Accelerator-Driven System and Inert Matrix Fuel

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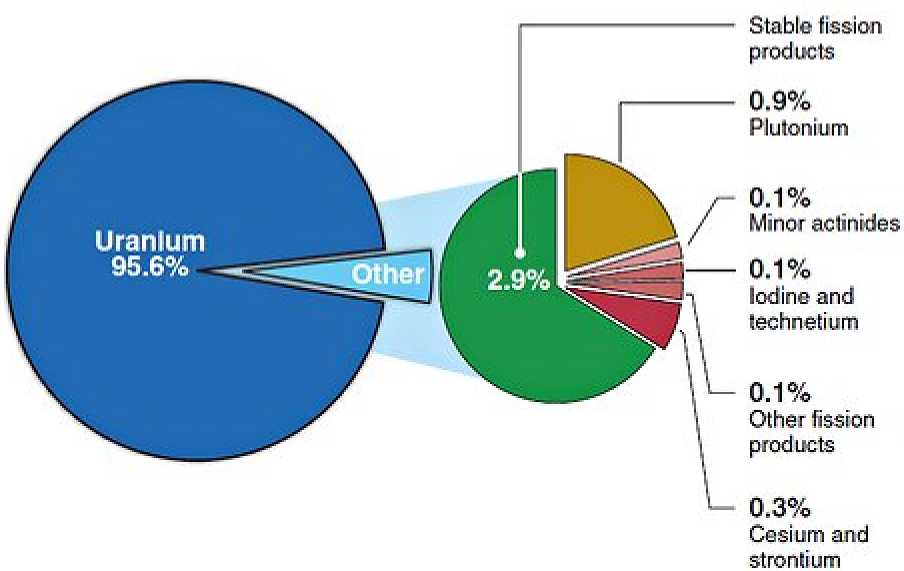
Most Urgent Issue in Nuclear Industry

How to dispose the spent fuel?
Or, specifically, how to incinerate the toxic Pu and MA contained in it?



Composition of spent nuclear fuel

Incineration of Pu and MA

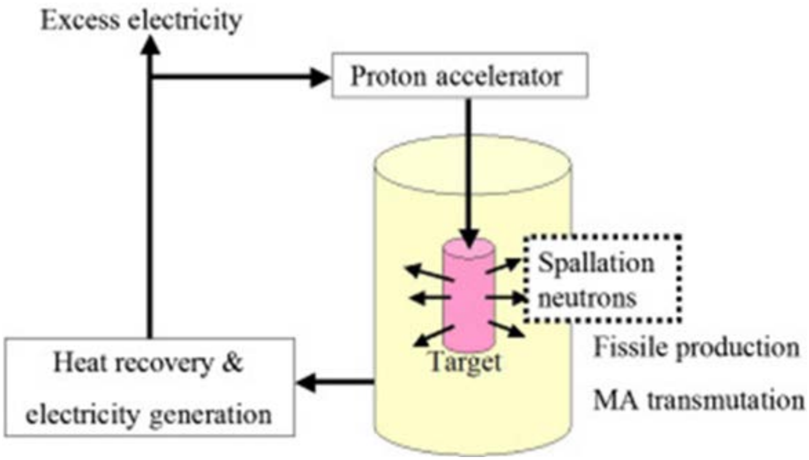
Pu is a fuel element while MA is just object of elimination. Hence, it is not easy to burn them in a single scheme but it is better to burn Pu and MA separately.

This talk proposes as a solution Accelerator-Driven System (ADS) for burning Pu in sub-critical reactors + Inert Matrix Fuel (IMF) for transmutating MA in critical light water reactors

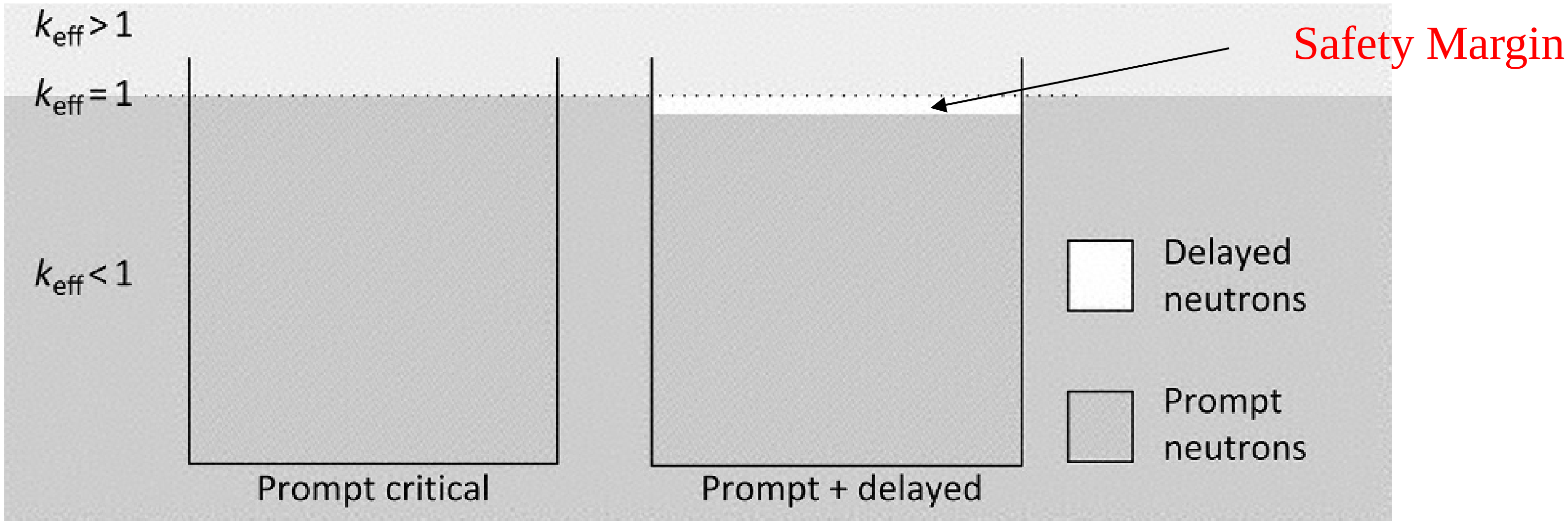
Accelerator-Driven System (ADS) for transmutating MA to short-lived species in sub-critical reactors

ADS =

Sub-Critical Reactor + Proton Accelerator



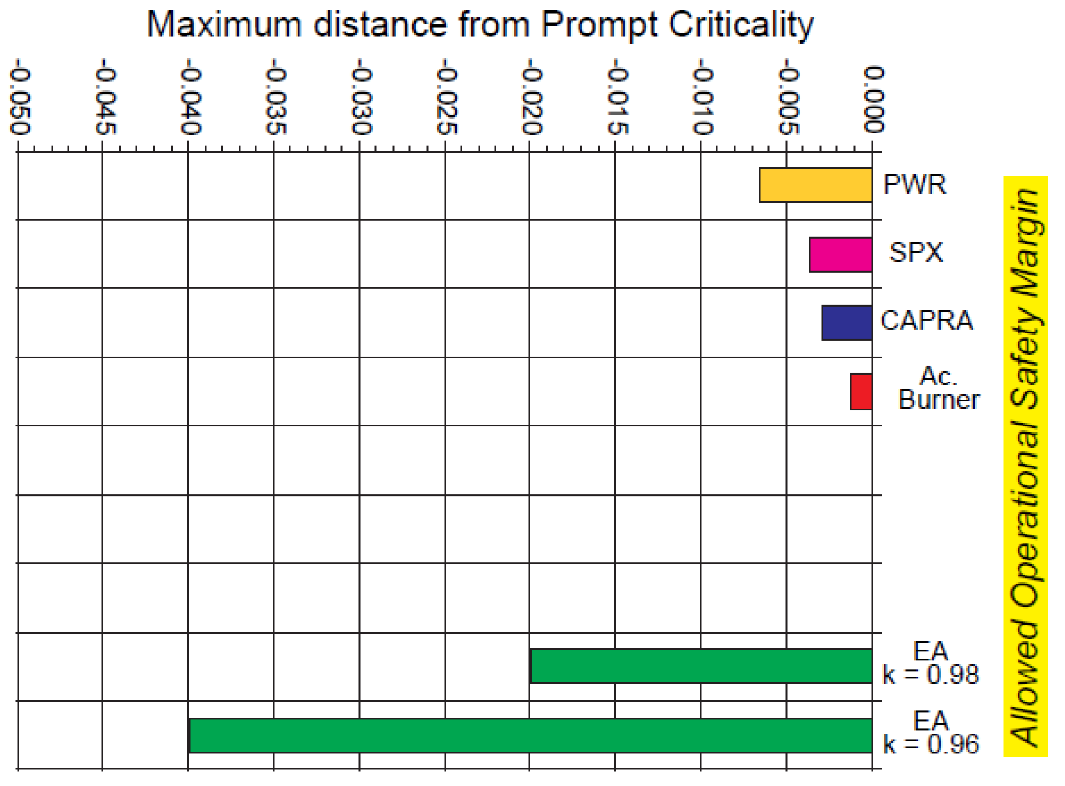
ADS: External Delayed-Neutron Source



Nuclide	β
^{238}U	0.0172
^{237}Np	0.00388
^{238}Pu	0.00137
^{239}Pu	0.00214
^{240}Pu	0.00304
^{241}Pu	0.00535
^{242}Pu	0.00664
^{241}Am	0.00127
^{243}Am	0.00233
^{242}Cm	0.000377

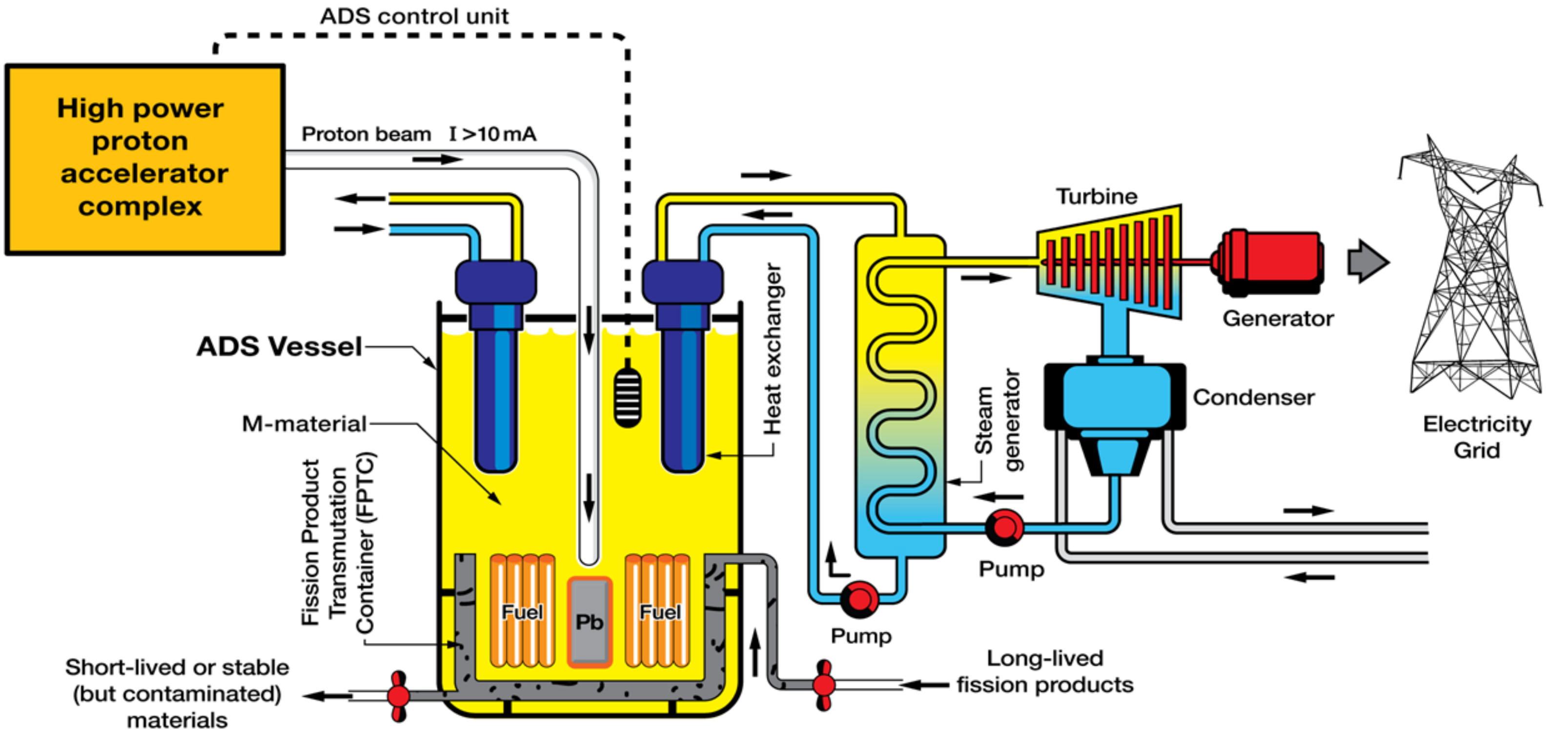
U238 generates much more delayed neutrons than Pu and minor actinides (MA). This is why U238 is an essential element for nuclear fuel. But, ADS has an external source of delayed neutrons, the accelerator, and so can use U-free fuel.

ADS can have larger Safety Margin



Large safety margin of ADS allows U-free fuel

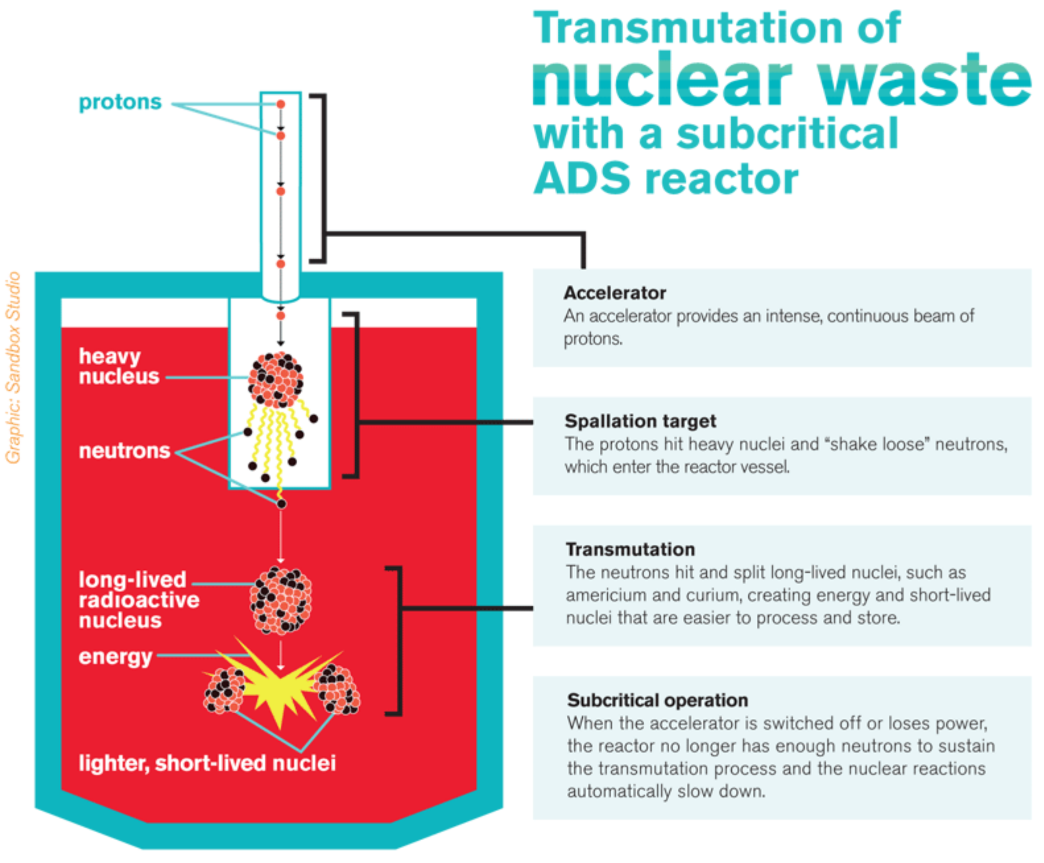
Ideal ADS = Transmutation + Power Generation

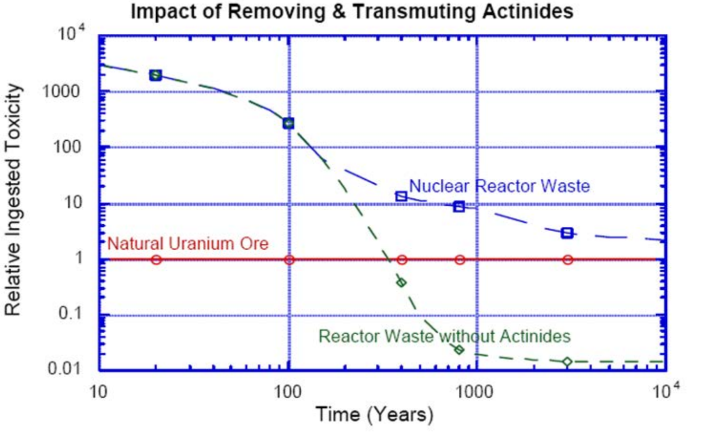


Current accelerator technology (particularly operation stability) is not matured enough for commercial power generation.

Realistic ADS now: Dedicated Transmuter

of Pu and MA





Ex.: ADS Plan in Japan

- Proton beam : 1.5GeV ~20MW
- Spallation target : Pb-Bi
- Coolant : Pb-Bi
- Subcriticality : $k_{eff} = 0.97$
- Thermal output : 800MWt
- Core height : 1000mm
- Core diameter : 2440 mm
- MA initial inventory : 2.5t
- Fuel composition :

  (60%MA + 40%Pu) Mono-nitride
- Transmutation rate :

  10%MA / Year (**10 units of LWR**)

Uranium-free fuel. This fuel composition cannot be used in Korea in which Pu cannot be separated from MA.

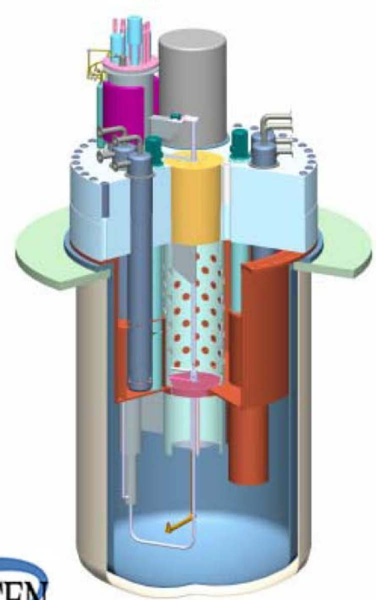
Comparison of ADS and critical reactor

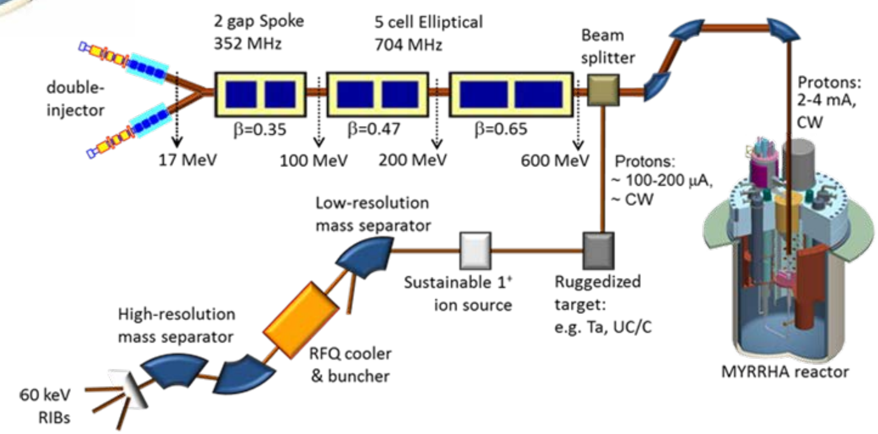
	Advantages of accelerator-driven systems	Disadvantages of accelerator-driven systems
Design and operation	♦ The possibility to operate a reactor core at a *neutron multiplication factor below 1* opens opportunities for new reactor concepts, including concepts which are otherwise ruled out by an insufficient neutron economy ♦ In particular, this allows transmuters to be designed as pure TRU or MA burners and hence the fraction of specialised transmuters in the reactor park to be minimised ♦ The proportionality of the reactor power to the accelerator current simplifies the reactor control	♦ *Accelerator:* Very high reliability required to protect structures from thermal shocks ♦ *Beam window and target* subjected to unusual stress, corrosion and irradiation conditions ♦ *Sub-critical core:* Increased power peaking effects due to external neutron source ♦ Compromises between neutron multiplication factor and accelerator power required ♦ Increased overall complexity of the plant ♦ Reduction in net plant electrical efficiency due to power consumption of accelerator
Safety	♦ The reactivity margin to prompt criticality can be increased by an extra margin which does *not depend on the delayed neutrons* ♦ This enables the safe operation of cores with degraded characteristics as they are typical e.g. for pure MA burners ♦ *Excess reactivity can be eliminated*, allowing the design of cores with a reduced potential for reactivity-induced accidents	♦ New types of reactivity and source transients have to be dealt with (external neutron source can vary rapidly and reactivity feedbacks in TRU- and MA-dominated cores are weak)

MYRRHA (Belgium)

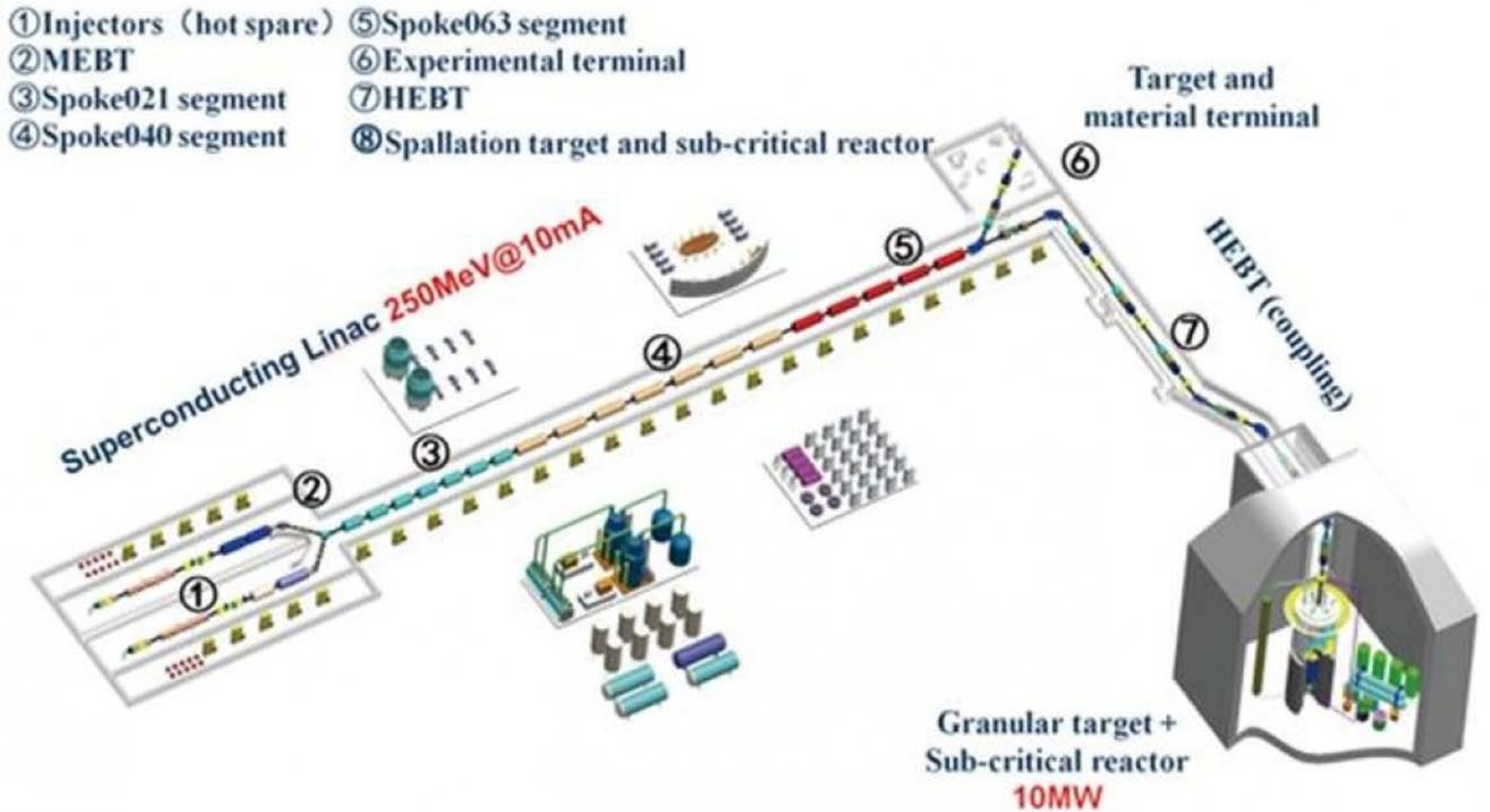
MYRRHA (located in Belgium)

- Chosen Linac technology to do transmutation.
- Expect to do this by 2020
- Experimental demonstration. Not intended for commercial energy production.
- Have chosen Lead/Bismuth Eutectic as spallation target/coolant





CIADS, China


①Injectors（hot spare）
②MEBT
③Spoke021 segment
④Spoke040 segment
⑤Spoke063 segment
⑥Experimental terminal
⑦HEBT
⑧Spallation target and sub-critical reactor
Target and material terminal
Superconducting Linac 250MeV@10mA
HEBT (coupling)
Granular target + Sub-critical reactor
10MW
①
②
③
④
⑤
⑥
⑦

Issues of ADS for Spent Fuel Problem

- Accelerator technology is mature enough to be applied to nuclear transmutation of spent fuel.
- High cost of ADS due to construction of the high energy and high power proton accelerator
- Therefore, only a few ADS machines may be constructed and this is possible if ADS combined with IMF

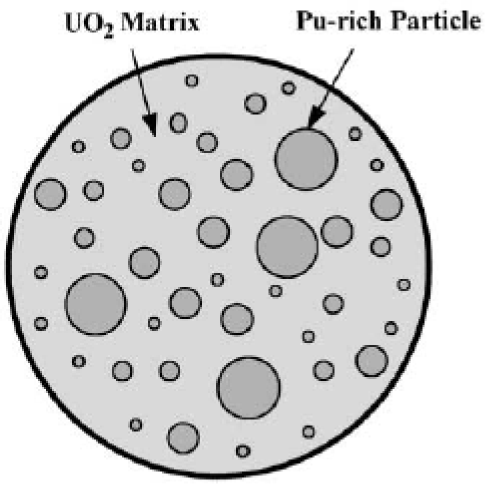
That is why we also need

Inert Matrix Fuel (IMF) for burning Pu in LWRs

MOX fuel with U238 matrix

Critical reactor is difficult to use as a pure TRU or MA burner without U238 because of small number of delayed neutrons (smaller safety margin).

MOX (mixed oxide) fuel that makes use of Pu is fabricated with U238 matrix as shown in the figure.

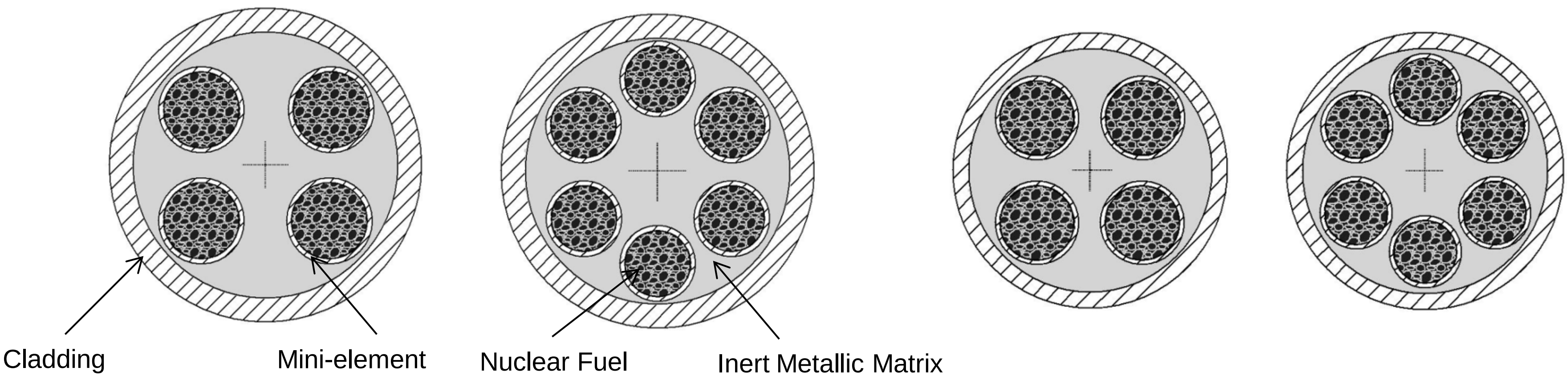


MOX fuel

But, it is possible to replace the U-matrix by neutron inert metallic matrix. This inert matrix fuel has no conversion to Pu and decently many delayed neutrons.

Inert Matrix Fuel (with no U238 matrix)

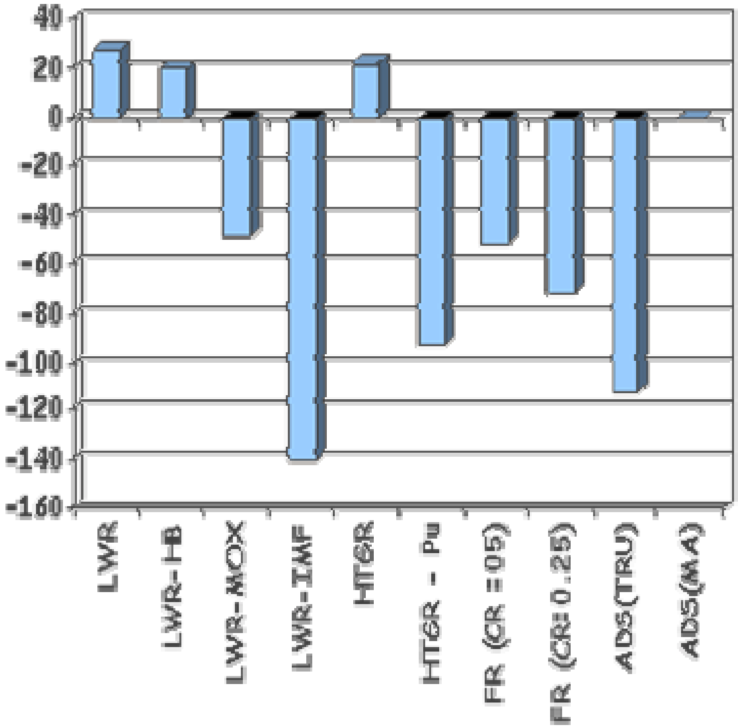
Schematic cross-section of IMF with 4 and 6 mini-elements	
Thermal reactors	Fast reactors

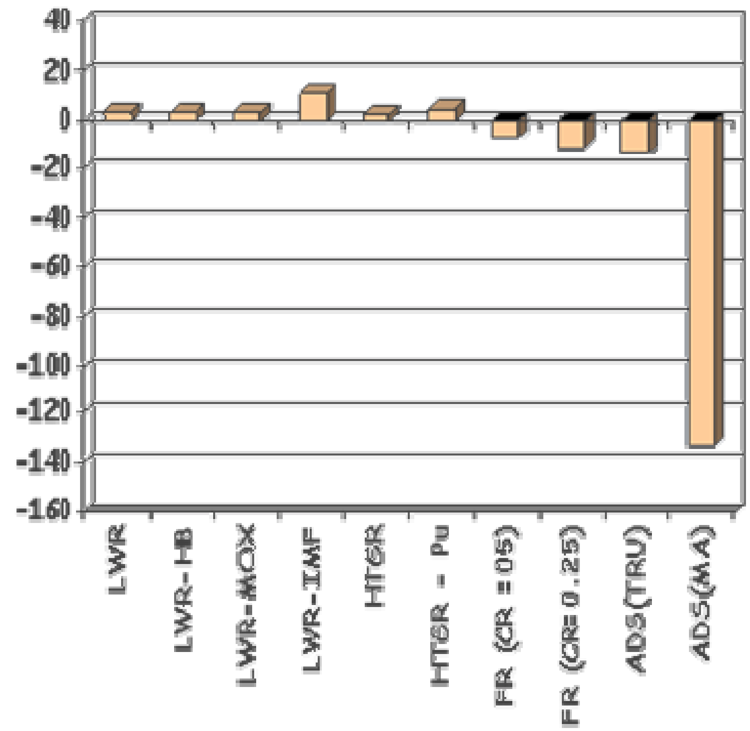


No U238 matrix: no conversion

IMF is an option for safe deep-burning of Pu (and MA) in a critical reactor including LWR.

Burn-up Effectiveness

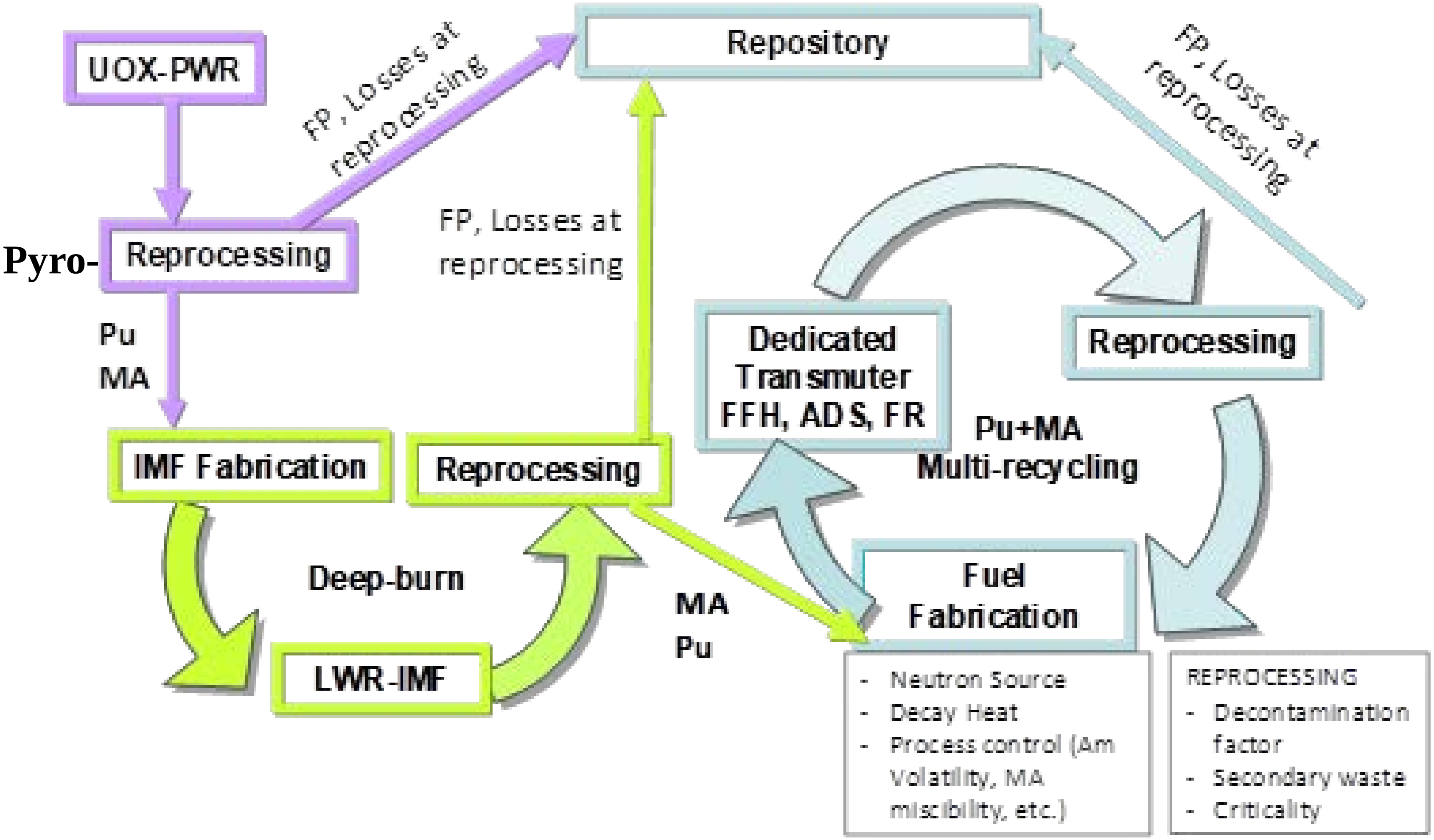




Pu Production Rate (grams / GWh) **MA Production Rate (grams / GWh)**

LWR-IMF is effective as Pu-burner and ADS is effective as MA transmuter.

Combination of ADS and IMF



Summary

1. Combination of ADS and IMF can effectively burn Pu and MA with minimal number of ADS that costs high.
2. Both ADS and IMF should receive sufficient attention to be realized in the near future.

Thank You for Listening!!