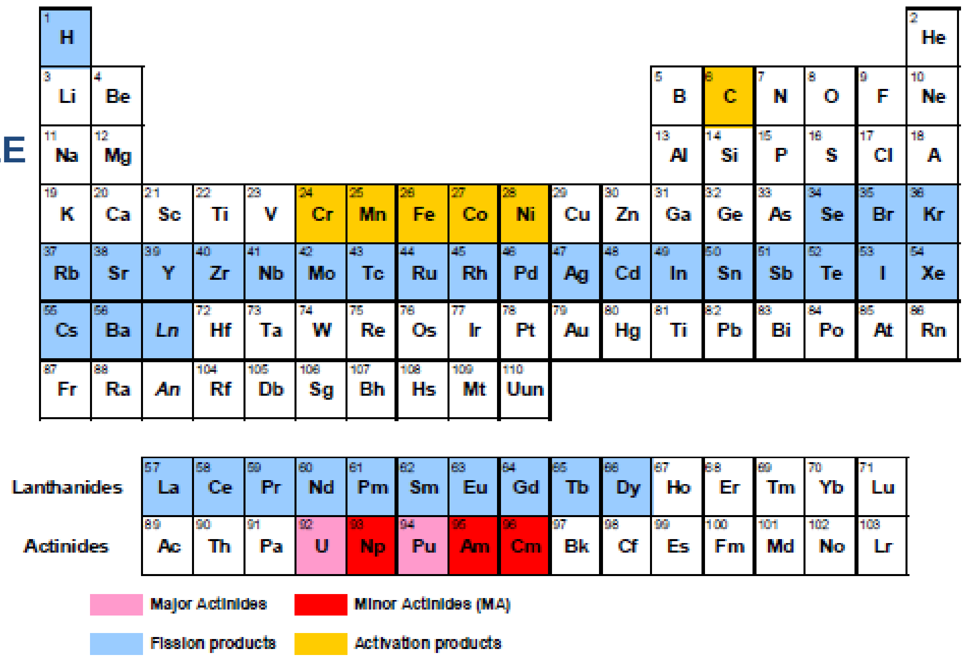
Nuclear Reactor

… are A WAY TO PRODUCE ENERGY

FROM THE CHEMICAL POINT OF VIEW…

Nuclear reactions and reactors … are an extraordinary WAY TO PRODUCE CHEMICAL ELEMENTS!!!
… also new transuranic (Pu, Am, …) and missing elements (Tc, Pm)

A «NEW» PERIODIC TABLE can be generated by Spent Nuclear Fuel and Nuclear Reactions



Minor/Major Actinides

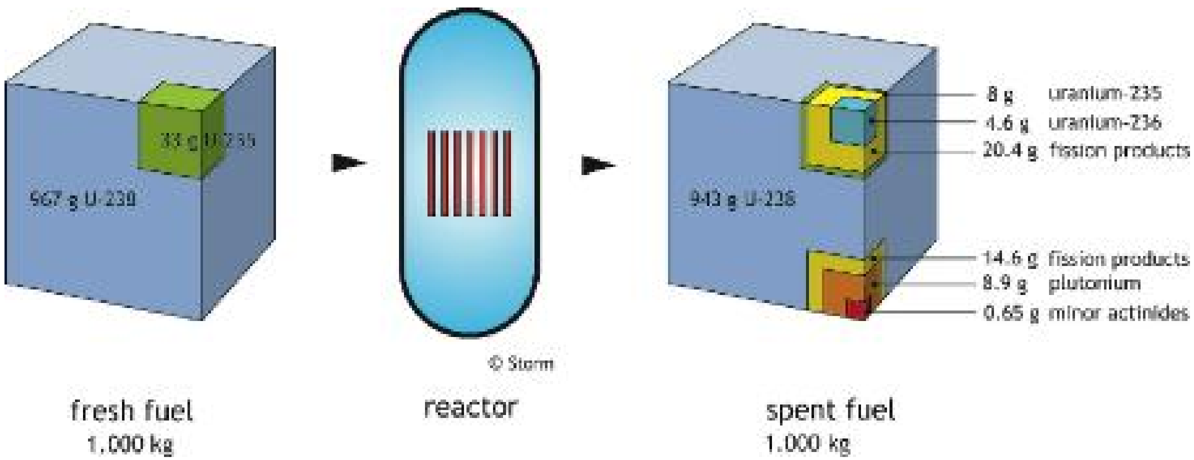
239Np	2.4 d
238Pu	86.0 y
239Pu	24 400.0 y
240Pu	6 580.0 y
241Pu	13.2 y
242Cm	163.0 d

Fission Products

33Xe	5.3 d
131I	8.0 d
134Cs	2.0 y
137Cs	30.0 y
132Te	78.0 h
89Sr	52.0 d
90Sr	28.0 y
140Ba	12.8 d
95Zr	1.4 h
99Mo	67.0 h
103Ru	39.6 d
106Ru	1.0 y
141Ce	33.0 d
144Ce	285.0 d

This is the domain of **RADIOCHEMISTRY**

Focusing on Nuclear Fuel…

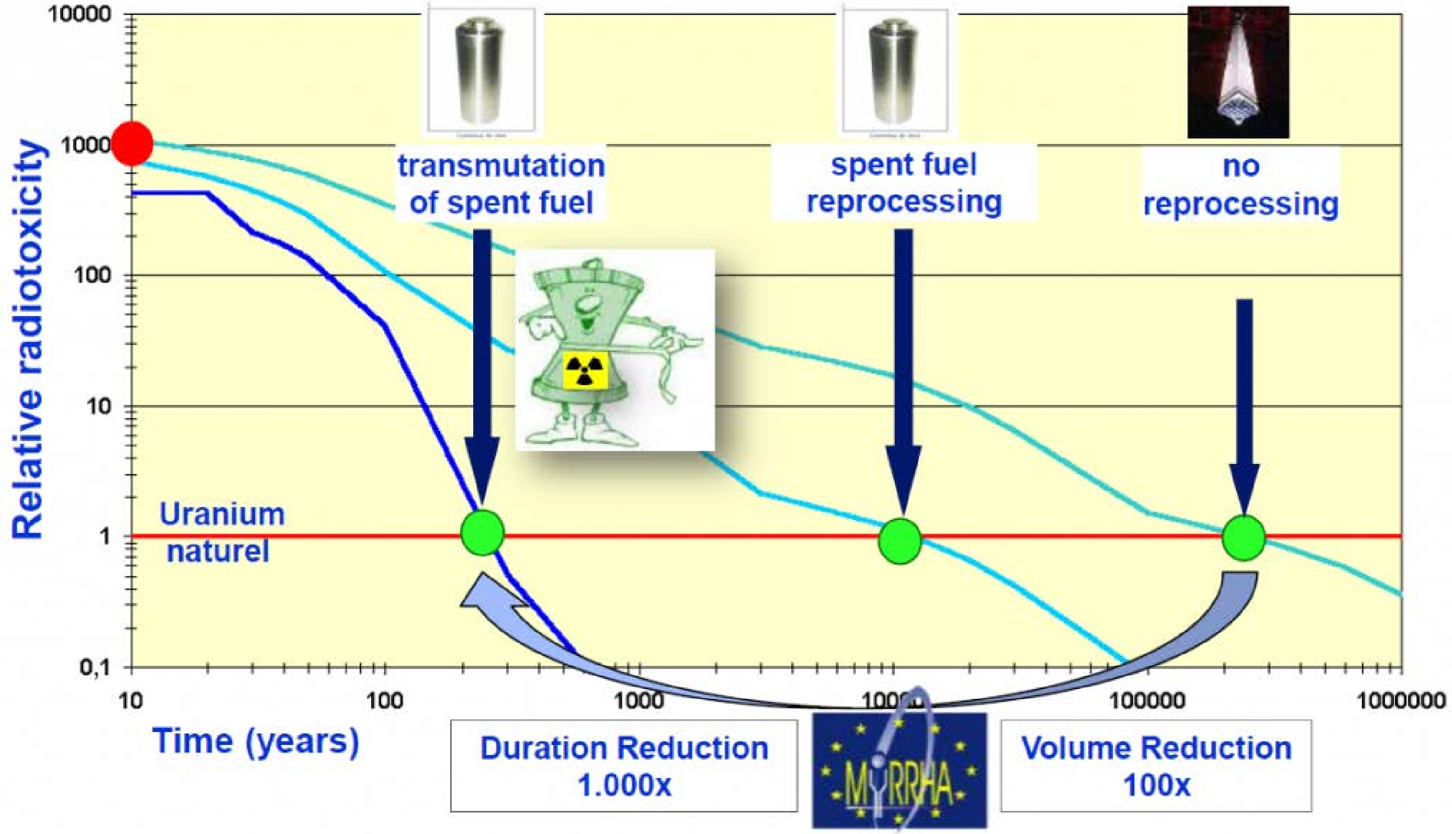


Spent Nuclear Waste

- About 95% of Uranium is still present (Major Actinides)
- About 3-4% of Fission Products
- About 1% of Plutonium (Major Actinides)
- Only 0.1% of Np, Am and Cm (MINOR ACTINIDES)

How to manage the Nuclear Waste? → **… Another domain of RADIOCHEMISTRY**

WHY A CHEMICAL TREATMENT OF SPENT NUCLEAR FUEL?

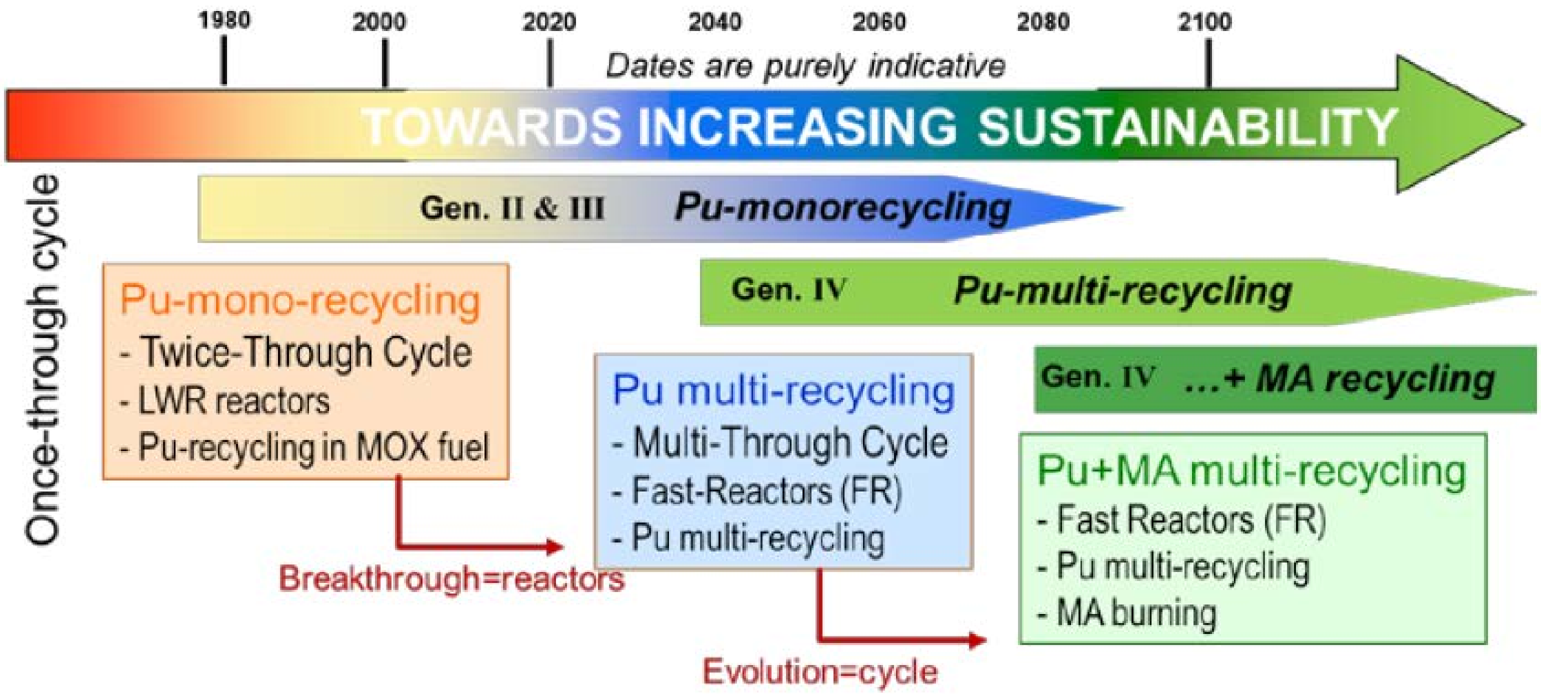


NEW STRATEGIES….

NEW *P&T&C* STRATEGIES….

GOALS

- *Radiotoxicity reduction*
- *Proliferation resistance*
- *Resources optimization*
- *Safe and sustainable waste management*



Radiochemistry

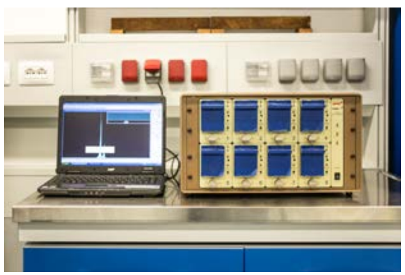
Some research topics @ PoliMi:

- **Decommissioning and Nuclear waste management**
  - Radiochemical characterization of:
    - waste from industrial plants (TENORM),
    - waste from nuclear power plants,
    - waste from nuclear medicine activities,
    - environmental contaminated matrices,
    - inert matrices for the confinement of radionuclides.

- **Partitioning of spent nuclear fuel**
  - Hydrometallurgical processes for separation of fission products, Major and Minor Actinides
- **Gen IV Systems for Transmutation of Minor Actinides: Lead-cooled Fast Reactors**
  - Fuel-coolant chemical interactions by theoretical and experimental investigations.

DECOMMISSIONING AND NUCLEAR WASTE MANAGEMENT

Radiochemical analyses of waste from nuclear power plants or industrial plants (TENORM)

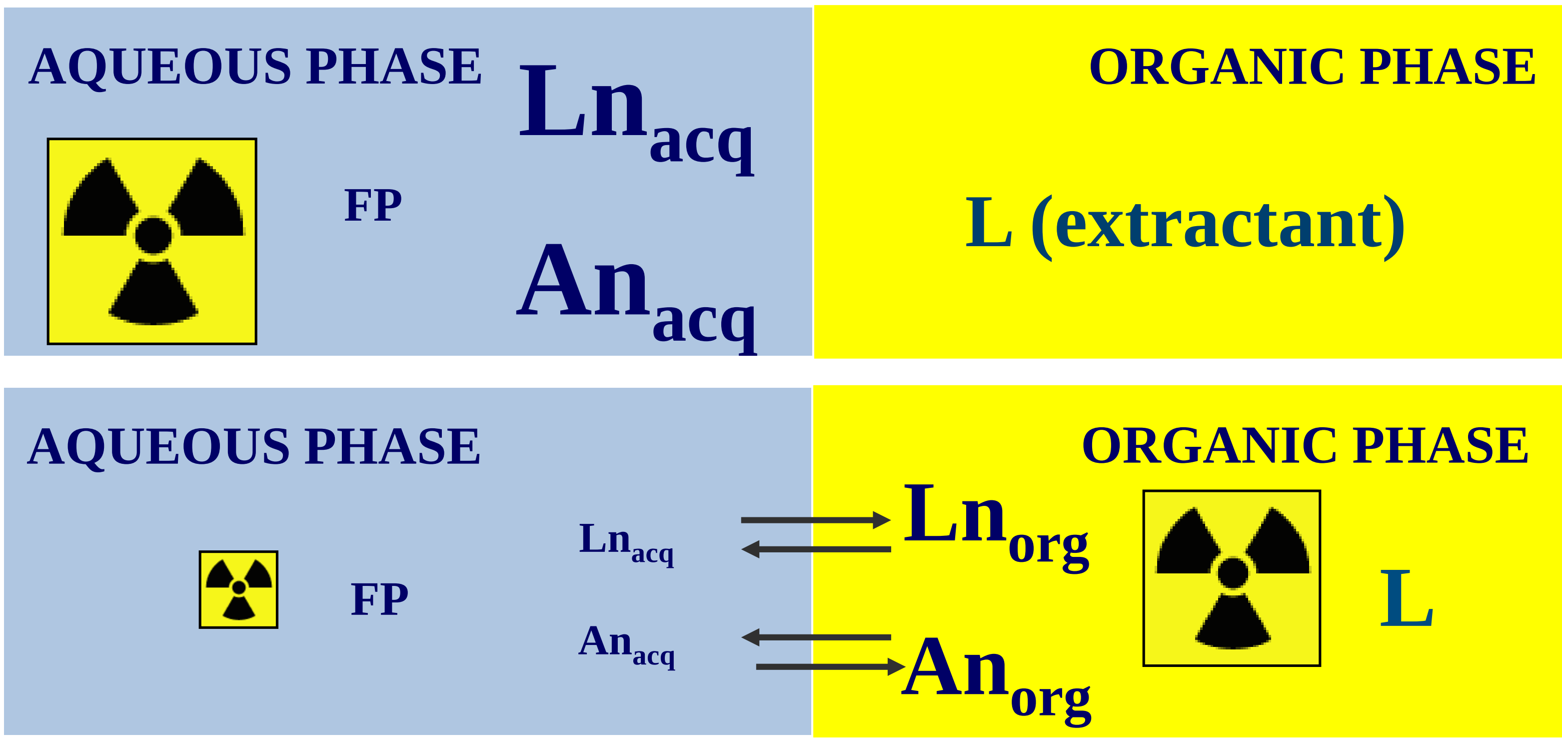


Radiometric counting (Alpha-Beta LSC, Alfa & Gamma-X Spectrometry)

ICP-MS analyses of materials and environmental matrices

Isotopic analysis at trace and ultra-trace level

Partitioning of Spent Nuclear Fuel



$$DF(An) = \frac{[An_{org}]_{eq}}{[An_{acq}]_{eq}}$$

$$DF(Ln) = \frac{[Ln_{org}]_{eq}}{[Ln_{acq}]_{eq}}$$

$$SF(An/Ln) = \frac{DF(An)}{DF(Ln)}$$

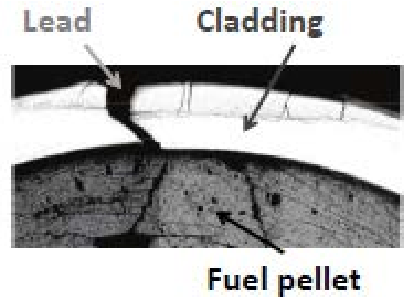
GEN IV SYSTEMS FOR TRANSMUTATION OF MINOR ACTINIDES

Lead-cooled Fast Reactor

- use a closed fuel cycle
- burners of minor actinides

GOAL

Chemical interaction between fuel-coolant due to cladding failure event during nominal and accidental operation conditions



Experimental studies
Onerous and hazardous

↔

Theoretical studies
Support and address for experimental activities

What’s the moral?

So, these few slides …

… to show you some interesting link between chemistry and nuclear world

… then to strongly support the study of Applied Radiochemistry & Radiation Chemistry…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+3
+4
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