Nuclear Energy and waste transmutation

A PASSION FOR EXTREME LIGHT
For the greatest benefit to human kind (Alfred Nobel)

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The Catholic Social Teaching from inception to the digital age:
How to live the Laudato Si’
World energy consumption

- 13.3 GTeP
- 2000 kWh/y per habitant
-(Europe 4000, USA 10000, Africa 500...)
EU Countries
Relative CO2 emission (g CO2 equivalent/Kwh) compared to Power generation

Jan, 1 – Dec 31 2018
NUCLEAR ENERGY : GLOBAL FACTS

A rather young form of Energy, of limited importance at the world level (5%, 0.67GTeP), economically viable source of electricity (2000TWh, 10%), **Carbon free!!**

**Efficient** → Fission of 14g of U = 1TeP = 42 GJ

- Production concentrated in a few countries
  (USA + FR + Jp + Ru) = 2/3 of the world nuclear energy

A passionately contested energy for
Its origin related to defense, Its cost structure (high investments, delayed returns)
And questions insufficiently dealt with in the past
Proliferation (Pu mostly), Safety, and Nuclear waste management

These questions generate social concerns for the future
Management of current waste
Two types of waste policies

U ore 200t

enriched U 30t

Once-through case (US, Sw)

1GWe.yr = 1t of fissioned material

Waste: nearly 1t
- Fission products
- 100% U, Pu
- 100% Np, Am, Cm

Geological storage of spent fuel
300,000 yr

Pu recycling (Fr, J)

U ore

enriched U

Reduction of final waste
- Once-through Pu recycling
- possibility of multirecycling

U, Pu (MOX)

Partition 10,000 yr

And if Transmutation 300 yr

U, Pu precious fuel!!

HL Waste: only 50 Kg
- Fission products
- 0.1% Pu
- 100% Np, Am, Cm
A few kg of minor actinides MA (Pu, Am, Cu, Np,..) are responsible for most of the radiotoxicity and the long lifetime of Nuclear waste.
Motivation for transmutation of spent fuel

- Duration reduction 1,000x
- Volume reduction 100x (1t to 0.05t)

Transmutation of spent fuel

Spent fuel reprocessing

No reprocessing

Relative radiotoxicity vs. time (years)

Uranium ore
An **Accelerator-Driven-System** is: a subcritical neutron multiplication assembly driven by an external neutron source, **10^17 n/s** obtained through the spallation mechanism with high energy (~1GeV) protons.
Ultra High Intensity Laser “A revolution”

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QCD $\sim 10^{35}$ W / cm$^2$
Nonlinear QED: $E \cdot e \cdot \lambda_e = 2m_0c^2$

Ultra High Intensity Laser

Donna Strickland
Gérard Mourou

Physics NOBEL Prize 2018
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Giant wakefield acceleration in solid
Tajima et Dawson (1979)

Laser-particle accelerations to the GeV/mm level become possible
Therefore new laser driven source may be the solution for transmutation

1PW Extreme Light is
1000 times the world grid power in
10-15s

ICAN (European Project)
The Future is Fibre Accelerators (Nature Photonic April 2013)
Compact, Safe, Mobile, Liquid and Scalable TRANSMUTATOR of Spent Nuclear Waste
T.Tajima, S.Gales, G. Mourou et al

* Safe by Liquid solution-FLiBe (molten salt with very high boiling point, passive safety valve)

**Safe by realtime monitor and control (by laser and laser Compton gamma)

***Safe by external Laser- Fusion Trigger (flexibility, safety, compact, mobile, inexpensive, compared to Acc technologies)
MA and TRU Transmutation

- Fast Reactor: 20 kg/Gw$_{th}$yr
- MYRRHA: 300 kg/Gw$_{th}$yr

Our approach (without any form of optimization):
- MA only: 100 kg/GW$_{th}$yr
- Pu+MA: 250 kg/Gw$_{th}$yr
Some conclusions

- Nuclear energy does not appear any more to be a solved technical question
  - Overall (societal, economic) boundary conditions have evolved significantly since 1980 and will still do so in future
  - Innovation is and will be required.
    - Both Fundamental and Applied research can contribute via:
      Multi-disciplinarity approach

In any nuclear energy scenario Transmutation of high level waste is a feasible solution to reduce the heat load, the volume and the time storage of remaining waste.
In addition on the long term it will make the transition to Carbon free energy more realistic through a safer and more acceptable nuclear energy contribution.
Laser Generation of Neutrons: Science and Applications

Thank you for your patience