Transmutation

From paper to reality

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Why P&T?

To reduce the engineering burden on a geological disposal for nuclear waste by reducing the heat emission and radiotoxicity of the waste to be stored

Heat emission: smaller footprint (surface and volume)

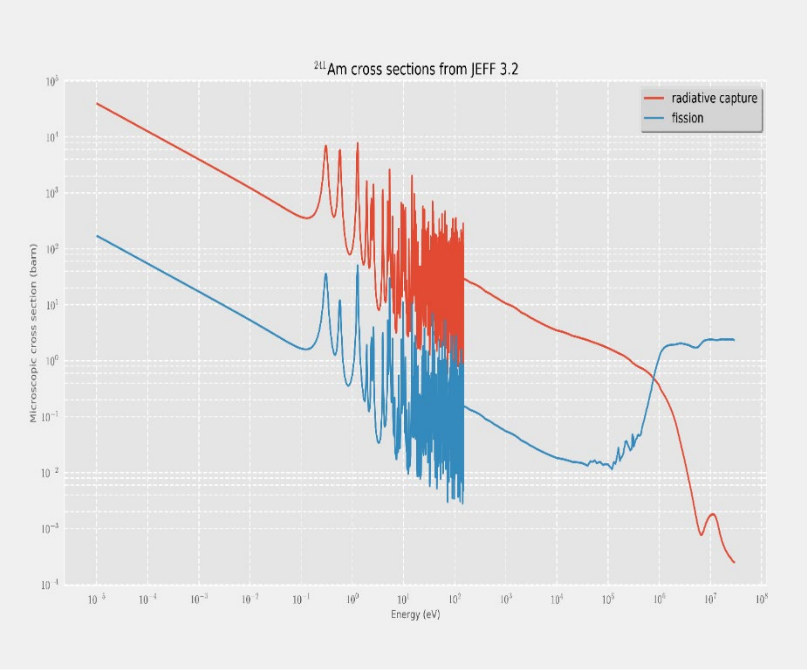
Radiotoxicity: reduce risks for future generations

The Four Building Blocks for P&T

1. Reprocessing of LWR irradiated fuel
   - Commercially available for uranium and plutonium (PUREX, DIAMEX, SANEX): TRL8−9
2. Fabrication of dedicated transmutation fuel
   - Feasibility proven on lab scale: TRL3−4
3. Industrial transmutation: European Facility for Industrial Transmutation
   - Let's look into more detail…
4. Reprocessing of transmutation fuel
   - Huh?

Transmuter: design requirements

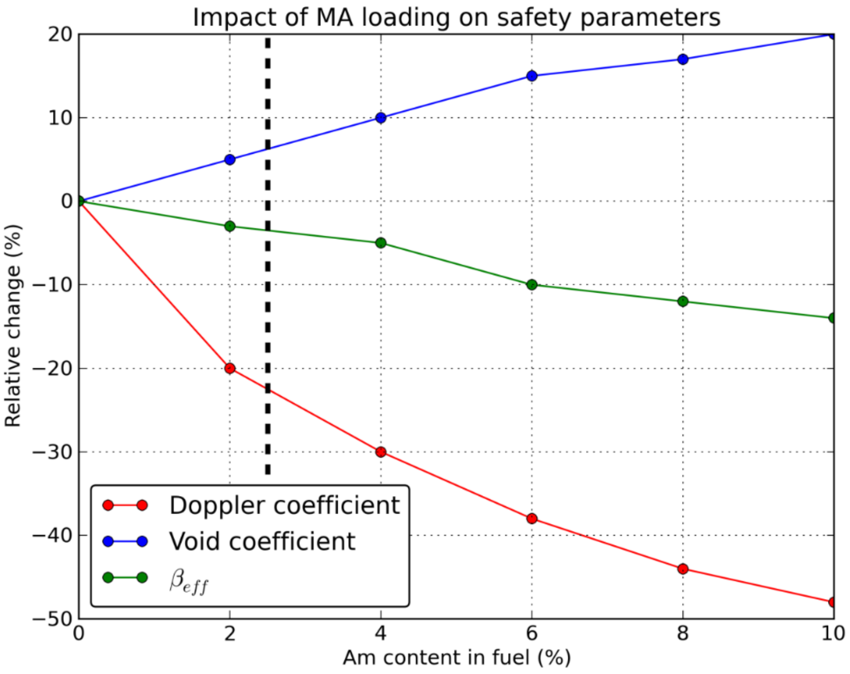
- Fast spectrum
  - Heavy liquid metal or gas cooling
  - No LLFP transmutation



- Presence of minor actinides
  - Impact on core physics
- Large quantities of minor actinide transmutation
  - Economy of scale

Minor actinide loading has an impact on reactor physics

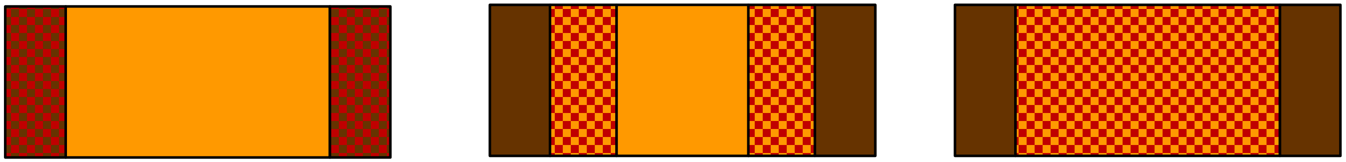
- Delayed neutron fraction β_{eff}
  - Determines time-constants for reactor control
- Doppler effect
  - Fuel temperature effect
  - PWR vs FR
- Void effect
  - Loss of coolant, boiling
  - PWR vs FR
  - Na vs Pb



Options for minor actinide burning: Fast Reactors

- Fast spectrum critical reactors
  - "Large" experience base from LMFBR based on Na
  - Homogeneous vs heterogeneous loading

heterogeneous 20% 2 x blanket	heterogeneous 7% in OC	homogeneous **2.5**%



-0.99 kg/TWh$_{th}$	-3.64 kg/TWh$_{th}$	-2.78 kg/TWh$_{th}$

  - Requires modifications in the whole FR fuel cycle

Options for minor actinide burning: ADS

- Accelerator Driven Systems
  - Very (very) limited experience base
  - Subcriticality allows larger quantities of MAs

- IP-EUROTRANS: 6th framework program
  - DM1: Design → XT-ADS (= MYRRHA) and EFIT
  - DM2: ECATS → GUINEVERE
  - DM3: AFTRA
  - DM4: DEMETRA
  - DM5: NUDATRA

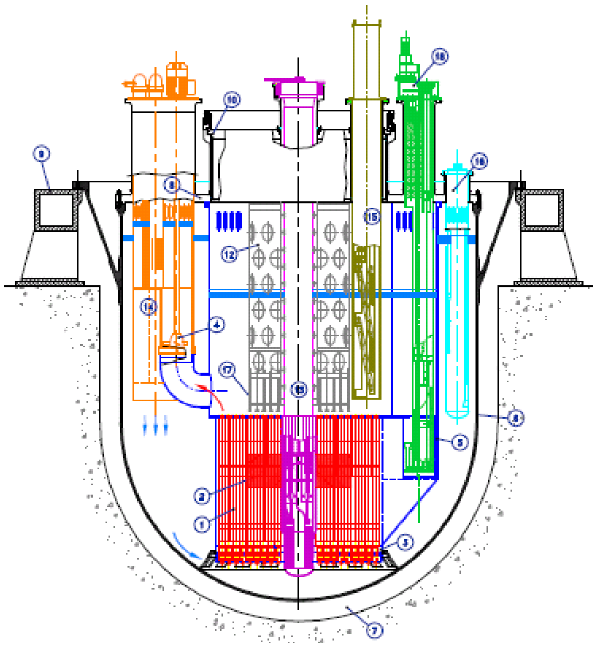
EFIT design criteria

1. Accelerator Driven System

2. Suitable core size and power for (economic) transmutation

3. Fast neutron spectrum
   - Lead-cooled or Helium-cooled

4. Fuel
   - Uranium-free
   - Plutonium-neutral
   - Fabrication routes?
   - Reprocessing routes (aqua vs pyro)?



EFIT Fuel

- Metallic fuel
  - Good thermal conductivity
  - Too low melting point → requires non-fissile material matrix
  - Difficult to mix TRU elements (limited mutual solubility)

- Nitride fuel
  - Allows high actinide densities
  - Swelling in TRU-nitrides
  - Nitrogen has to be enriched in ^{15}N to avoid ^{14}C production
  - Limited experience

- Carbide fuel
  - Aqueous reprocessing difficult
  - Limited experience

EFIT fuel

- Oxide fuel
  - Inert Matrix Fuels
    - CERMET: $(Pu,MA)O_{2-x}$ in Mo metal matrix
      - Good thermal conductivity of the matrix
      - Mo enrichment (price, recovery?)
    - CERCER: $(Pu,MA)\ O_{2-x}$ in MgO ceramic matrix
      - Better transmutation (less absorption in matrix)
      - Cheaper

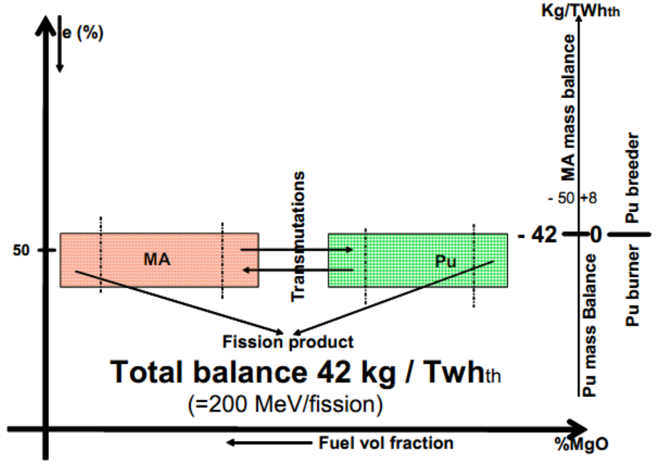
These were selected as the reference options

EFIT fuel: isotopic composition

- Uranium-free
- Plutonium as driver
  - Composition from UOX-LWR (90%) and MOX-LWR (10%) spent fuel
    - Pu238/Pu239/Pu240/Pu241/Pu242 = 3.7/46.4/34.1/3.9/11.9
- Minor actinides
  - Composition from UOX-LWR (90%) and MOX-LWR (10%) spent fuel
    - Np237/Am241/Am243/Cm244: 3.9/75.51/16.1/3.0

EFIT fuel pin & core design

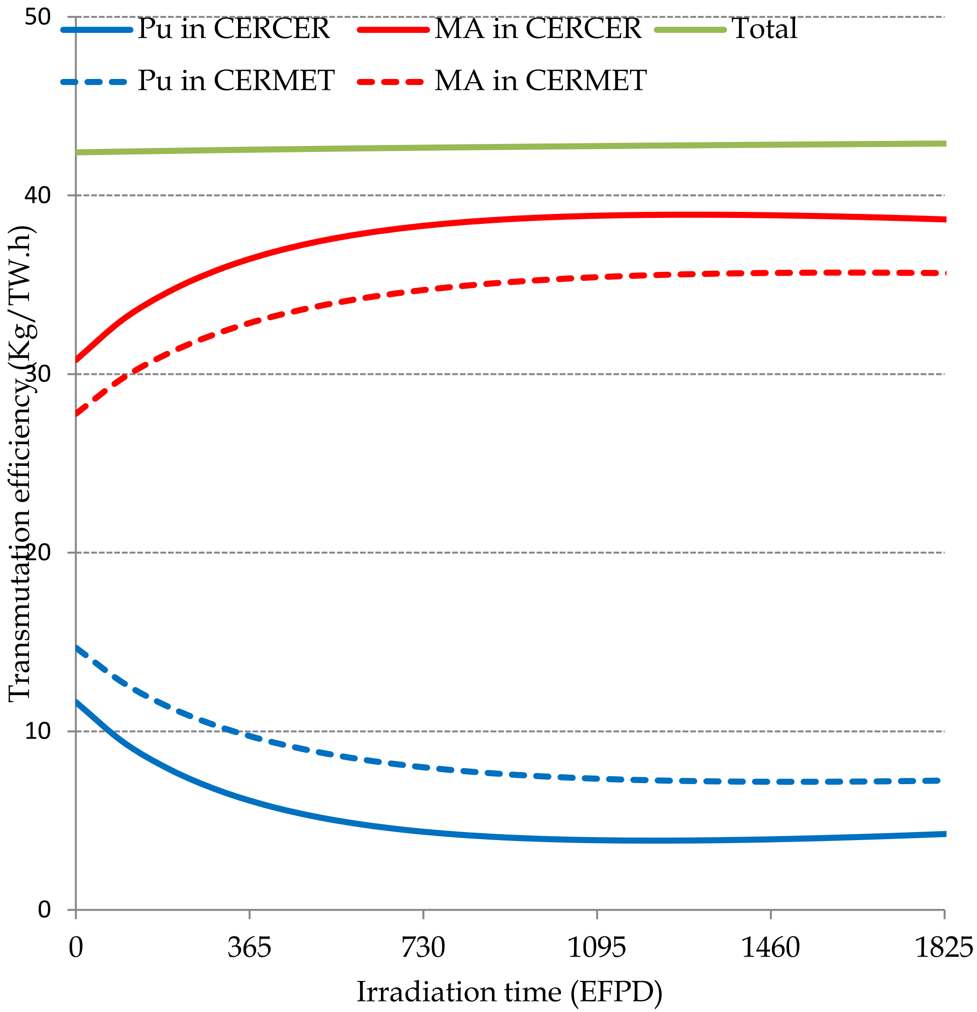
- Strategy
  - Subcriticality level + accelerator power
    → core power at 400 MWth
  - 42-0 approach
    → fixes the Pu/(Pu+MA) ratio to ~46%

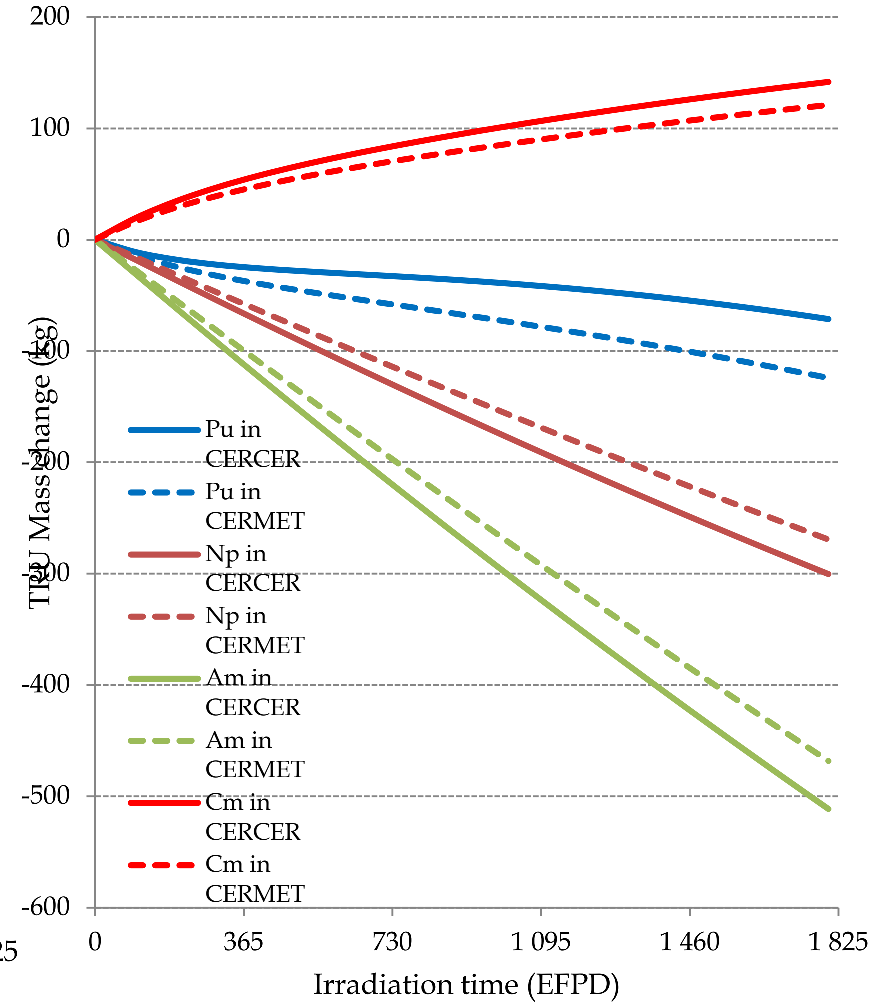


  - As low as possible reactivity swing
    - Cycle has been fixed at 3 years (cladding), 3 batches

    → fixes the matrix fraction to 53%

EFIT: transmutation capabilities





EFIT fuel: fabrication & reprocessing

- Designing fuel for transmutation

1. Fabrication
   - Different routes have been tested (powder, solgel)
   - High contents of Cm lead to shielding, remote handling issues
   - TRLs are 2−4

EFIT fuel: fabrication & reprocessing

- Designing fuel for transmutation

1. Fabrication

2. Irradiation
   - Test programs for MA bearing fuels have been conducted
     - Superfact, EFFTRA, SPIN, AM1
   - Conceptual design of EFIT
     - Safety analysis (using scarce available data)

EFIT fuel: fabrication & reprocessing

- Designing fuel for transmutation

    1. Fabrication

    2. Irradiation

    3. Reprocessing
        - Impact of fuel choice on reprocessing
            - CERMET: what about Mo in aqueous reprocessing?
            - Does high Cm content prohibit aqueous reprocessing?
            - Required cooling time?

IP-EUROTRANS conclusions

- Project IP-EUROTRANS was concluded in 2010
- Conceptual design of European Facility For Industrial Transmutation based on Pb or He cooled ADS
- EFIT was used in scenario studies for P&T
  - FP6 PATEROS
  - FP7 ARCAS
- But work on EFIT stopped in 2010…

What next?

- If Europe wants to progress in P&T…

There is still a lot of work to be done!

1. Reprocessing of LWR irradiated fuel
2. Fabrication of dedicated transmutation fuel
3. Industrial transmutation: European Facility for Industrial Transmutation
4. Reprocessing of transmutation fuel

Revisit some options

- Pu neutral?
  - Do we need to “save” our Plutonium for the deployment of a fast reactor fleet?
    - Belgian context? European context?
    - Safeguards?
  - Impact on EFIT fuel cycle and reactivity swing?

Revisit some options

- Pu neutral?

- What minor actinides to transmute?
  - LWR fuel: Cm < 0.01% (Cm-244: 85%, Cm-245: 15%)
  - Cm-244: $T_{1/2}$ = 18.1y
    - Significant contributor to decay heat
    - Major source of spontaneous fission neutrons
  - Separation of Cm from Am
    - "Cm decay tank"
    - Shielding, heat removal, safeguards ?

Revisit some options

- Pu neutral?
- What minor actinides to transmute?
- Aqueous vs pyrochemical
  - Aqueous suffers from radiation damage of solvents
    - Requires longer cooling times (impact on turn-over)
  - What is needed to push pyrochemical TRLs to the same level?
  - What are the secondary waste streams of both options?

In P&T we design for

Garbage in, garbage out

But preferably the "garbage out" should be less of a problem than the "garbage in"

We need to re-establish an "Integrated Project" for P&T integrating partitioning, fuel fabrication, transmutation systems design, radwaste management, geological disposal design, social sciences, …

Eendracht maakt macht – L'union fait la force !