TRANSMUTEX

Comment détruire les déchets des centrales nucléaires

Maurice Bourquin

DPNC, 22 Décembre 2021

NZZ am Sonntag

Atom ohne Müll: Kommt jetzt die Stromrevolution?

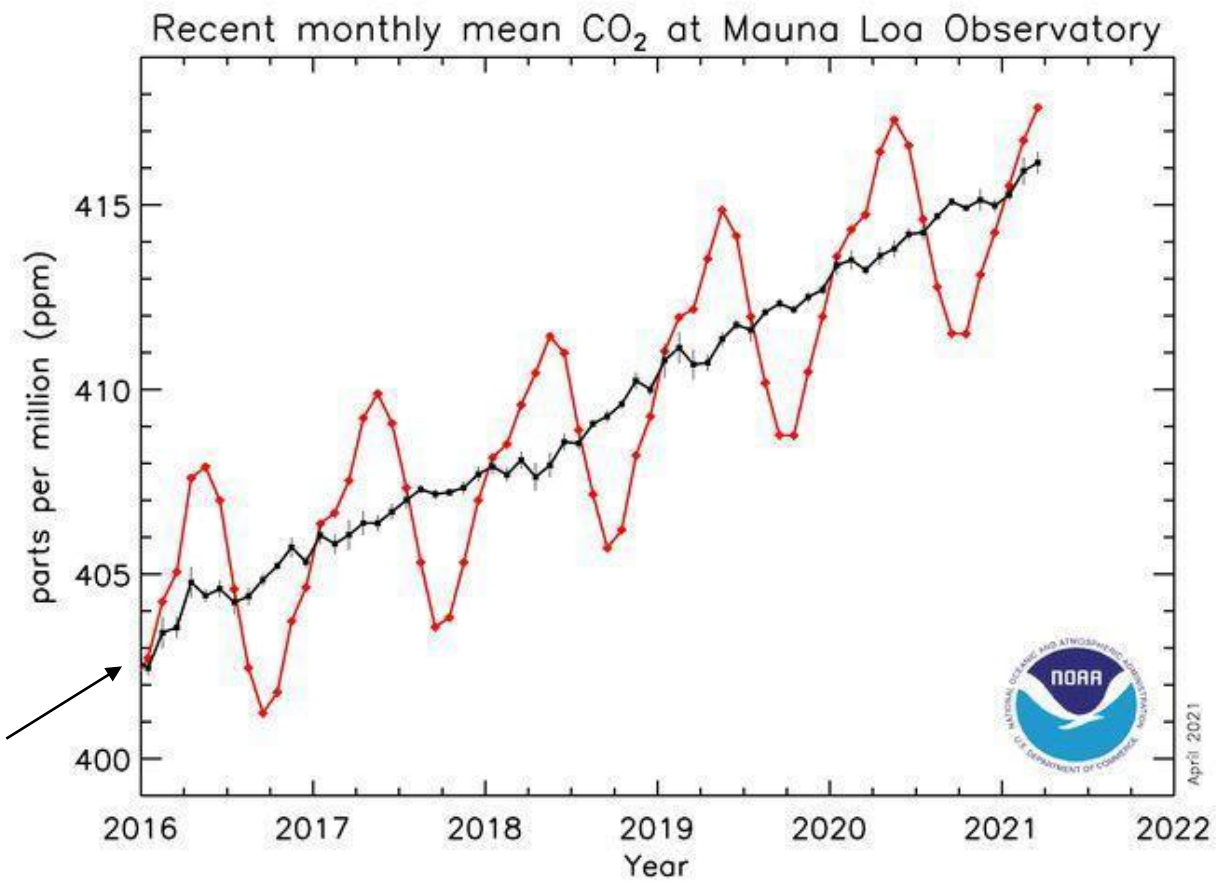
Ein Genfer Startup entwickelt ein Kernkraftwerk, das vollkommen sicher ist. Doch nicht nur das. Es kann auch den Atommüll unschädlich machen.

Jürg Meier
04.12.2021, 21.45 Uhr

Gründer und Mitarbeiter von Transmutex (von links): Maurice Bourquin (Berater), Dorothée Baumann-Pauly (Verwaltungsrätin), Franklin Servan-Schreiber (Mitgründer und CEO), Jean-Pierre Revol (Mitgründer) und Massimo Morichi (Berater). (Vernier, 14. Oktober 2021)
Anna Pizzolante

1. Augmentation irresistible du CO_2

2015
Accord de Paris

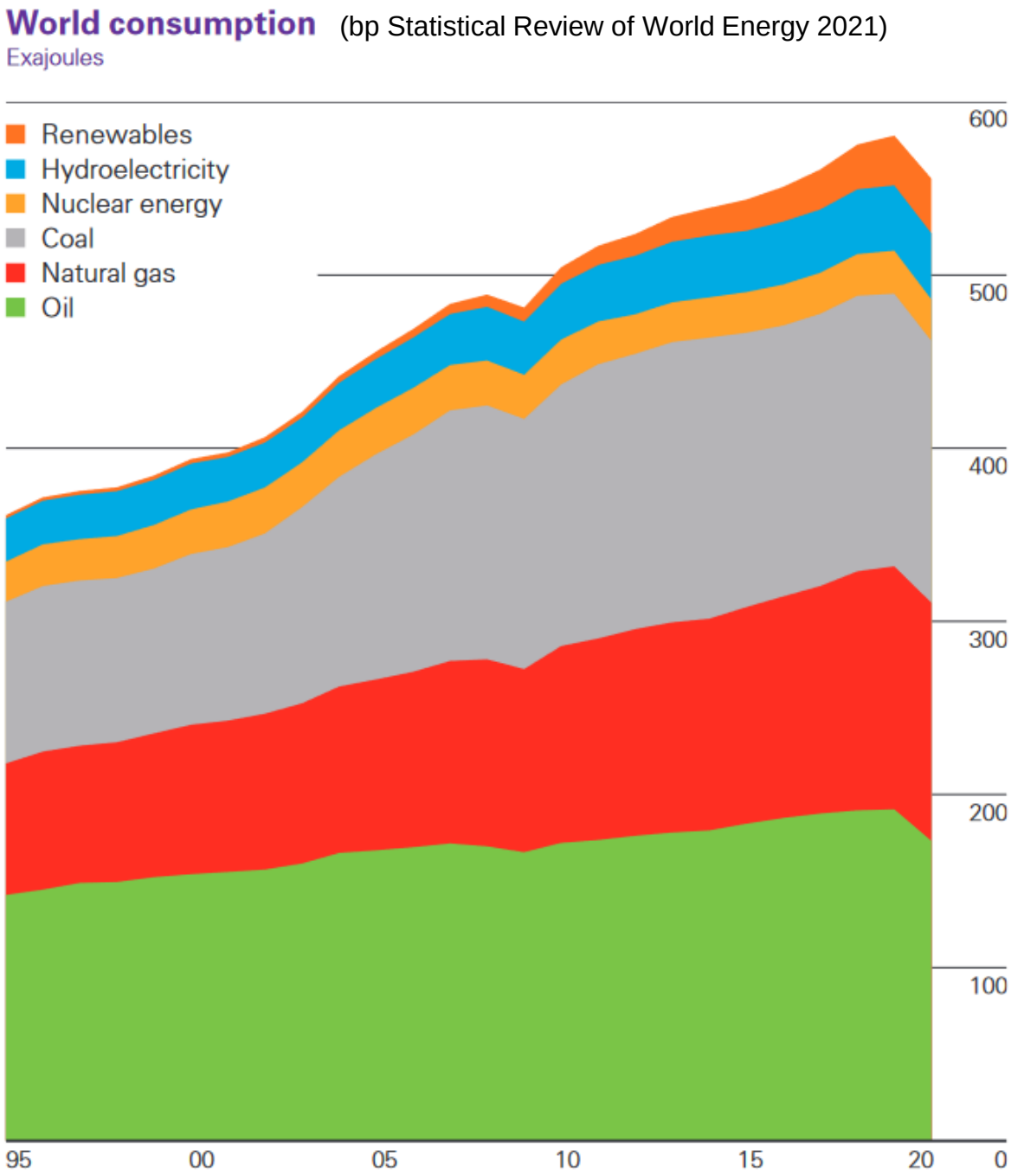


Motivations

2. Augmentation de la consommation d'énergie

Sous forme d'électricité 20% dans le monde

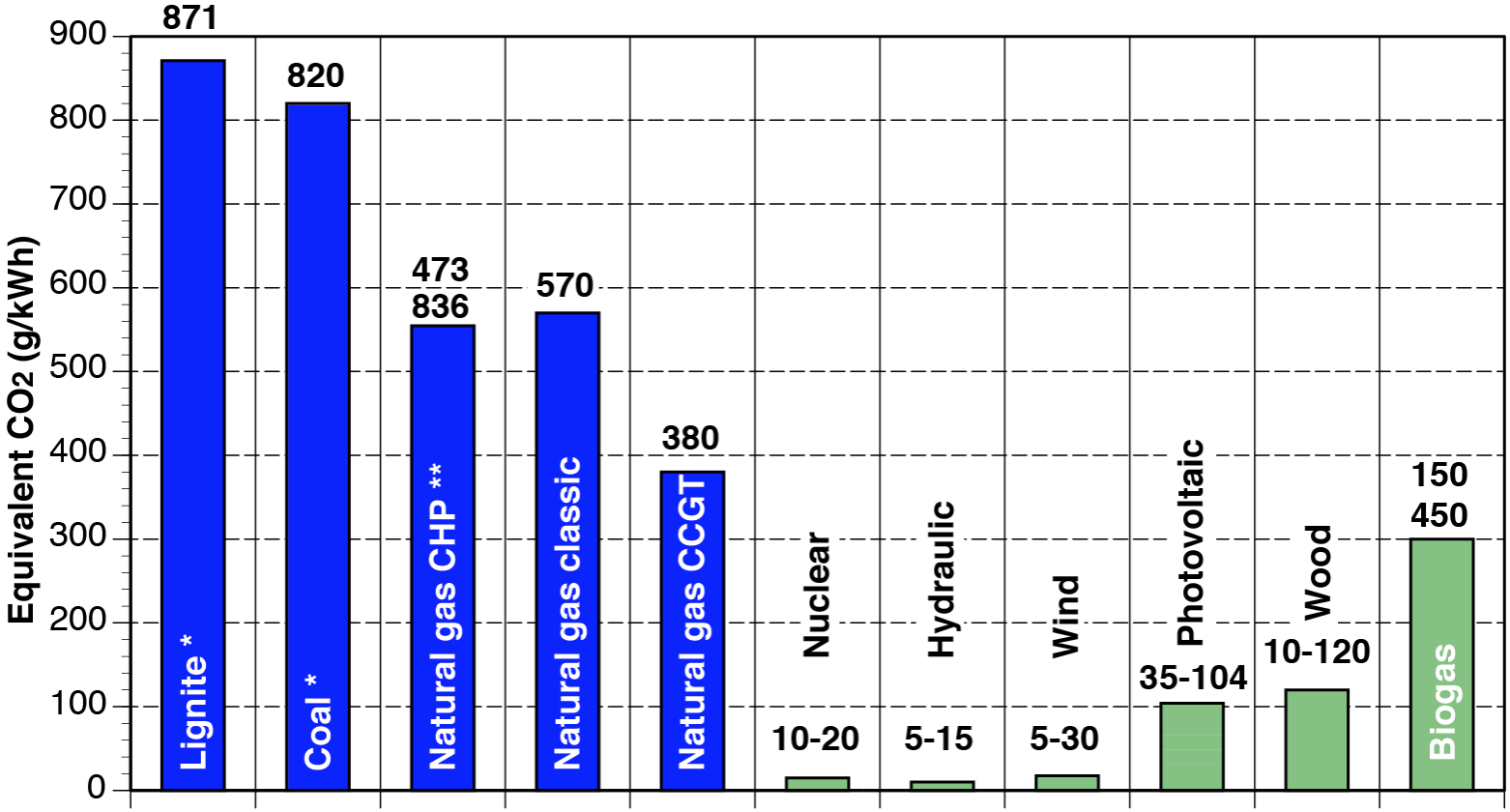
En Suisse 27%, attendue 43% in 2050



Emissions de GAS par sources d'énergie électrique

(See www.electricitymap.org for live data)

Source : Office Fédéral de l'énergie, Suisse,



* Values for large modern gas power plants with coal gasification

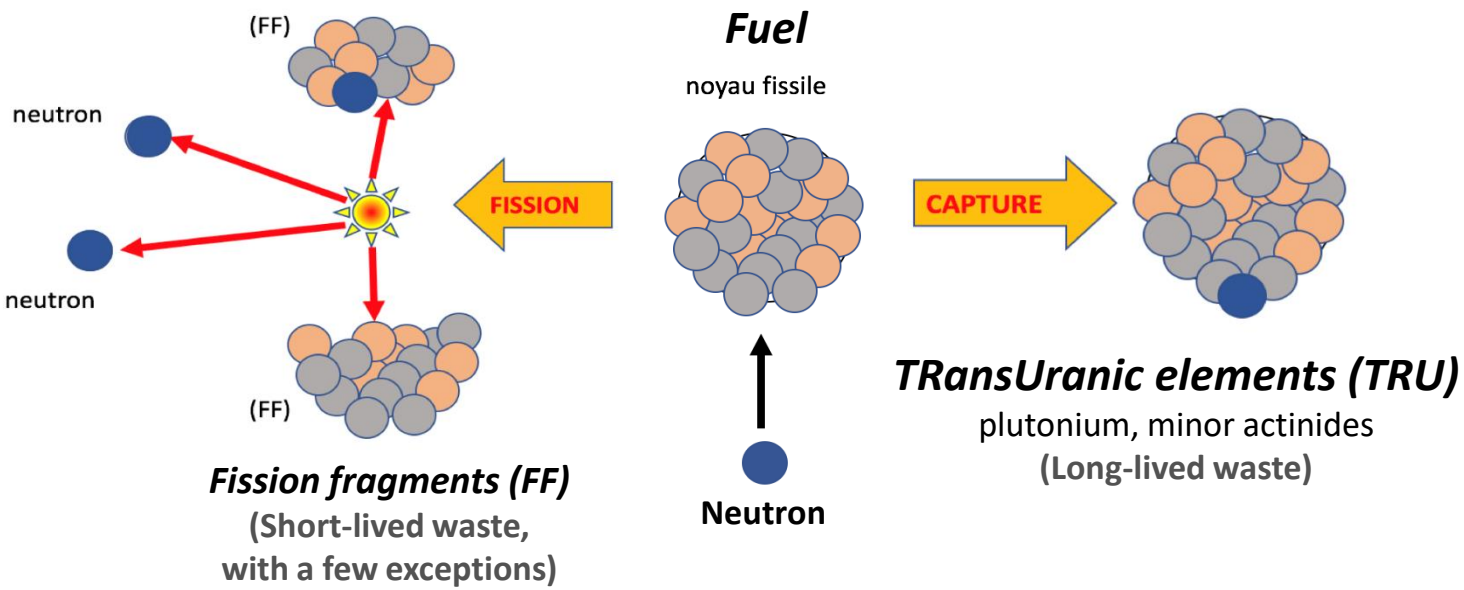
** Cogeneration plants, often called combined heat and power (CHP) facilities

Motivations

- L'énergie nucléaire pourrait jouer un plus grand rôle (émissions minimales de CO2, production stable, indépendante de la météo…)

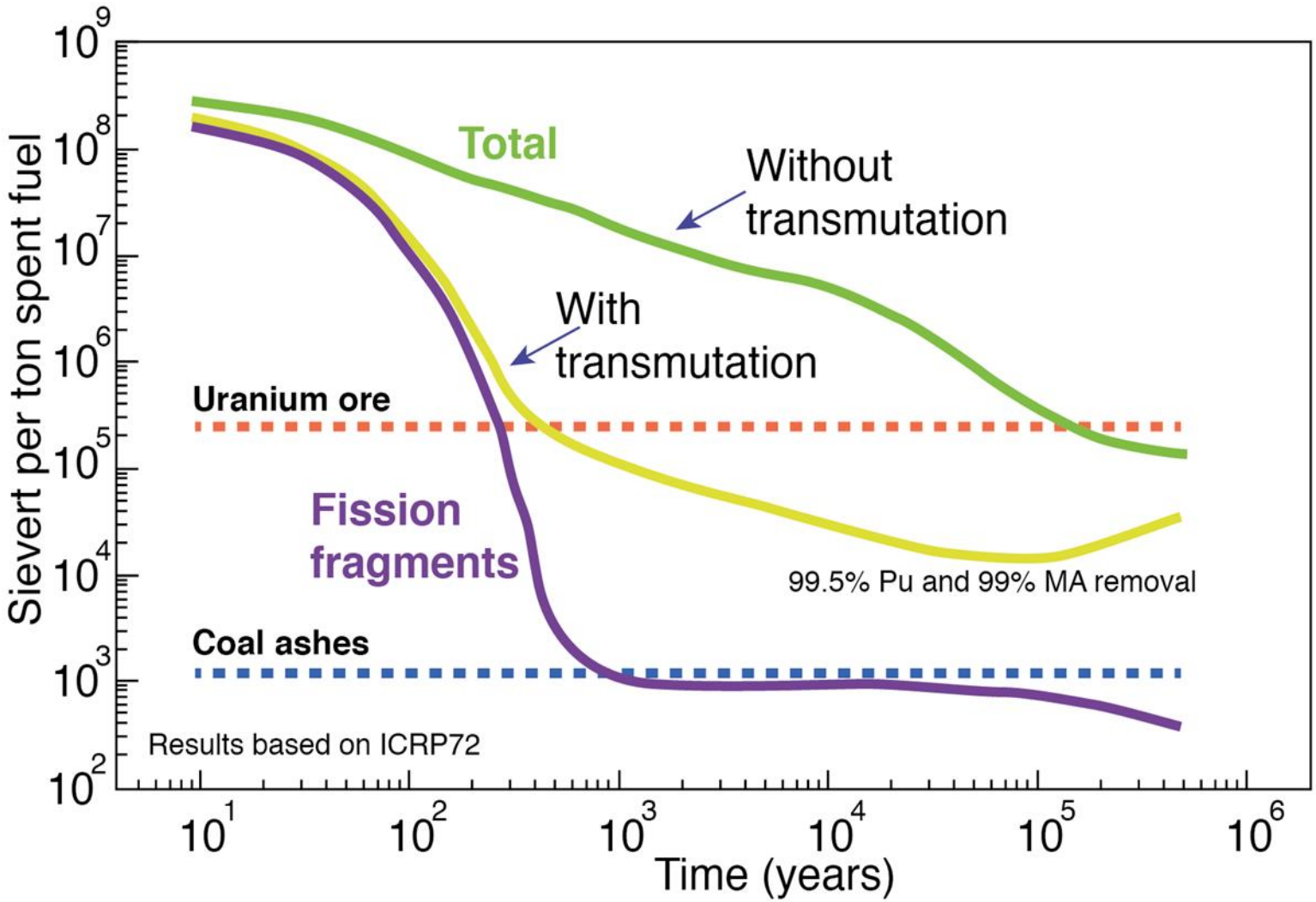
- Cependant, les centrales nucléaires au combustible uranium sont problématiques:
  - Risques d'accidents (sécurité active, refroidissement à l'eau…)
  - Risques de proliferation militaire
  - Gestion du combustible usé

Combustible nucléaire usé

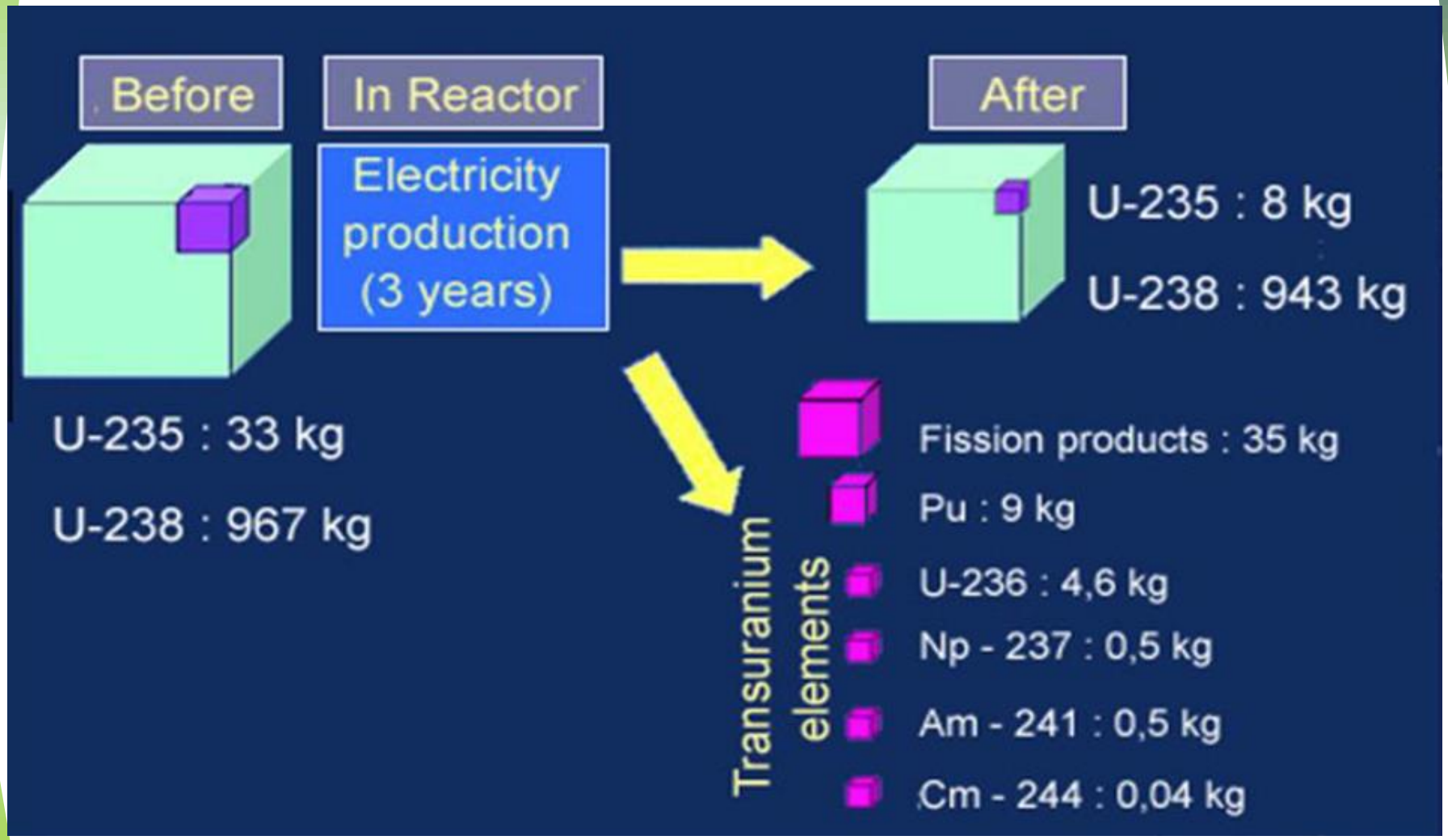


Radiotoxicité par ingestion de combustible nucléaire usé

en Sv par tonne de metal lourd en function du temps après décharge du réacteur



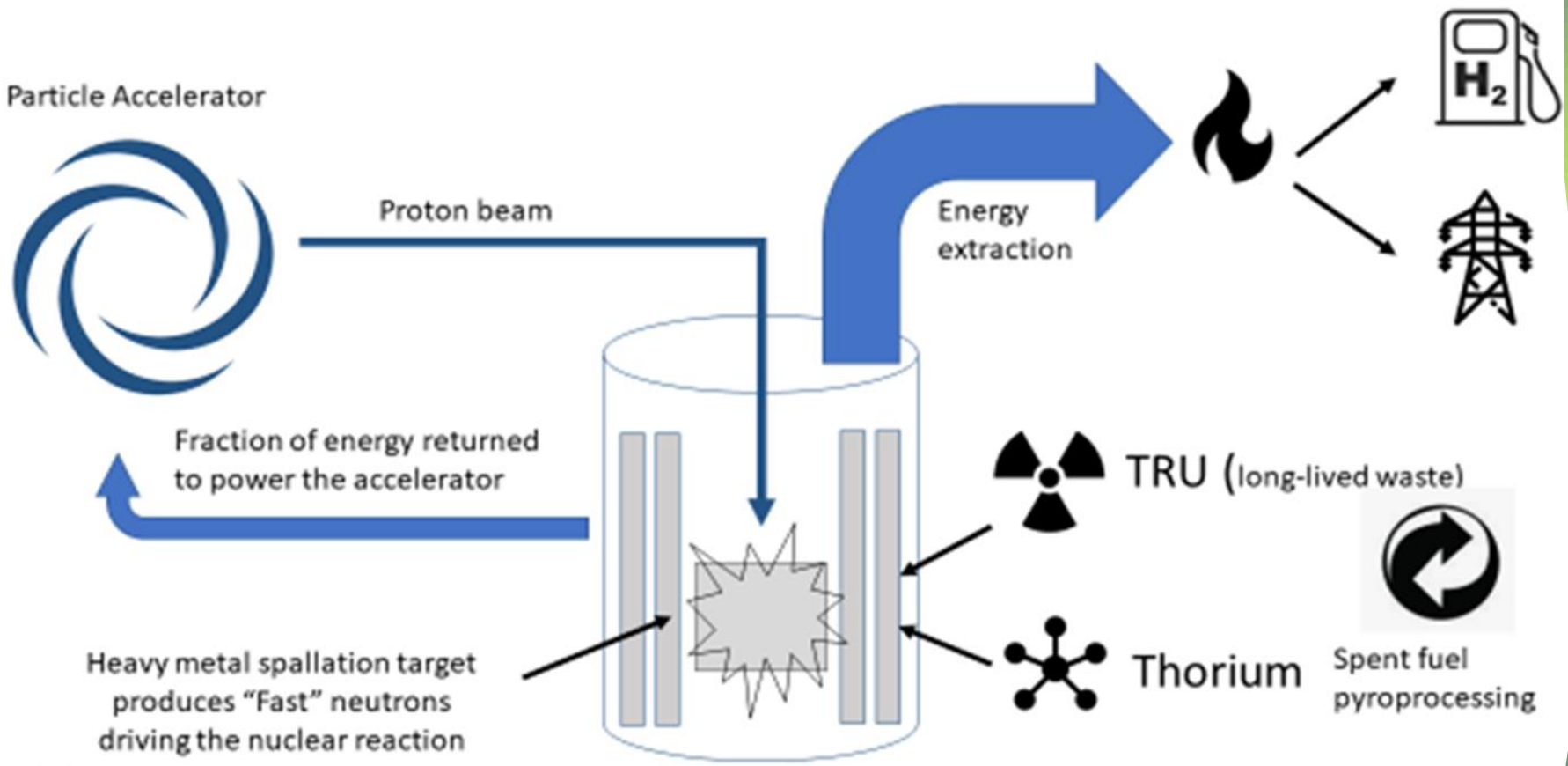
Combustible nucléaire usé de centrales à uranium



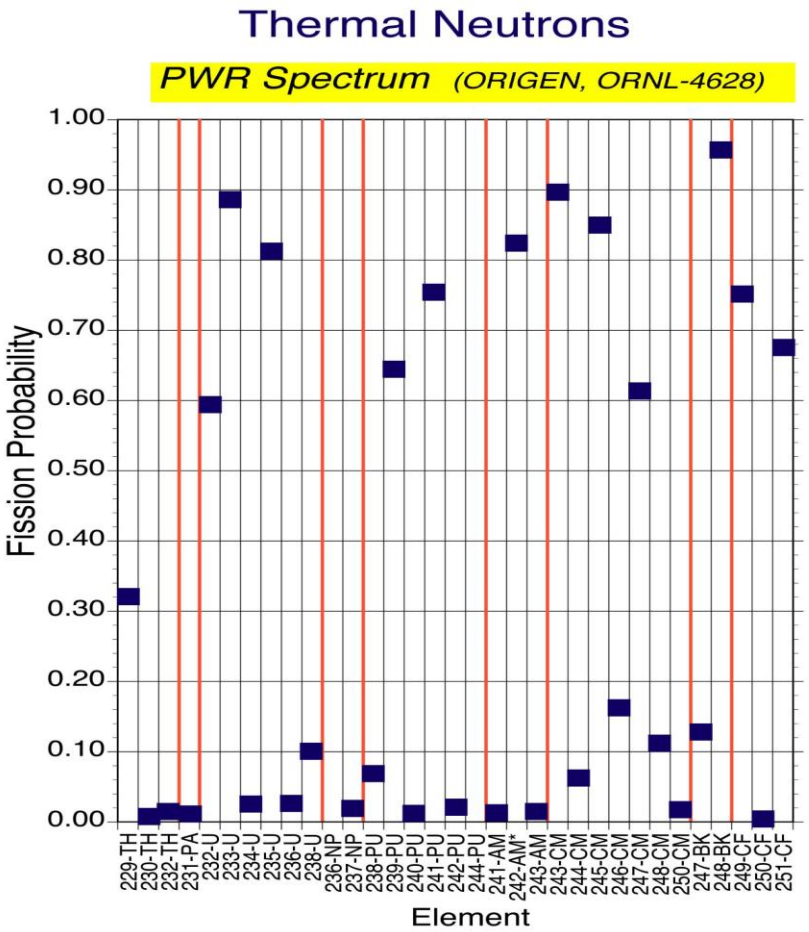

CETTE FOIS TOUT LE MONDE EST CONCERNÉ ...
MÊME LES AUTRUCHES !
ON NE PEUT PLUS ÊTRE TRANQUILLE NULLE PART...
GOUTAL

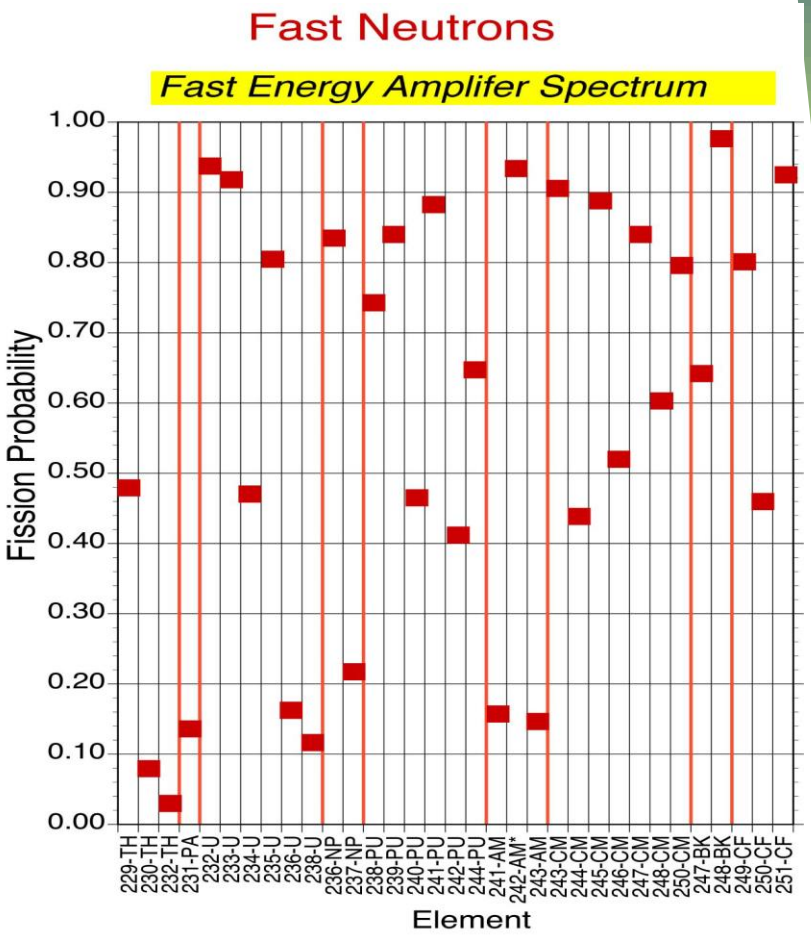
Réacteur piloté par accélérateur

Accelerator-Driven System (ADS)



Probabilités de fission des éléments transuraniques



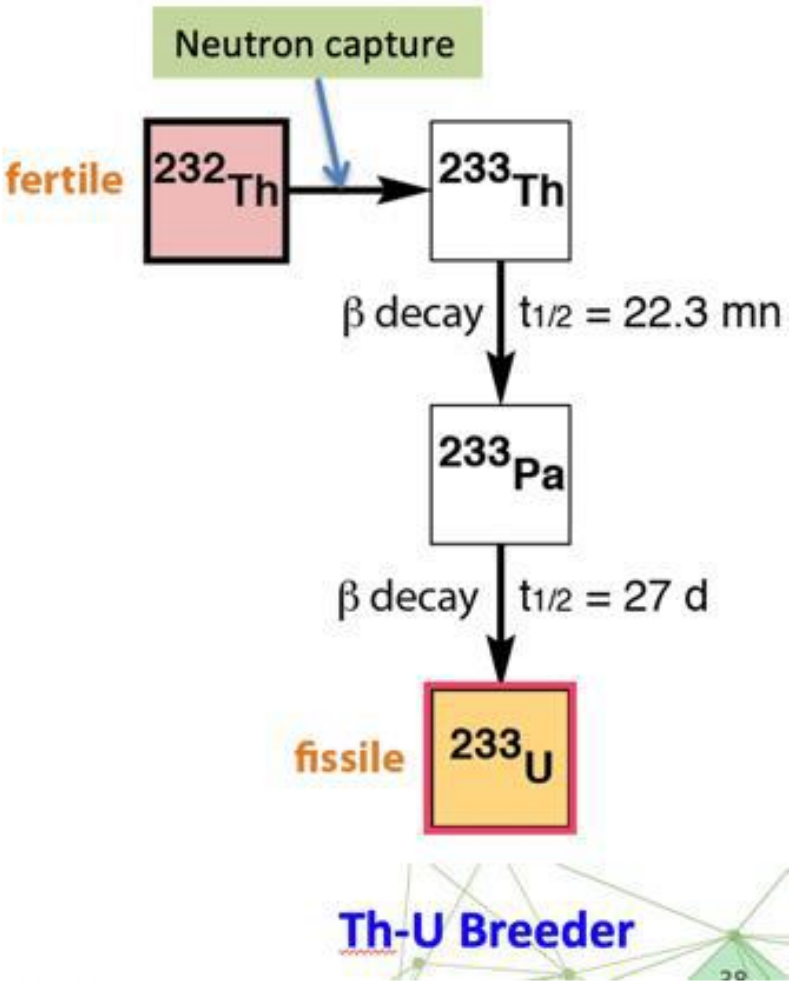


Fast neutrons also reduce captures in FF

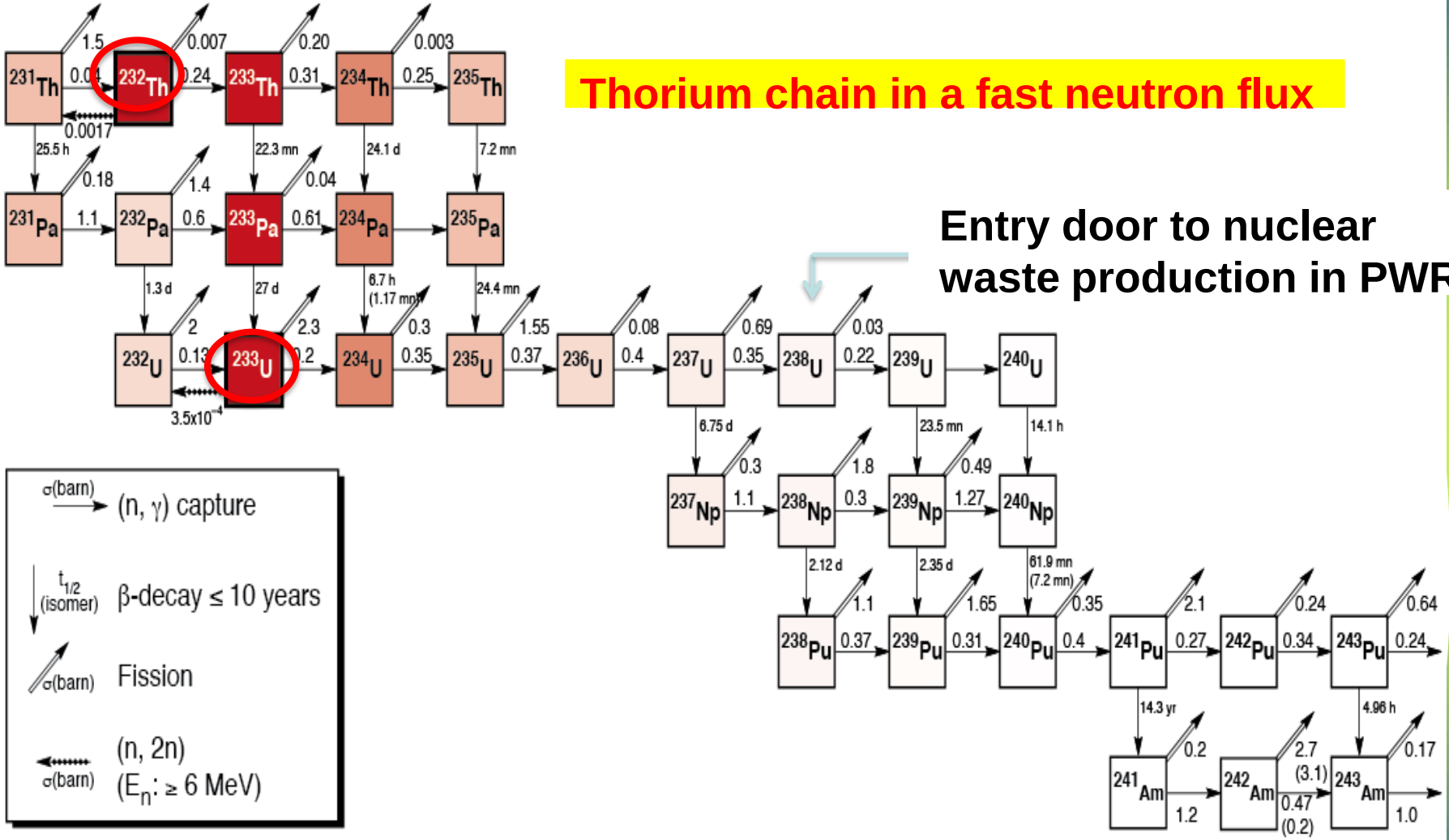
Avantages des ADS au Thorium

- Très haut niveau de sécurité intrinsèque (sous-criticalité, metal liquide…)
- Haute résistance à la prolifération
- Destruction des déchets de longue durée de vie (transmutation des TRU dans un flux de neutrons rapides)
- Production négligeable d'actinides de longue durée de vie (combustible thorium)

^{233}U breeding chain from ^{232}Th.

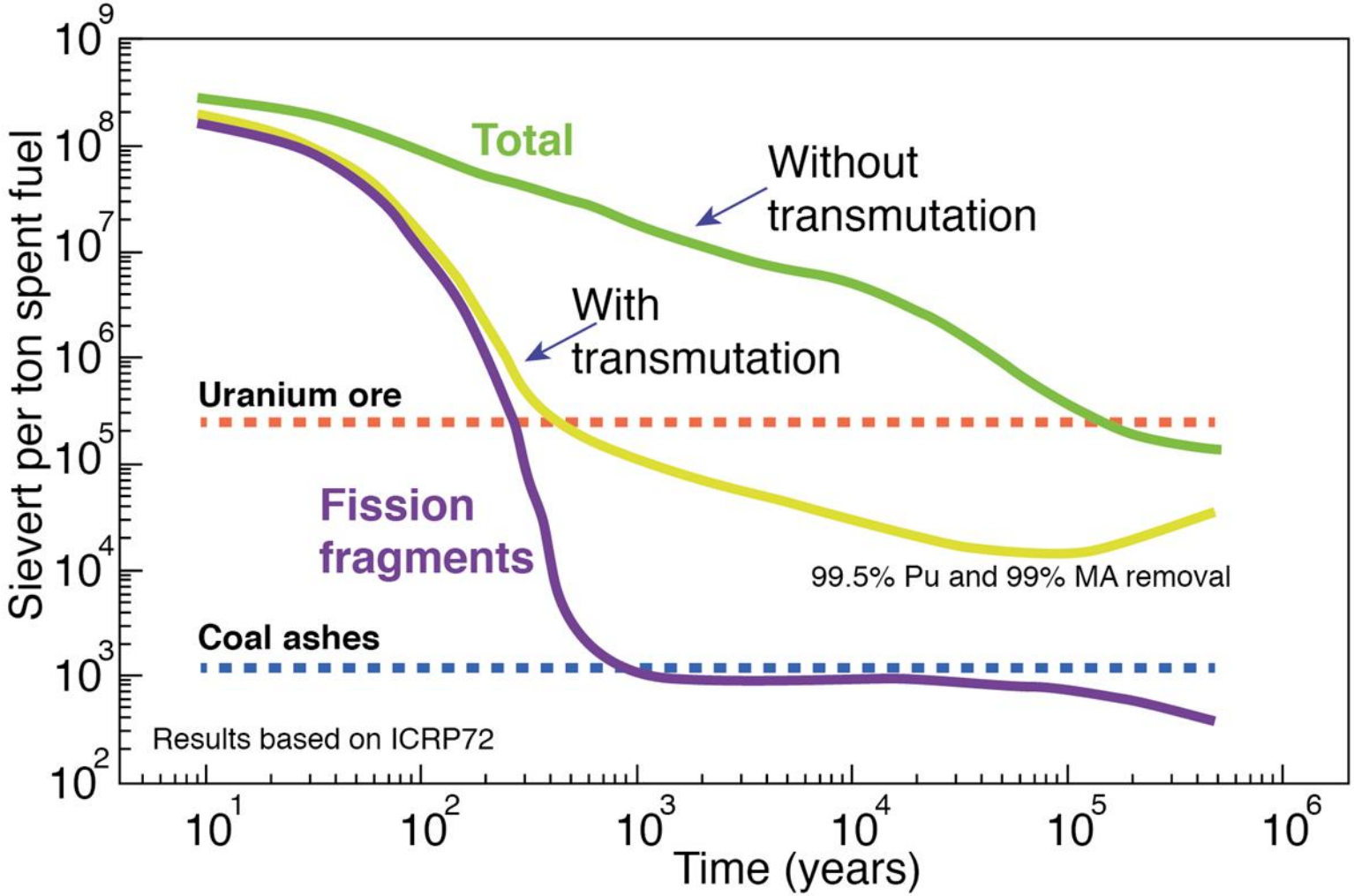


Thorium minimizes high level waste production




minéral monazite =
lanthanides +
thorium
credit P.K. Wattal, BARC, India

Radiotoxicité par ingestion de combustible usé



Equilibrium concentrations are orders of magnitude lower than in a uranium-plutonium based fuel.

The Three Levels of ADS Validation and Development by Transmutex

- **First**, validation of the different component concepts, taken separately (accelerator, target, subcritical core, dedicated fuels and fuel processing methods).

- **Second**, validation of the coupling of the different components in a significant environment including full simulations:

  in KIPT, Ukraine

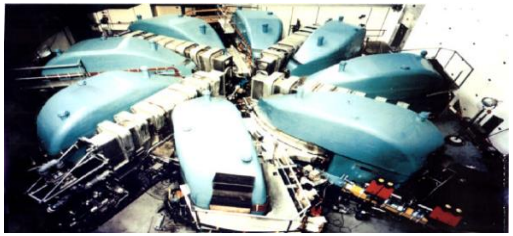
  in CVR, Czech Republic

  in ENEA, Italy

- **Third**, validation in an installation explicitly designed for demonstration.
  - **Should evolve to a demonstration of fuel transmutation**

TRANSMUTEX's Strategy

Based on existing technologies for a demonstration of a 300 MW Pilot Plant by 2032

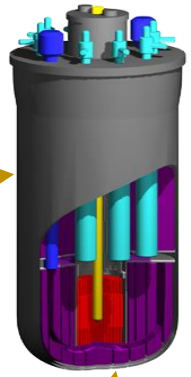


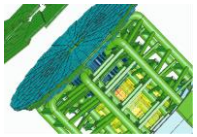
High-power cyclotron

PSI

Liquid metal spallation target

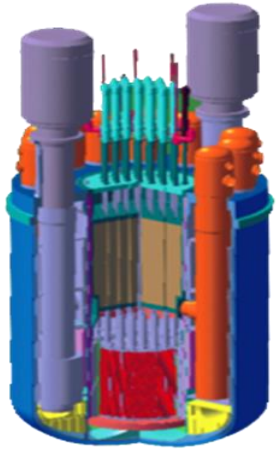
PSI, ENEA





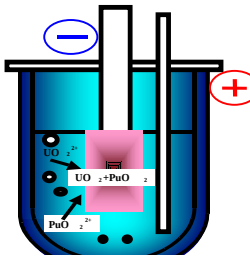
Simulation technology based on FLUKA and GEANT4

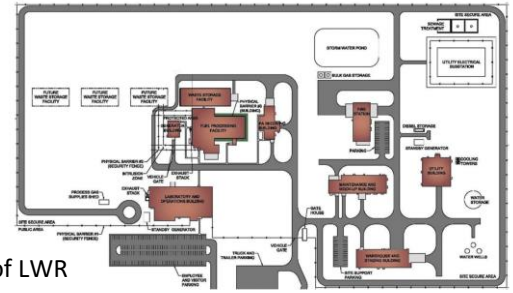
ENEA, CERN



Lead-Bismuth fast neutron reactor SVBR-100

ROSATOM



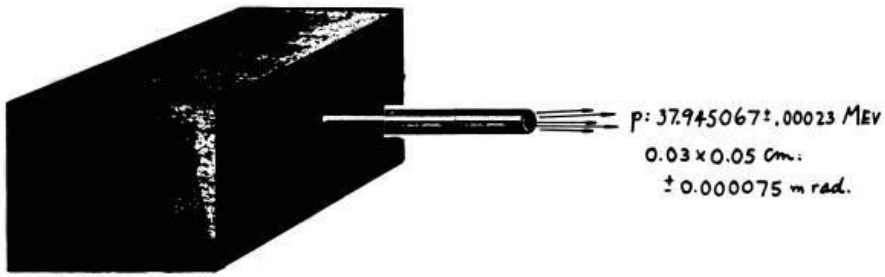


Pyroprocessing of LWR spent fuel,

production of Th fuel, reprocessing of Th fuel

Argonne National Lab, USA
ALCEN and Egis, France

“Le cyclotron, vu par”



. . . the experimental physicist

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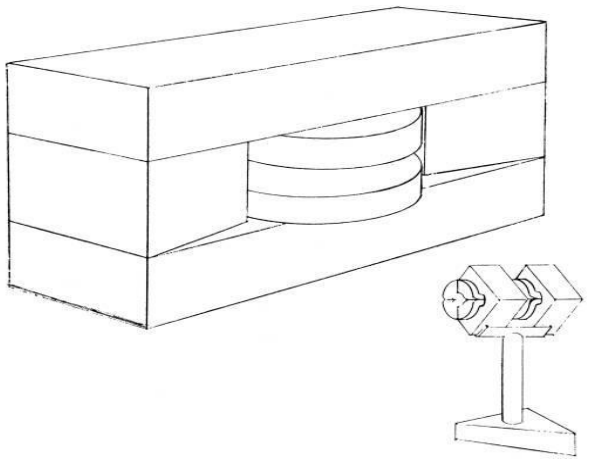

. . . the mechanical engineer

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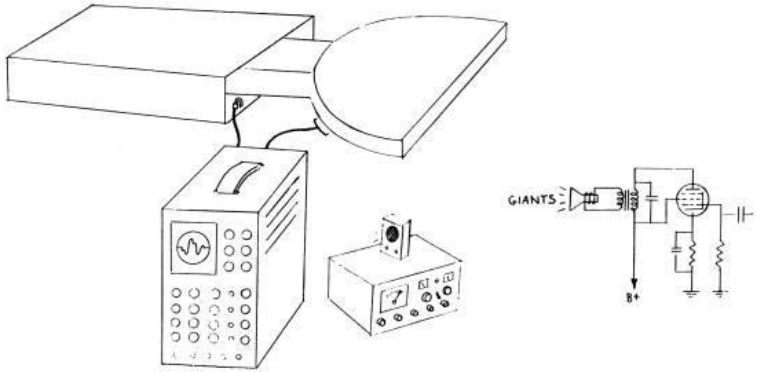

. . . the electrical engineer

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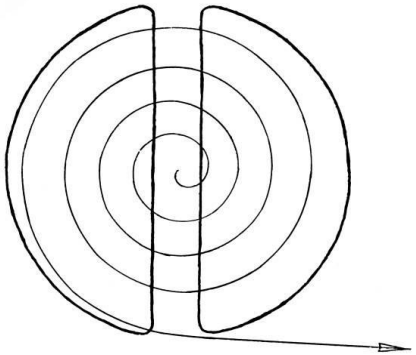

. . . the student

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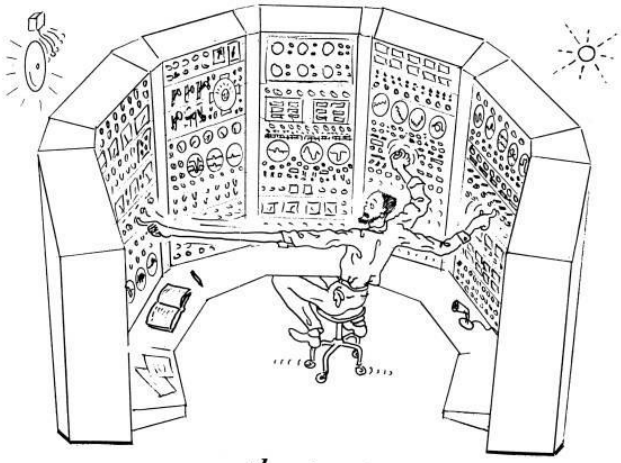
Courtesy David L. Judd and Ron MacKenzie



. . . the operator

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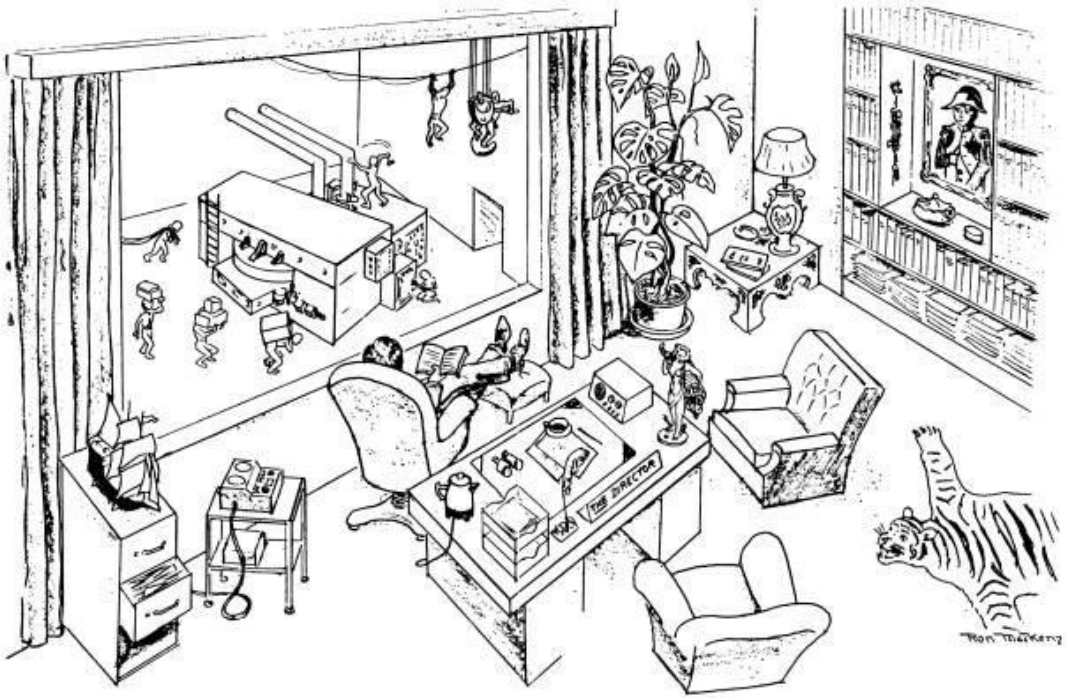

. . . the laboratory director

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A Cyclotron for Transmutex ADS

Accelerator requirements		
	600 MeV ADS	800 MeV ADS
E_{beam} [MeV]	600	800
I_{beam} [mA]	5.1	3.3
P_{beam} [MW]	3.1	2.7
P_{ADS} (th) [MW]	300	300
G_0	2.00	2.29
Gain (k = 0.98)	98	112

- Evolution of PSI Ring Cyclotron and Injector II (1.4 MW)
  - Larger number of cavities
  - Two injections
  - …
- **Transmutex is evaluating options, together with PSI**

A Lead-bismuth Eutectic Fast Neutron Reactor

The fast reactors used on Alpha class submarines of the Soviet Union are the only one that have many years of real proven experience and are the only one already realized that are providing the flux needed for the ADS

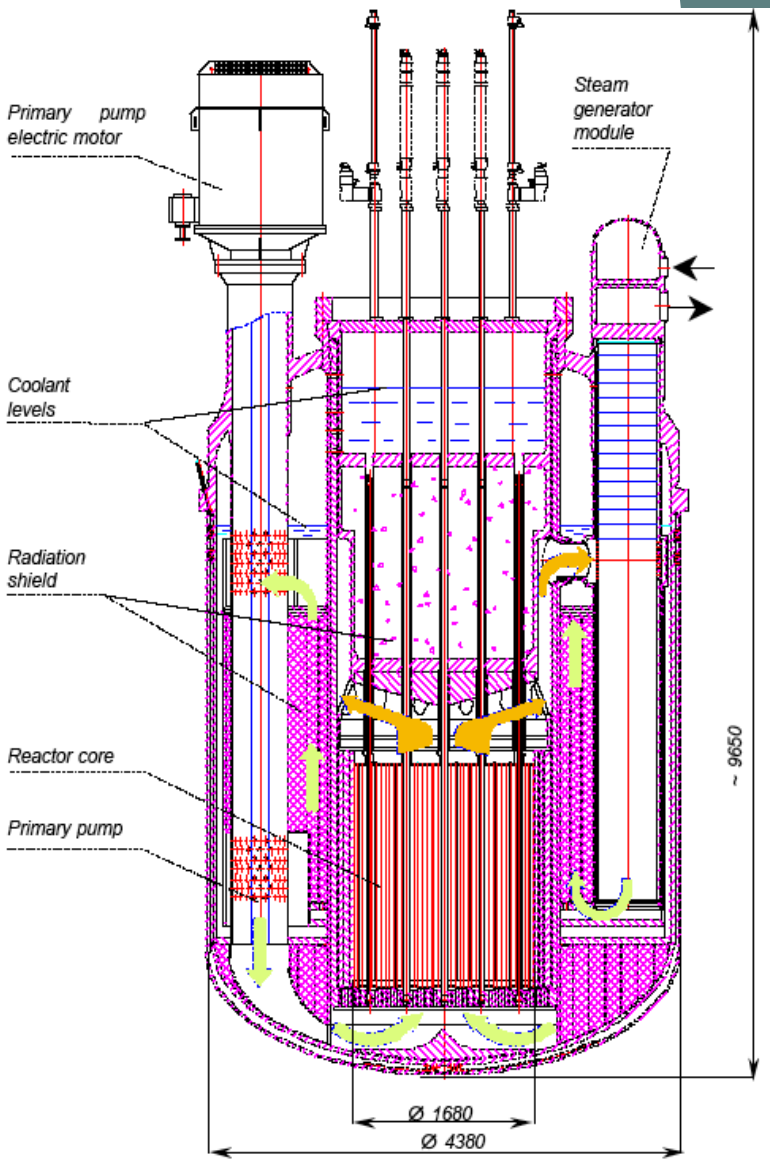
Prof. G.I. Toshinsky

Lead-bismuth Eutectic Fast Neutron Reactor:

Russian SVBR-100

- Commercial version of the LBE fast reactor used on Alpha class subs (thermal output 280 MW (th))

- Studying the modifications of the SVBR to accommodate a spallation target and use ThO_2 fuel
  - Detailed calculations in progress



A most Advanced Simulation Project

Based on existing well validated codes

FLUKA	GEANT4
General-purpose Multi-particle Design of accelerator Radiation protection High-energy Physics Experiments ... N-Multigroup transport Soon: pointwise No criticality evaluators Source available	General-purpose Multi-particle High-energy Physics Experiments ... N-pointwise transport Criticality evaluators added by TRANSMUTEX Open source

Validated for many aspects of neutronics but not adapted to nuclear fuel evolution

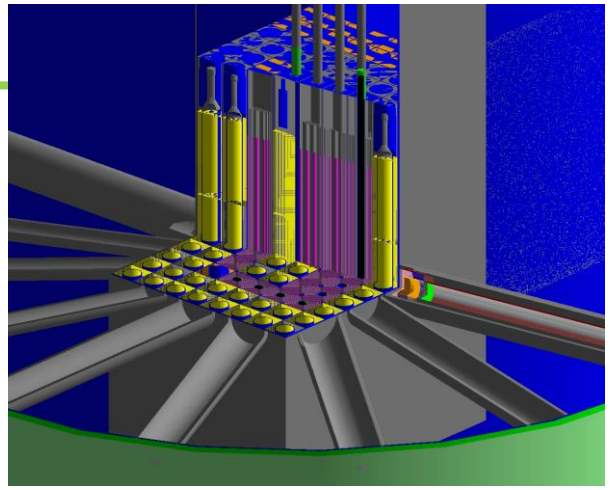
Extending current codes

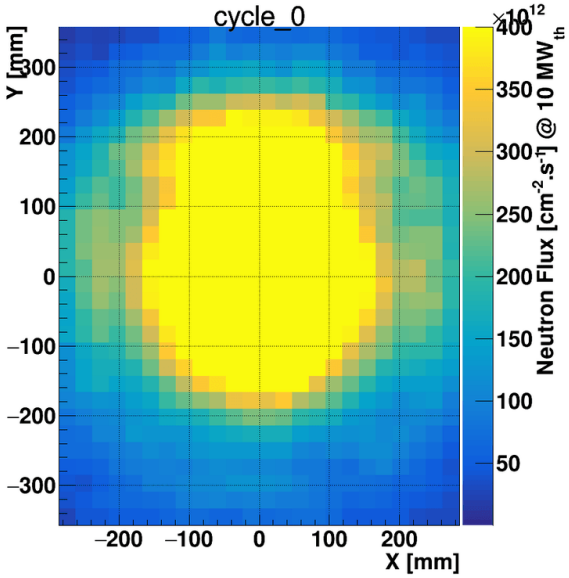
Additional features

- Time evolution of materials composition by neutron flux and coupled Bateman equations (burnup evolution)
- State-of-the-art k_{eff} estimators
- Time evolution of the beam current to keep the thermal power constant
- DPA calculation
- Radiotoxicity calculation

Under development

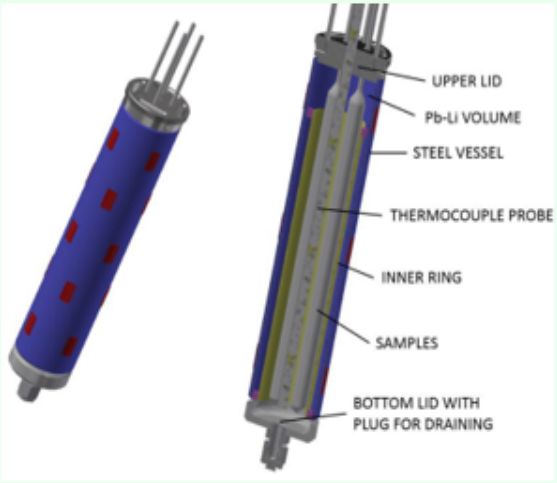
- Temperature evolution
- Coupling with deterministic fluid-dynamic codes
- Extended validation with international benchmarks
- Cloud computing



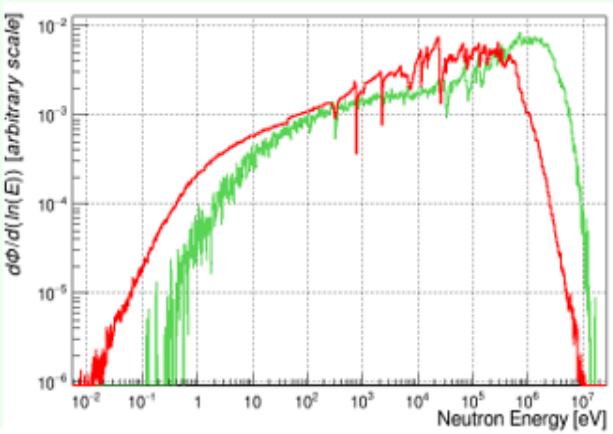


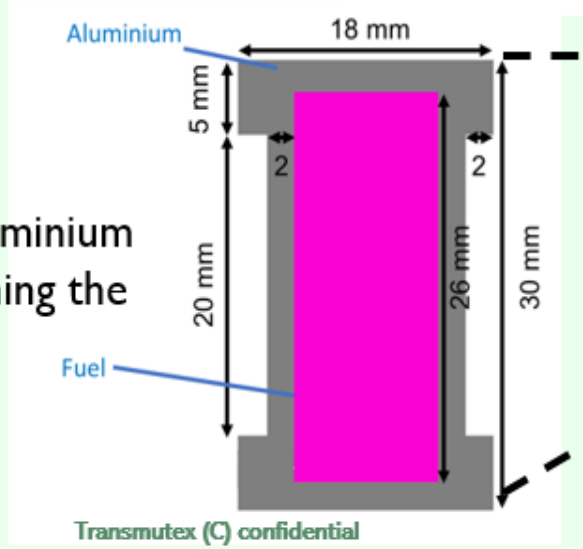
FUEL PELLETS IRRADIATION IN A FAST LEAD RIG

PbLi rig already tested at CVR

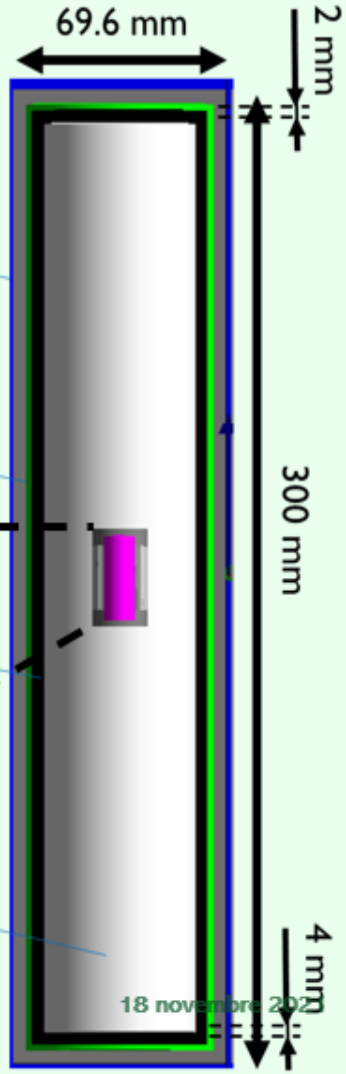


Conceptual lead rig for fuel sample irradiation





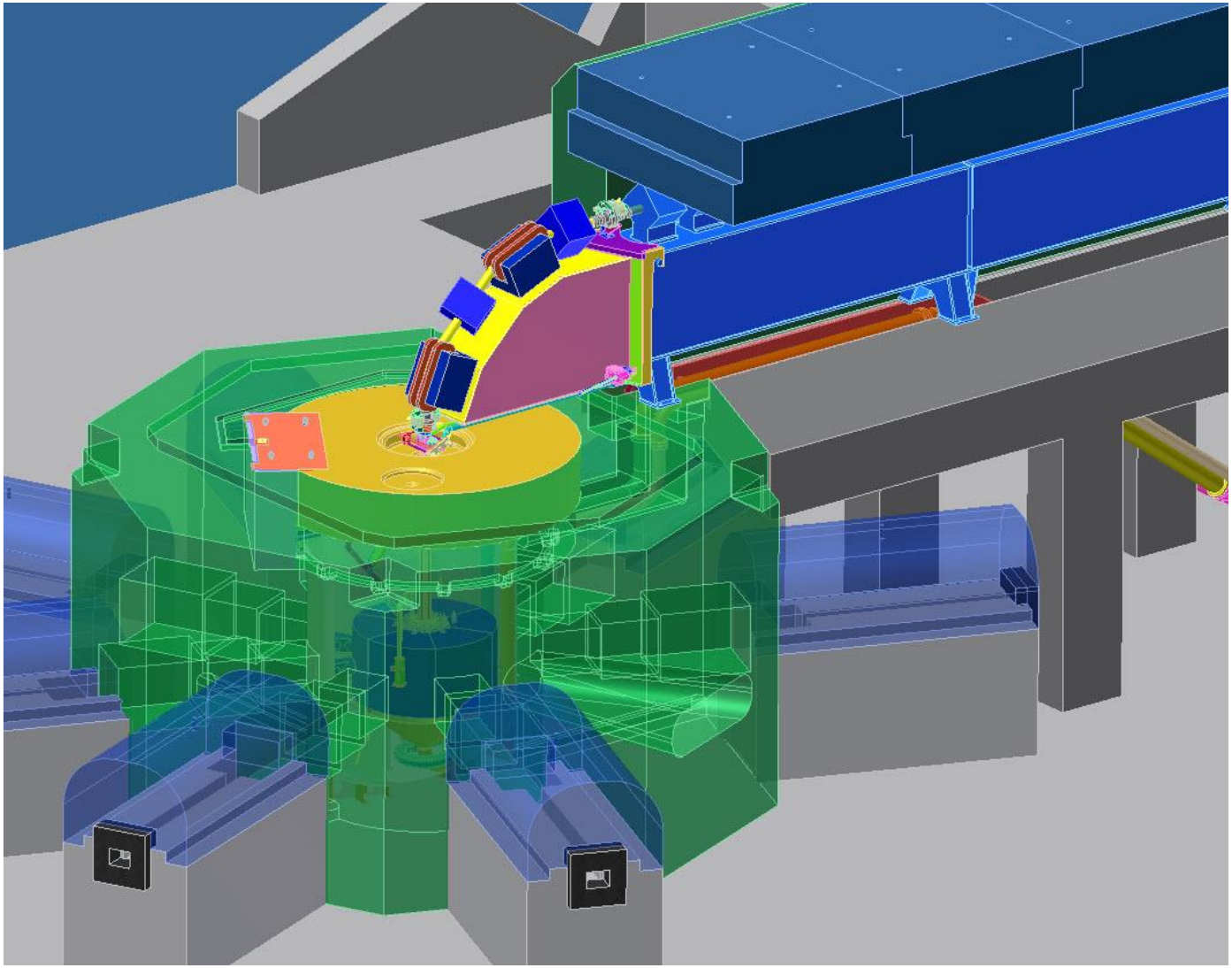
Conceptual aluminium capsule containing the fuel sample



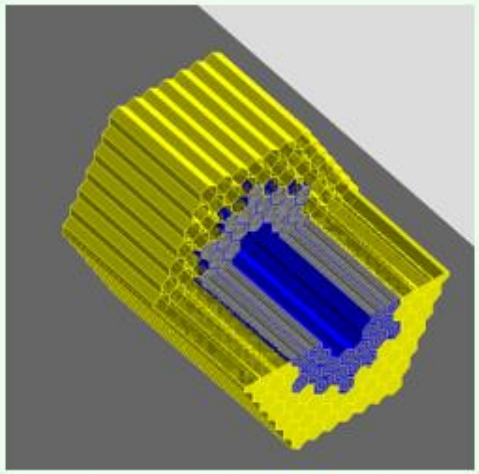
TRANSMUTEX
Nuclear Waste to Green Energy

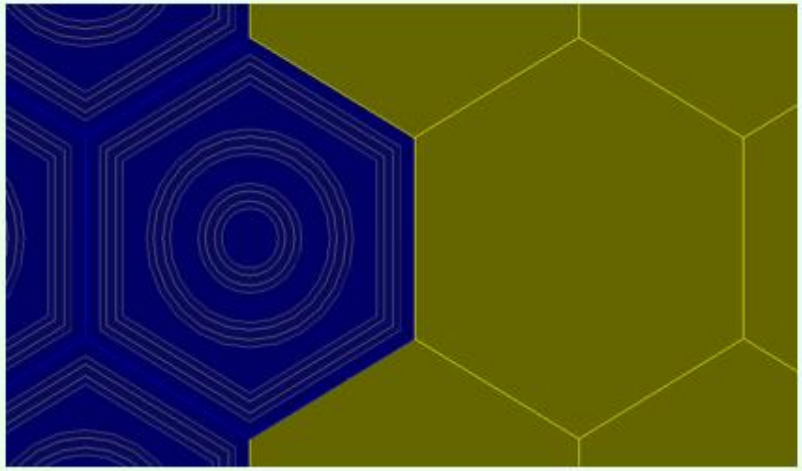
At Kharkov Institute of Physics & Technology, Ukraine:

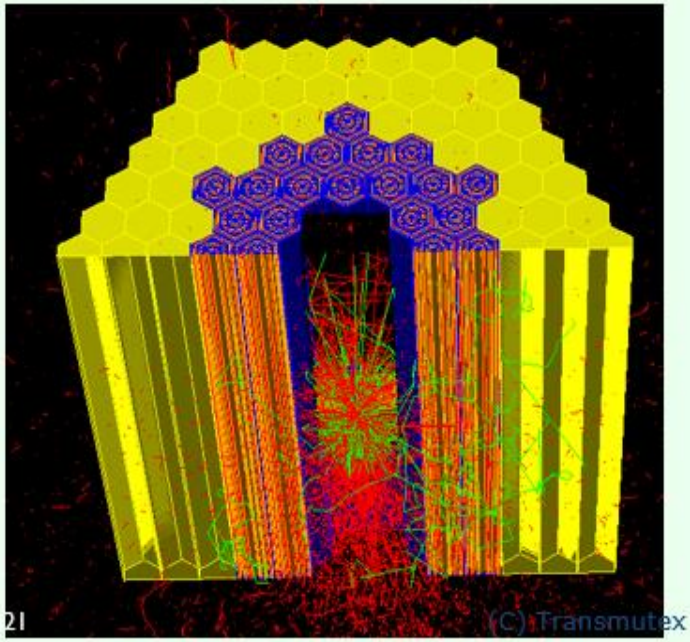
Validate the Transmutex simulation code with the data coming from the KIPT accelerator driven subcritical facility

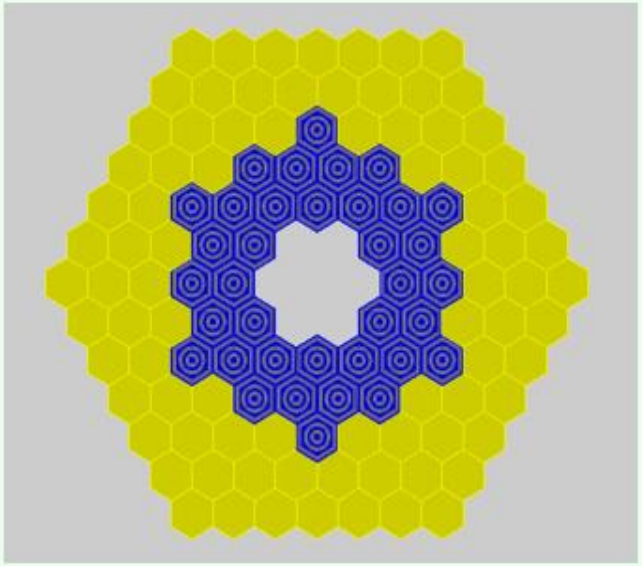


REPRODUCTION OF THE KIPT REACTOR



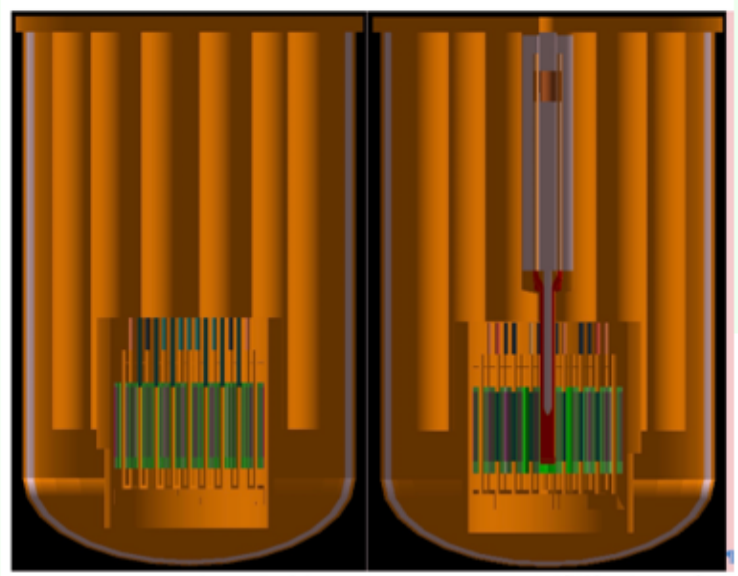




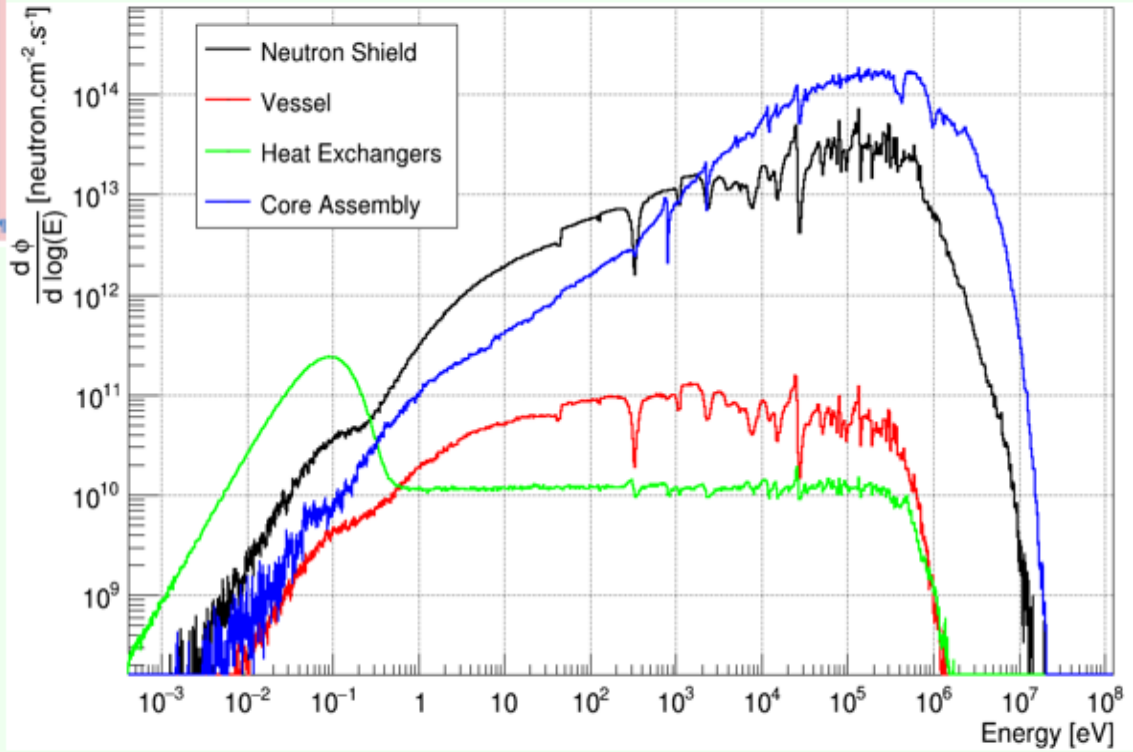


TRANSMUTEX
Nuclear Waste to Green Energy

DETAILED SIMULATION



SVBR-100 with GEANT4:
a sub-critical assembly



Conclusion

- The technology is ready
  - Cyclotron
  - LBE/Lead reactor cores
  - Spallation targets
  - Pyroprocessing plant
- A safe and efficient way to
  - Produce carbon-free energy
  - Transmute TRU and LLFP
- Demonstrator by 2032

Merci