FRANCQUI Chair 2005-2006

Universiteit Gent

Nuclear reactions, unicity of matter and mass From Thalès to Einstein

Inaugural lecture

J. CUGNON, ULg

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Emile FRANCQUI

(1862-1935)

Jean JADOT

(1862-1932)

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PhD, ULg:

"persistance of luminous impressions"

1935: Prof. Experimental Physics, UG

Joseph Antoine PLATEAU

(1801-1883)

Nuclear reactions are fascinating:

- *Unicity of matter*
- *Large release of energy*
- *Power of Life*

Milet ~640 BC


EMPEDOCLES
Agrigentinus

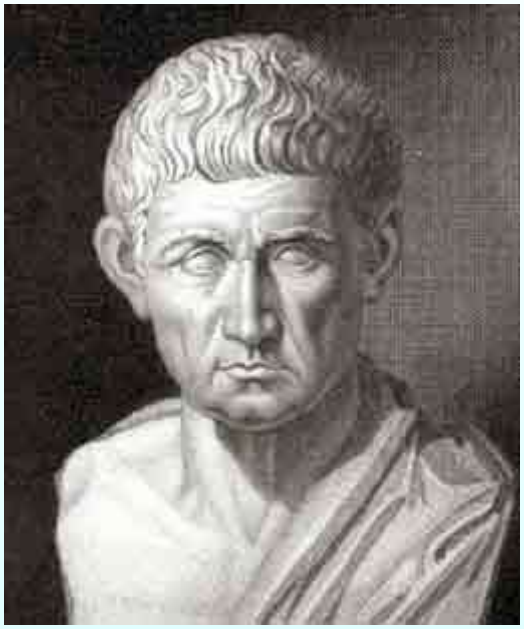
(504-450 BC)


WORLD
YEAR
HUMAN
FIRE
Dry
Hot
Summer
Chol-
eric
AIR
Hot
Moist
Spring
Sang-
uine
EARTH
Dry
Cold
Autumn
Melan-
cholic
WATER
Cold
Moist
Winter
Phleg-
matic

DEMOCRITUS of Abdere
(~460-360 BC)

atomistic theory

"*nothing comes from the non-existing and nothing returns to it*"



ARISTOTLE (384-322 BC)

restaured Empledocles's four element theory

denied conservation of mass

Alchemists

David Teniers the jong (Antwerpen 1610-1690)

... Chemists:

materials = mixtures of pure substances

pure substance = element or compound

mixture ≠ compound

iron ore⇒
magnetite+silicates+...

air⇒oxygen+nitrogen

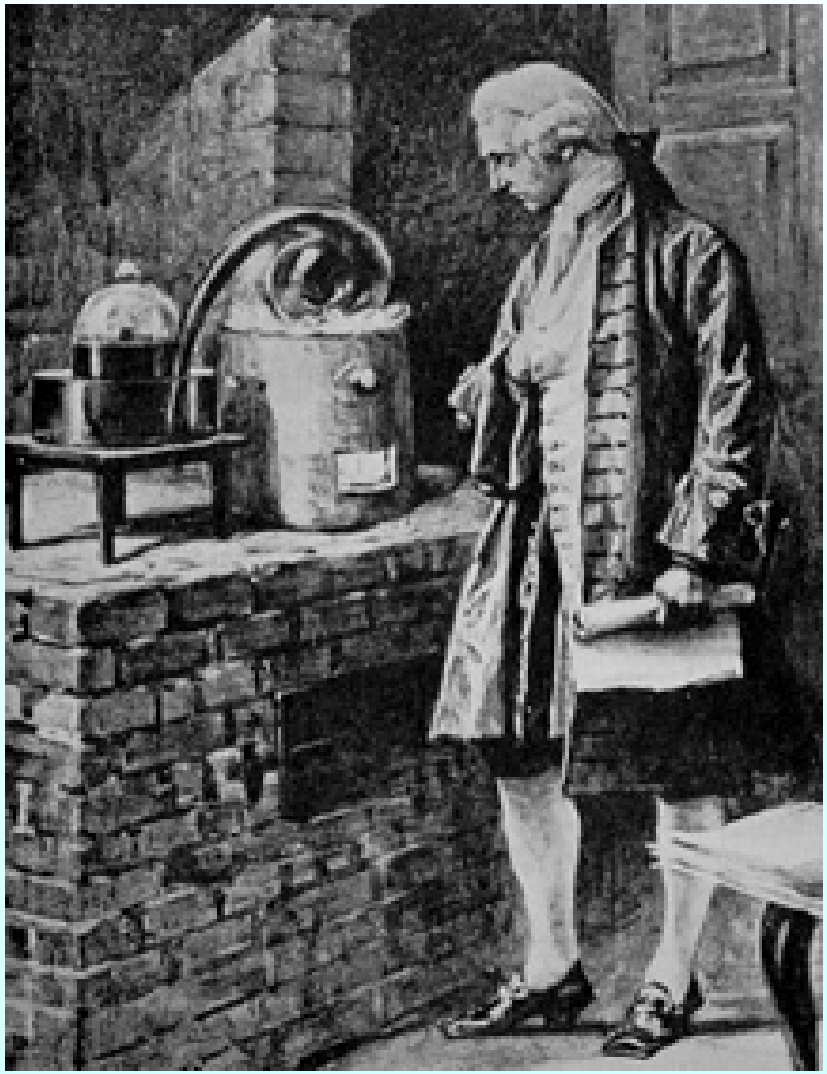
magnetite ⇒ iron+oxygen

water ⇒ oxygen+hydrogen

Chemical reactions:

- elements ➔ compounds Ex: oxygen + hydrogen ➔ water
- compounds ➔ compounds Ex: copper oxyde+sulphuric acid ➔ water + copper sulphate

elaborated from ~50-60 elements (at the end of the XVIIIth century)



"Rien ne se perd, rien ne se crée"

father of modern chemistry

An element cannot be transformed into another one

Antoine LAVOISIER (1743-1794)

John Dalton (1766-1844)

law of multiple proprotions:

-nitrogen + oxygen➔ nitrogen oxyde

-nitrogen + oxygen➔ nitrogen peroxyde

N/O = 7/12, 7/20

elements made of identical atoms,
atom weights are commensurable

$2\ N + 3\ O \rightarrow 2\ N_2O_3$

$2\ N + 5\ O \rightarrow 2\ N_2O_5$

A simple world:

a few tens of different atoms combine to myriads of compounds

chemical reactions=rearrangements of atoms

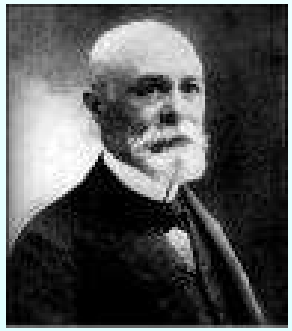
$Hg + O \rightarrow HgO$

$2\,H_2 + O_2 \rightarrow 2\,H_2O$

$Cu_2O + H_2SO_4 \rightarrow Cu_2SO_4 + H_2O$

In 1897:

- Discovery of the electron (J. J. Thomson)
- Discovery of the radioactivity (H. Becquerel)

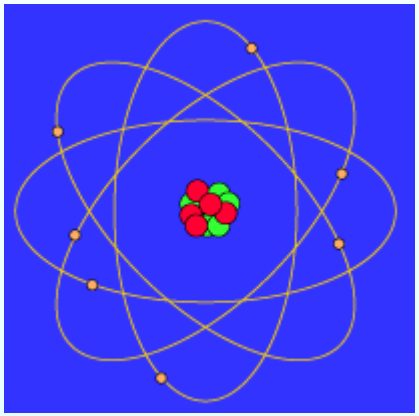


- atom = positively charged stuff + electrons
- elements changes into one another (U➞Ra➞Po):

  “metabolous matter”

In 1912, E. Rutherford :

- atom = positively charged heavy and tiny nucleus + orbiting electrons
- first nuclear reaction:



nucleus of helium + nucleus of nitrogen ➞ nucleus of oxygen + nucleus of hydrogen

In radioactivity & in nuclear reactions, elements can be transmuted!!!

1932: Discovery of the neutron (J. Chadwick)

nuclei made of neutrons (n) and protons (p)

nuclear reactions = rearrangements of n's and p's

$$(2p,2n) + (7p,7n) \rightarrow (8p, 9n) + 1p$$

$$^{4}He + ^{14}N \rightarrow ^{17}O + ^{1}H$$

An extraordinary simple world:

- matter is made of p, n, e
- reactions: rearrangements of atoms or of protons and neutrons

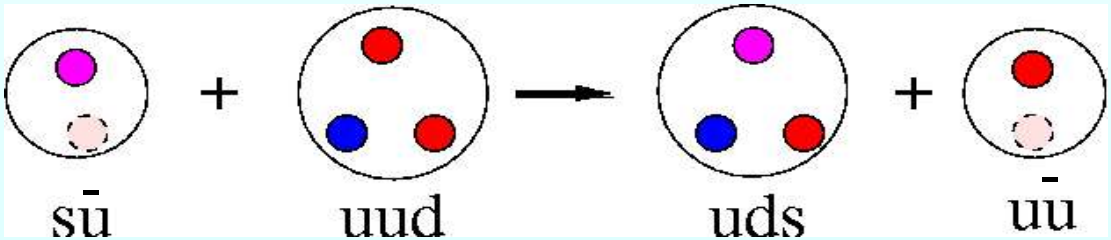
☞ *Unicity of matter*

At smaller scale :

nucleons and similar particles (hadrons) are made of quarks

- some reactions may look like chemical or nuclear reactions

$$K^- + p \Rightarrow \Lambda + \pi^0$$



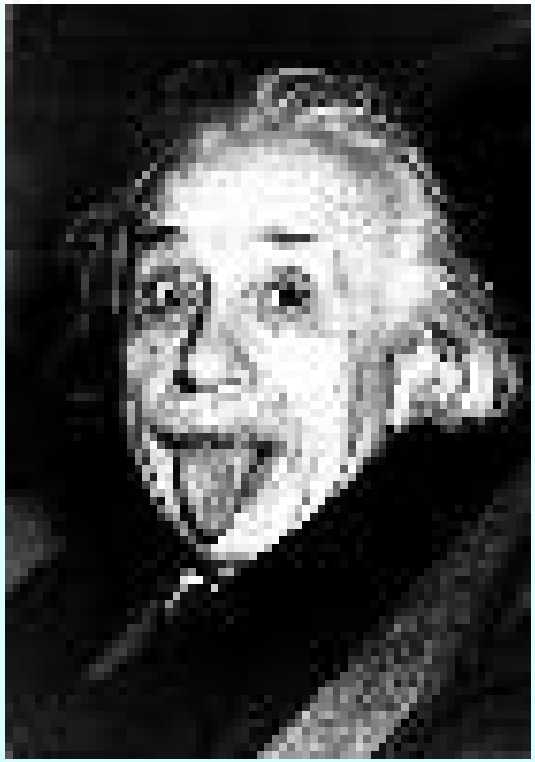
- but: - p → u+u+d does not exist (HCl→H+Cl)
  - quarks and antiquarks can be created
  - other component (sea)

Energy production in nuclear reactions:

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$: 890 KJ/mole or 55KJ/gr

$n + {}^{235}U \rightarrow$ 2 fission fragments: 20 TJ/mole or 600 MJ/grU

Nuclear reactions and the conservation of mass



1905: “annus mirabilis”

Lavoisier's principle
is challenged

Albert EINSTEIN (1879-1955)

June: basis of Special Relativity

- constancy of light velocity
- principle of relativity

⇨ time is not running the same for all observers

Newton's law should be modified:

$$T = \frac{1}{2} m v^2 \rightarrow T = m c^2 \left\{ \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right\}$$

September: an application of SR

If a body emits a radiation of energy ΔE, its mass is reduced by Δm:

$$\Delta m = \frac{\Delta E}{c^2}$$

Mass-Energy Equivalence

⇒conservation of mass + energy

"with bodies whose content in energy vary in large proportions (for example in radium salts)"

chemical reactions: combustion of methane

$$\Delta m = \frac{\Delta H}{c^2} = \frac{890\,KJ/mole}{c^2} = 10\,ngr/mole$$

In 1932, first accelerator of particles

First experiment:

$$p + {}^{7}Li \rightarrow \alpha + \alpha$$

Conservation of mass + energy verified (<1%)

E. Walton

Einstein ⇔ nuclear fission, atomic bomb

"$E=mc^2$, the equation that changed the world, leading to the discovery of fission, of the atomic bomb and of nuclear energy"

Nuclear fission would have been discovered, even if Einstein had not published his paper on mass-energy equivalence.

"*I do not consider myself as the father of the release of atomic energy*"

(A. Einstein, 1945)

Einstein and the atomic bomb

Fission is discovered in 1938 (O.Hahn)

Large release of energy (L. Meitner, 1939)

Chain reactions by neutrons (F. Joliot-Curie, E. Fermi and L. Szilard, 1939)

Szilard and Teller approach Einstein in summer 1939

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an unofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work,which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,
A. Einstein
(Albert Einstein)

myth : Einstein's sole support to the atomic bomb program and use =
sending this letter (with reluctance)

nourished by:

Einstein's antimilitarism (especially during 1st World war)

Einstein-Russell manifesto against nuclear weapons (1955)

Einstein wrote 3 letters to Pres. Roosevelt (Aug 39-April 40)

He made (limited) work on gaseous diffusion

In March 1945, he wrote to Truman concerning "atomic policy"

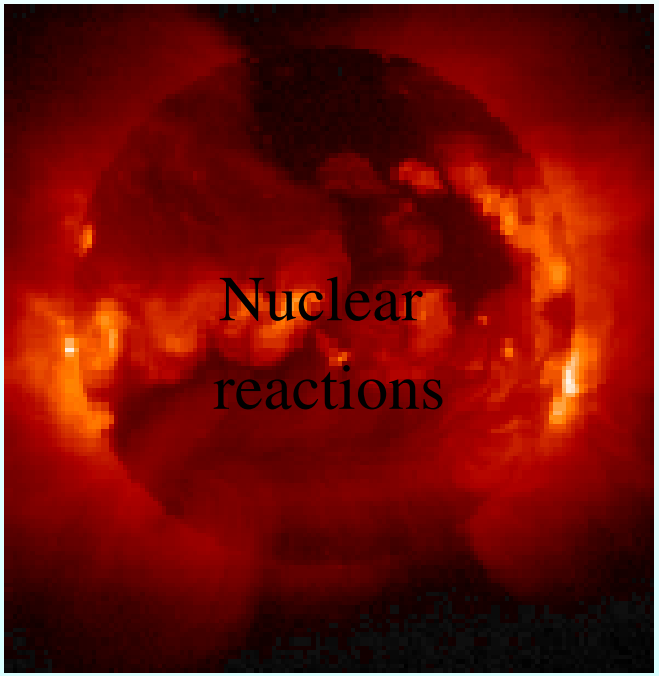
He didn't make any public statement during the year after the 1st bombings

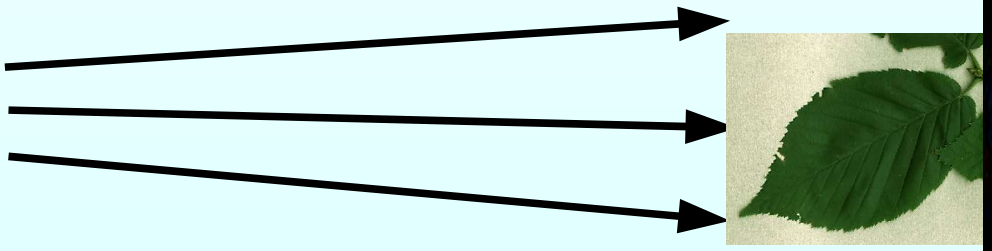
Afterwards, he opposed clearly to the development of nuclear weapons

"*The discovery of nuclear chain reactions need not bring about the destruction of mankind any more than did the discovery of matches*" (A. Einstein, 1953)

"I made one great mistake in my life... when I signed the letter to President Roosevelt...;
but there was some justification - the danger that the Germans would make them." (Clark, pg. 752).

Nuclear reactions and life





600 million tons of H are transformed into He every second

$L_\odot = 3.85 \times 10^{26}$ W

Only 50 parts in a billion for the Earth (166×10^{15} W)

Only 0.023% is used to power Life (photosynthesis) 3800 GW

Contents of the lectures:

1. Description of nuclear reactions

2. Nuclear reactions have shaped (and are shaping) our World

3. Applications

4. Relation with fundamental science

DESCRIPTION OF NUCLEAR REACTIONS

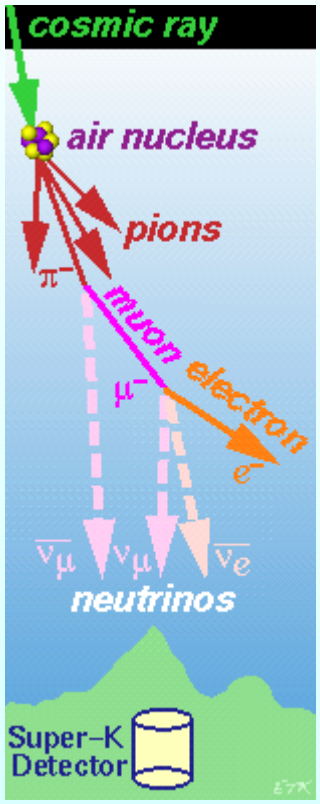
We do not have a unified (tractable) theory

Recent progress: this could be achieved in ~40 MeV- a few GeV range

NUCLEAR REACTIONS SHAPE OUR WORLD

Primordial matter (H,He) has been processed in early stars

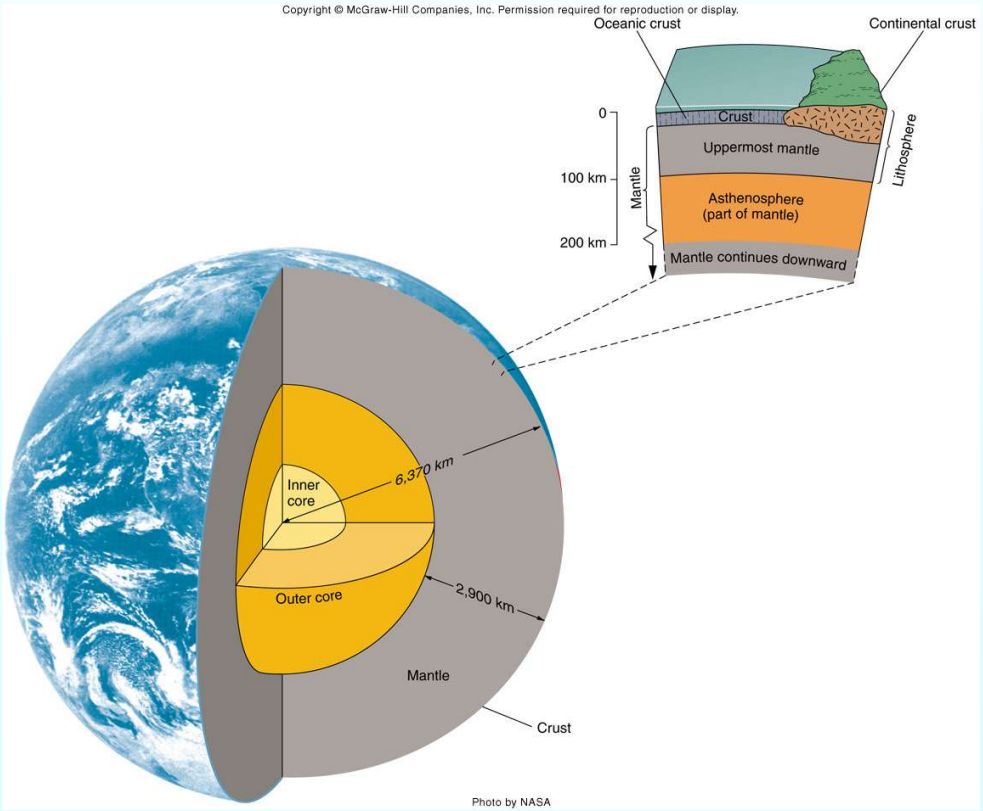
We have been “made” inside a star by nuclear reactions



← ground level

Cosmic rays are responsible for part of natural radioactivity

$$p + {}^{16}O \Rightarrow {}^{14}C + \ldots$$



Radioactive decay of
^{238}U, ^{232}Th, ^{40}K, ^{87}Rb

Heat flow 0.090 W/m^2

Motor for tectonics, orogenesis, volcanism, tsunamis, etc...

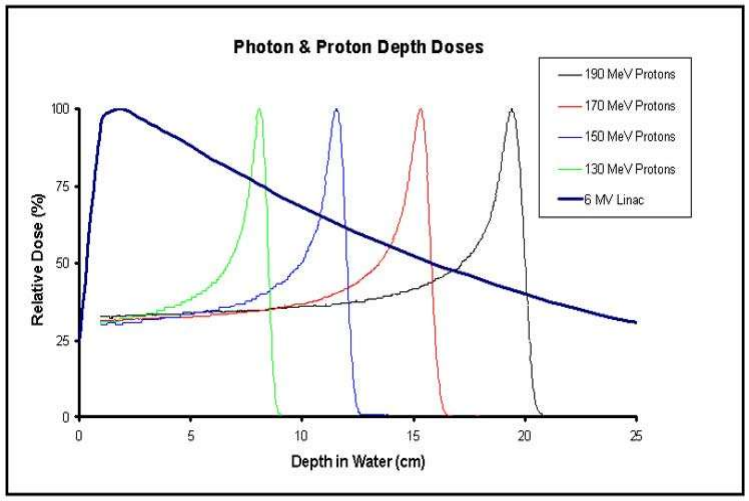
Two billion years ago,
a natural nuclear reactor
worked for a million year

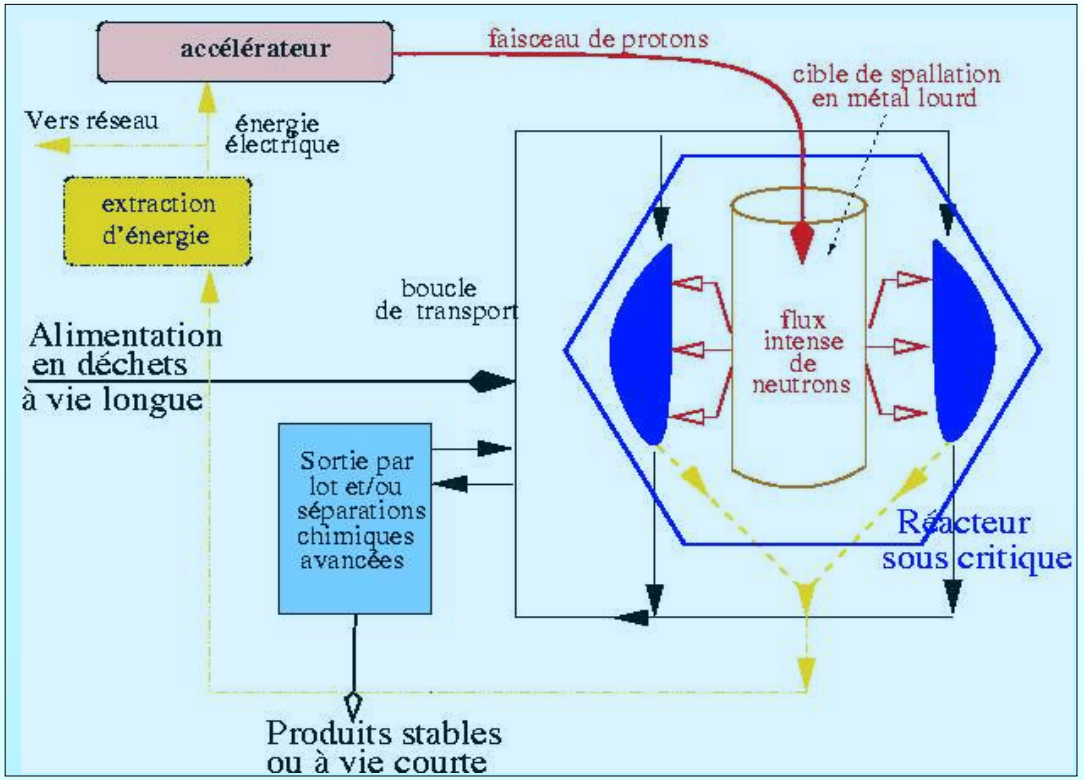
OKLO, Gabon

Current APPLICATIONS:

- energy production
- medical diagnosis and therapy
- environmental science
- water resources
- pollution control
- food sterilisation
- engineering, new materials
- archeology and art

Two recent (or future) applications





Proton Radiotherapy

MYRRHA, SCK-CEN

Transmutation of nuclear waste

NUCLEAR REACTIONS & FUNDAMENTAL SCIENCES

- primordial nucleosynthesis → number of neutrinos
- Oklo data → variability of physical constants (Dirac)
- heavy-ion reactions → quark-gluon plasma
- ...

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May 17, 2p:m. Nuclear reactions: properties and description

May 31, 2p:m. Fusion nuclear reactions (ITER and the sun)

June 14, 2p:m. Nuclear reactions in the cosmos

Sept. 6, 2p:m. Nuclear fission and applications

Sept. 13, 2p:m. Modern transmutation: a solution to the nuclear waste problem?

http://www.theo.phys.ulg.ac.be/