Karlsruher Institut für Technologie

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ADVANCED FUEL CYCLE SCENARIO STUDY IN THE EUROPEAN CONTEXT BY USING DIFFERENT BURNER REACTOR CONCEPTS

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Introduction

- Despite a renewed interest in nuclear energy production, nuclear waste management still represents a major source of concern in public opinion

- In this context, Partitioning and Transmutation (P&T) strategies are widely investigated worldwide and different concepts of burner reactors have been proposed

- In the present study we performed, within a collaboration between the GA-Tech (USA) and KIT (Germany), a preliminary comparison between an Accelerator Driven System (the ADS-EFIT *(Accelerator Driven System – European Facility for Industrial Transmutation)* and an hybrid Fusion Fission reactor (the SABR, *Subcritical Advanced Burner Reactor, concept developed at GA-Tech)*

- Further details about SABR are presented in the poster session *("SABR fusion-fission hybrid fast burner reactor based on ITER")*

- The SABR fusion-fission hybrid concept is a sodium cooled sub-critical fast reactor driven by a D-T fusion neutron source while ADS-EFIT is Pb cooled and uses an accelerator driven source

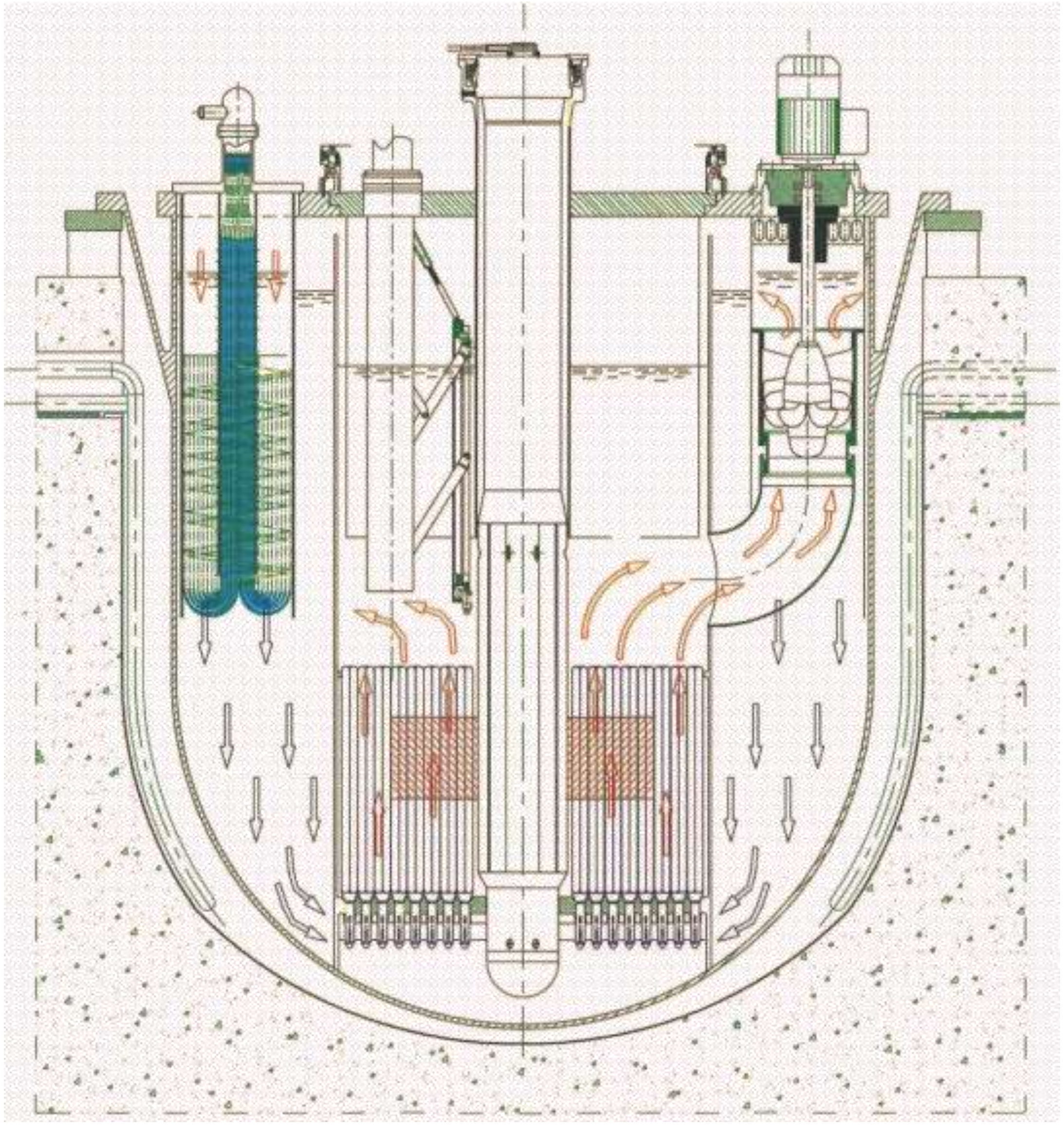
- At first, the two systems (SABR and ADS) have been compared in terms of minor actinides (MA) burning performance

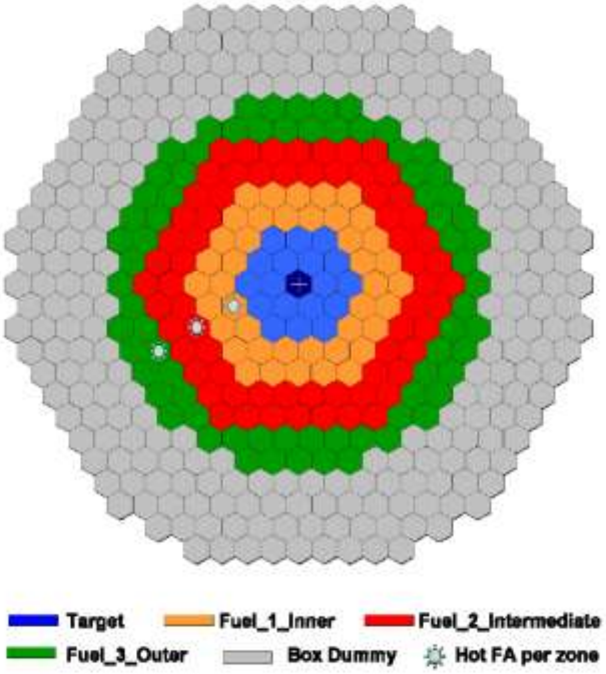
-As a second step, a comparison was made within a fuel cycle scenario using the COSI6 (ver. 5.1.4) system analysis code:

- The two burner reactors performance is compared in a *'double strata'* fuel cycle scenario, developed in order to manage Spent Fuel (SF) inventories of European countries

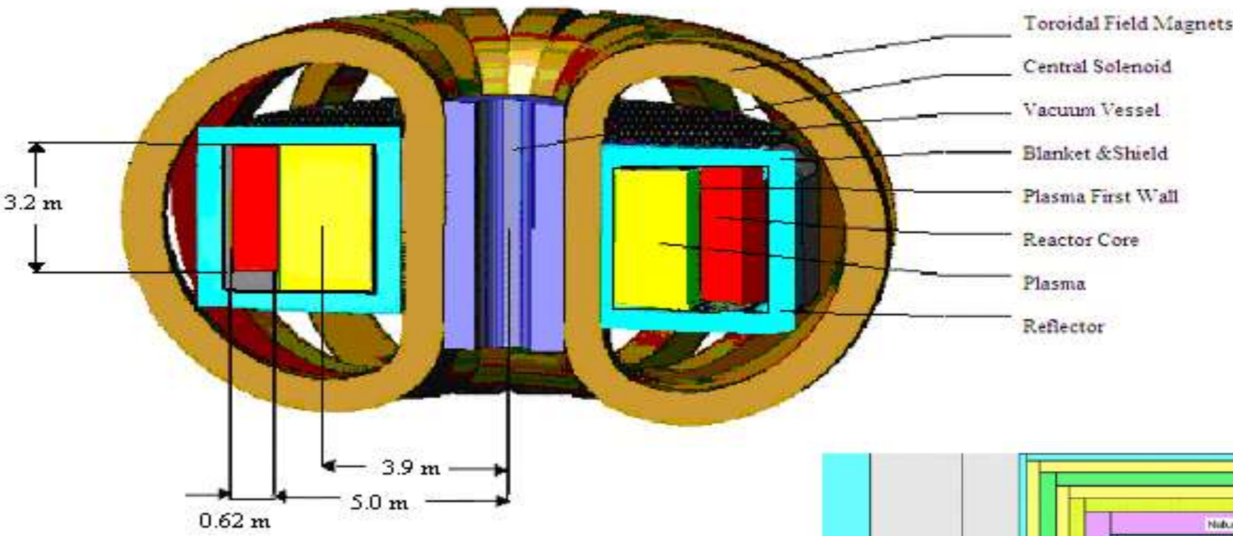
- The main objective of the scenario is an optimized waste management in a geographical region with nation-specific nuclear energy policies.

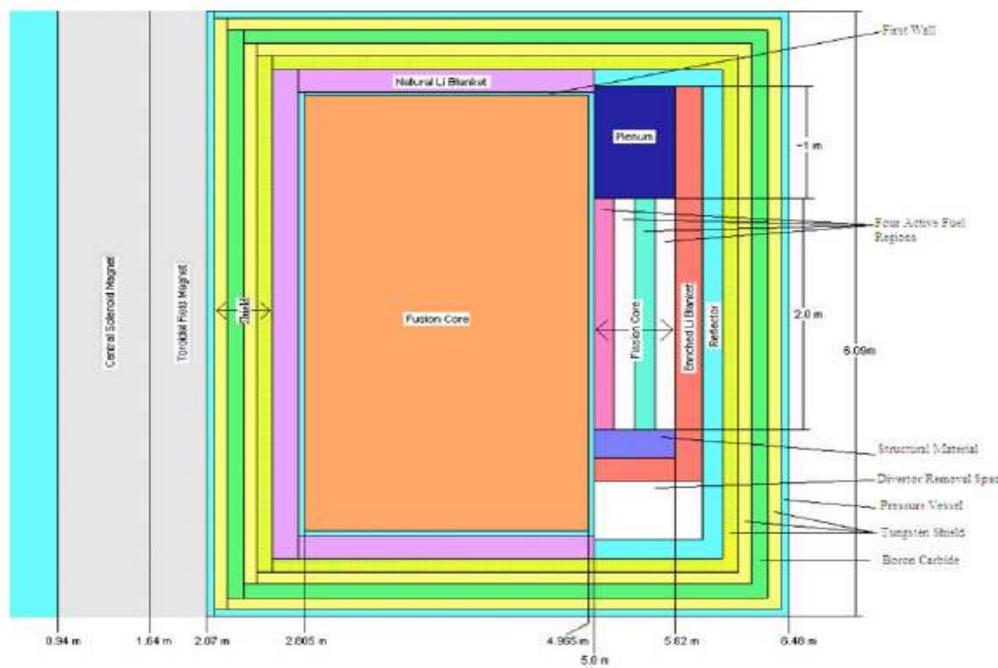
ADS-EFIT Layout





SABR Layout





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Transmuters Main Features

Parameter	ADS-EFIT	SABR
Fuel type	$(TRU)O_2$-MgO	$(TRU)O_2$-MgO
MA/Pu	~1.2	~1.2
Conversion ratio	0.0	0.0
Cycle length (EFPD)	365	700
Average fuel irradiation time (EFPD)	1095	2800
Av. TRU content (%)	51	45
Power (GW_{th})	0.384	3.0
Average discharge burnup (MWd/kg)	78	184
Reactivity Loss (%Δρ)	~0.0	-60.1
Efficiency	40 %	40 %
TRU transmutation rate (kg/yr)	141	1097
MA transmutation rate (kg/yr)	135	1050
Pu transmutation rate (kg/yr)	7	46
Support ratio	5.4	42

- **Same fuel, same TRU composition, same MA/TRU ratio in both systems**
- **Different coolant**
- **Different power**
- **Different fuel irradiation strategy and burn-up:**
  - **Constraint due to max dpa in SABR**
  - **Requirement for ADS-EFIT to keep proton beam power ~constant during irradiation**

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Systems Comparison - Neutron spectrum differences

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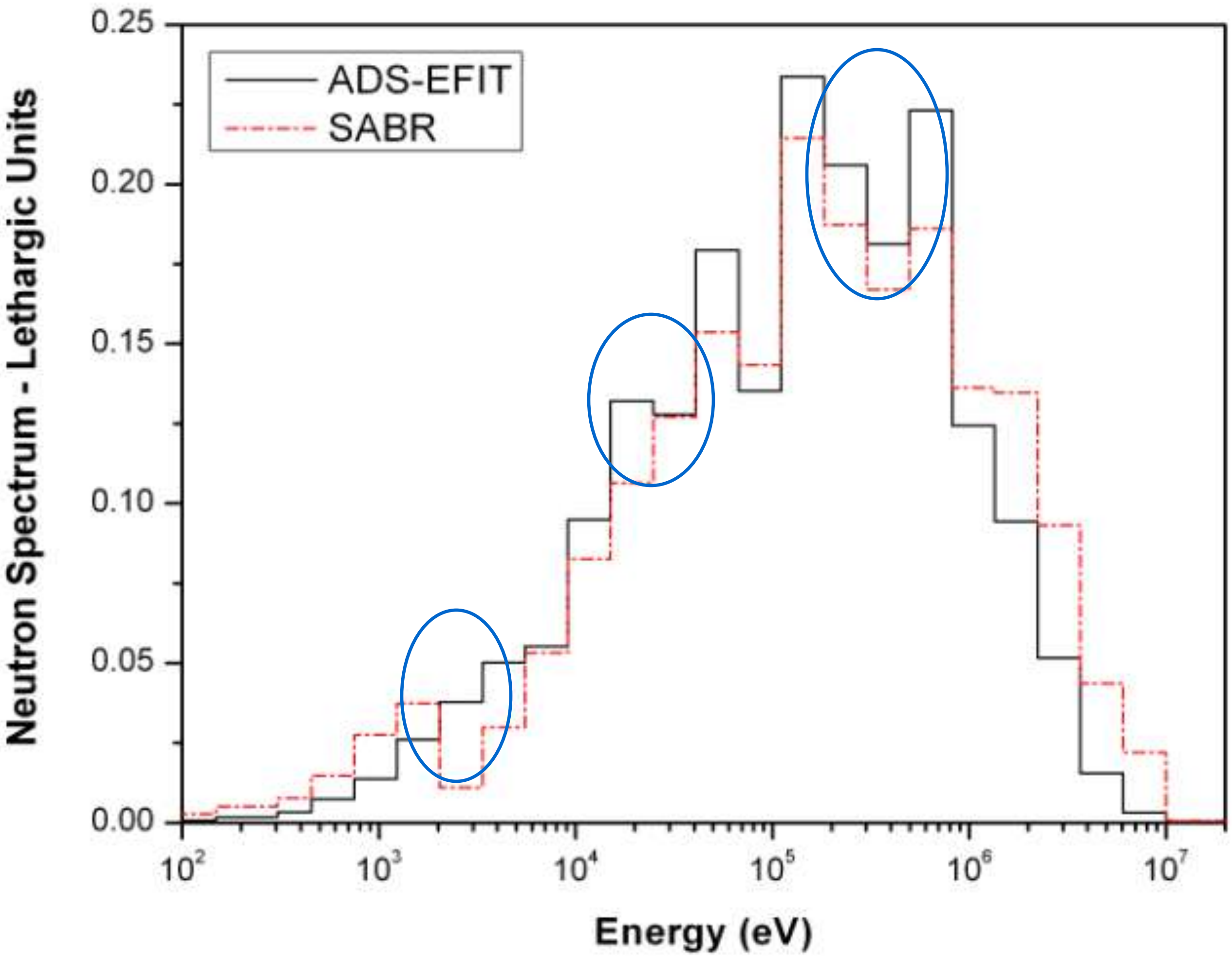

SABR spectrum harder than that of ADS-EFIT due mainly to coolant type and volume fraction differences

Effect of resonances of Mg-24, O-16 *(from inert matrix in both systems),* and Na-23 *(SABR coolant)* is visible

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Systems Comparison - TRU burning performance

Isotope	ADS-EFIT (EFPD=1095)	SABR (EFPD=2800)
Pu^{238}	19.3	18.2
Pu^{239}	-23.2	-21.9
Pu^{240}	-1.6	-2.3
Pu^{241}	0.1	1.2
Pu^{242}	3.4	3.0
Am^{241}	-45.4	-41.7
Am^{242M}	4.5	2.6
Am^{242f}	0.3	0.01
Am^{243}	-8.4	-6.4
Np^{237}	-1.2	-1.3
Cm^{242}	5.5	2.7
Cm^{243}	0.2	0.2
Cm^{244}	4.8	3.6
Cm^{245}	-0.4	0.2
Cm^{246}	0.1	0.0
Total Pu	***-2.0***	***-1.8***
Total MA	***-40***	***-40.0***
Total	***-42***	***-41.8***

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Systems Comparison - Scenario study

In the selected scenario two groups of nations are taken into consideration:

- **the first one with a stagnant or phasing-out nuclear policy *(Group A)***
- **the second with an ongoing nuclear power development *(Group B)***

The objective of Group A is to reduce its TRU inventory down to zero till the end of the century, while the objective of Group B is to stabilize the MA inventory, in order to allow an easier introduction of fast reactors in a successive step.

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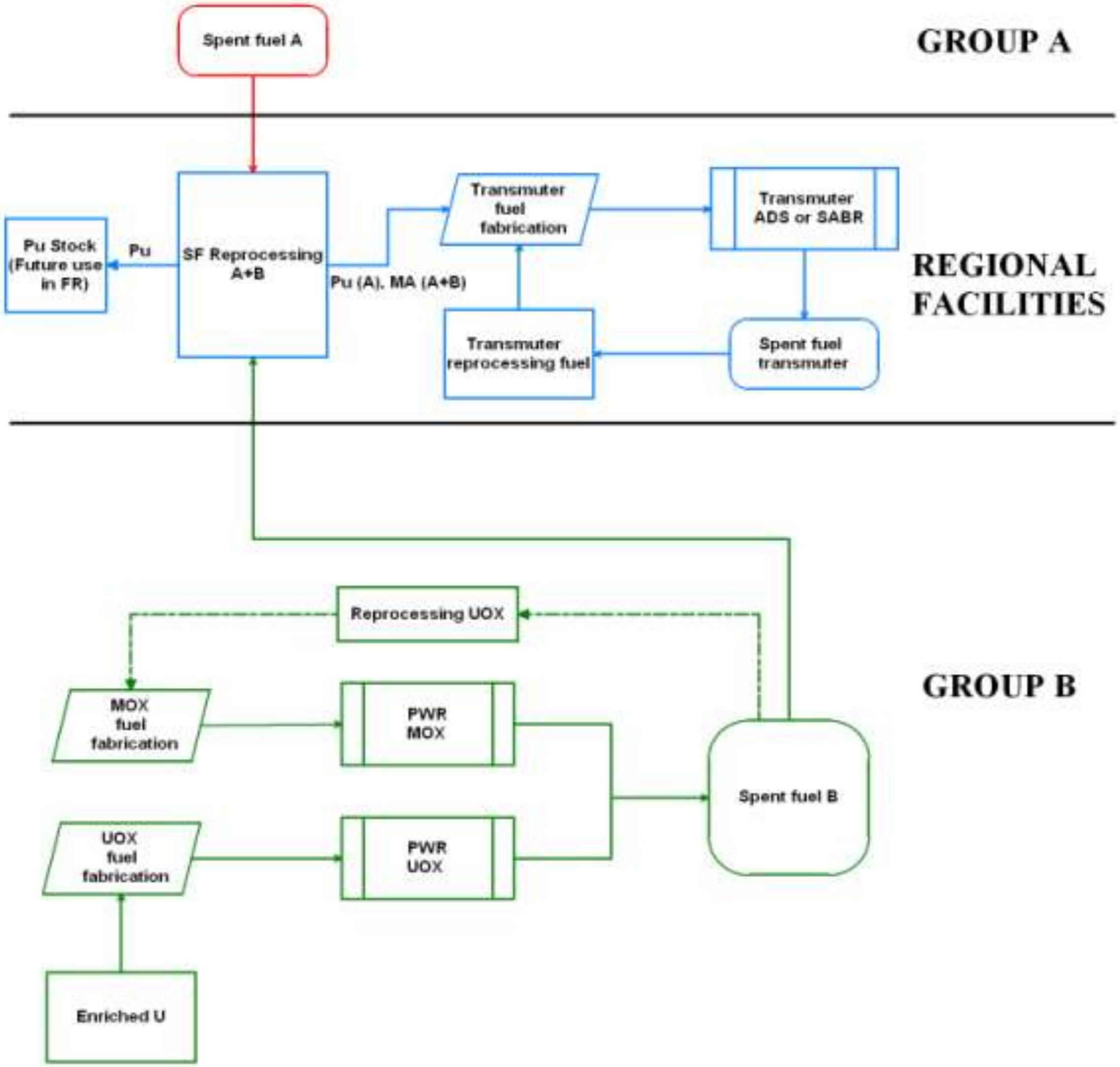
Scenario Flow Sheet



Group A: Belgium, Czech Republic, Germany, Spain, Sweden and Switzerland

Group B: France

Regional facilities (i.e. burner reactors, fuel fabrication and reprocessing facilities) begin operation in 2045

In the fuel cycle transmuters first use MA coming from their closed cycle, then those of Group A, and finally those of Group B

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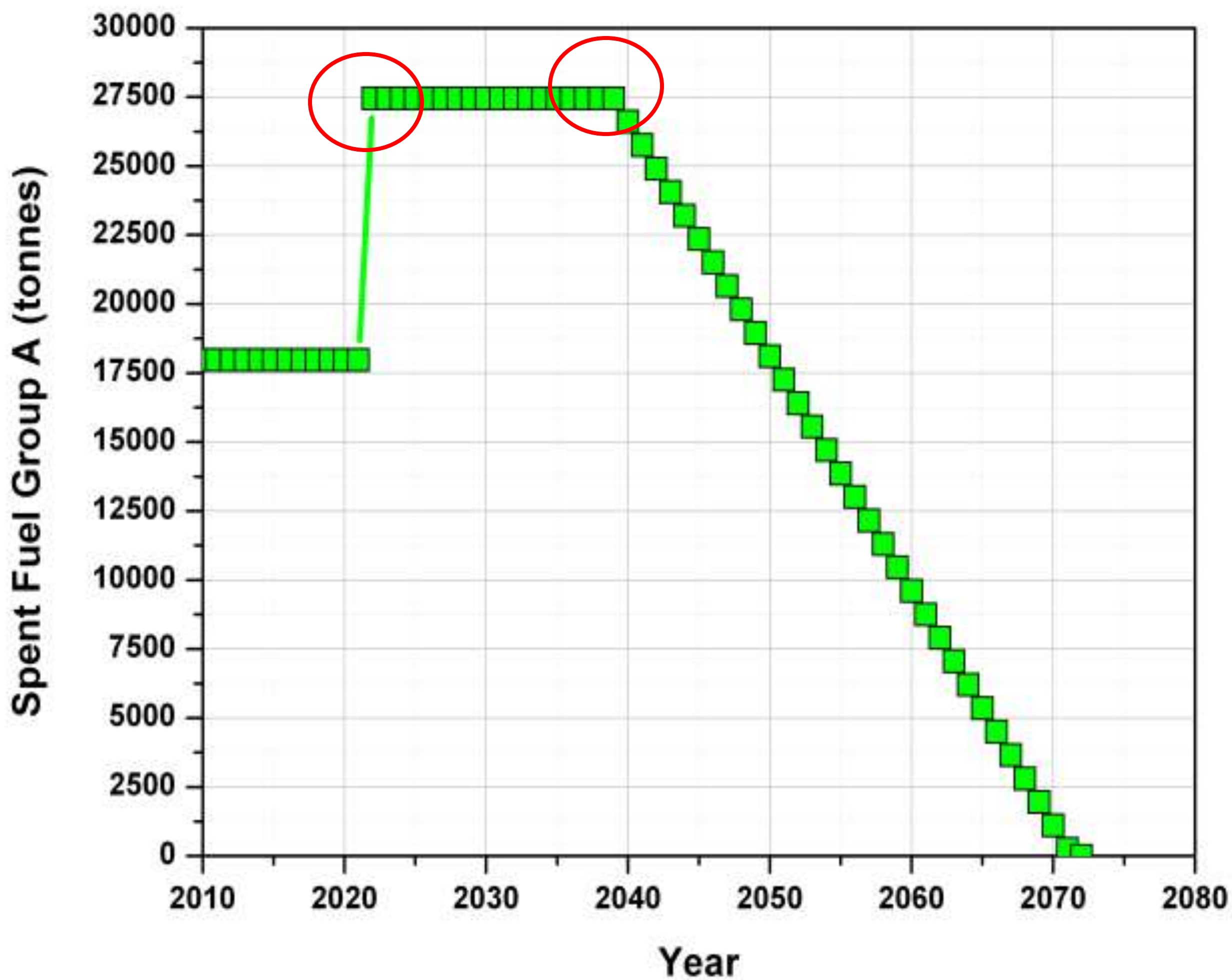
Scenario Simulation Results- Group A Spent Fuel stocks evolution



Spent Fuel of Group A, which amounts to ca. 17,500 tonnes in 2010, is increased by ca. 10,000 tonnes in 2022 due to Germany phase-out policy

In 2040 spent fuel reprocessing starts and is completed by 2072 *(yearly annual reprocessing capacity simulated: 850 tonnes/year)*

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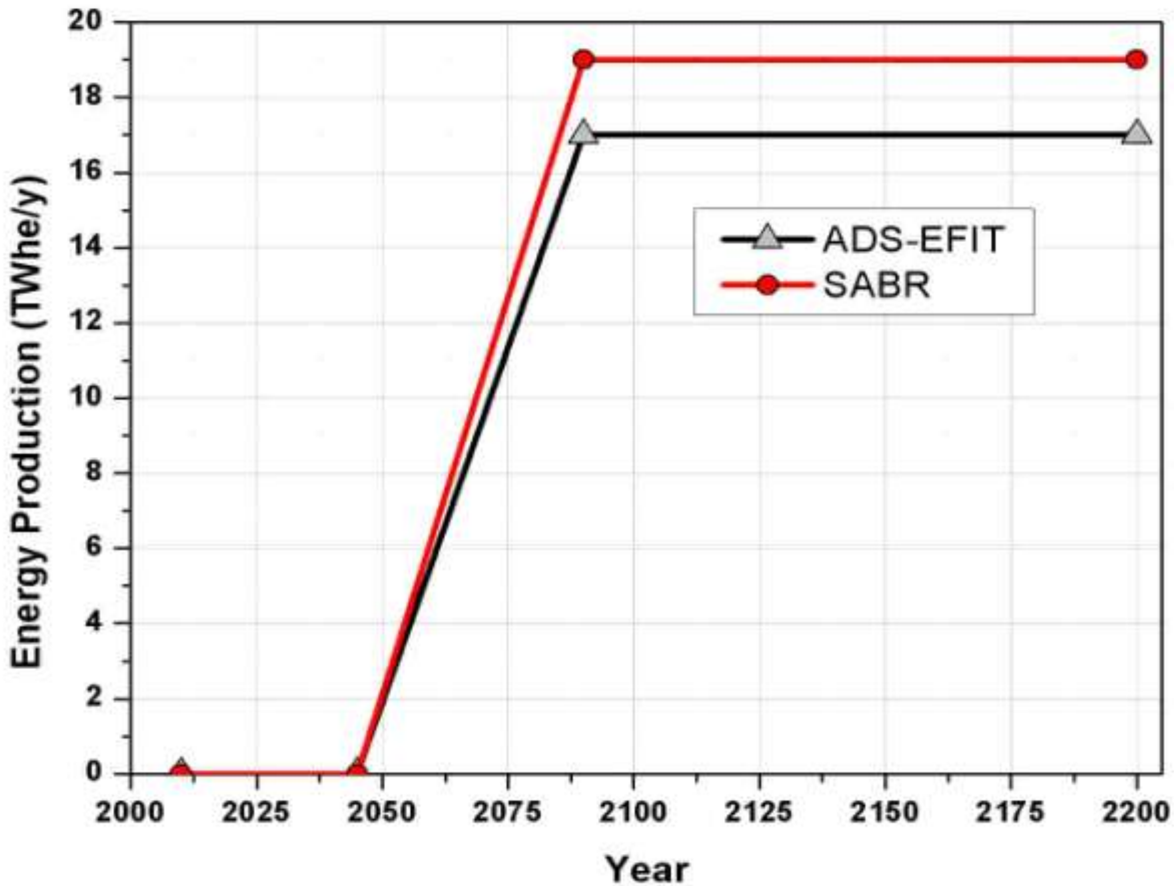
Scenario Simulation Results - Required Transmuters Energy Production



Units are deployed from 2045 to 2090

After 2090 a constant energy production was considered

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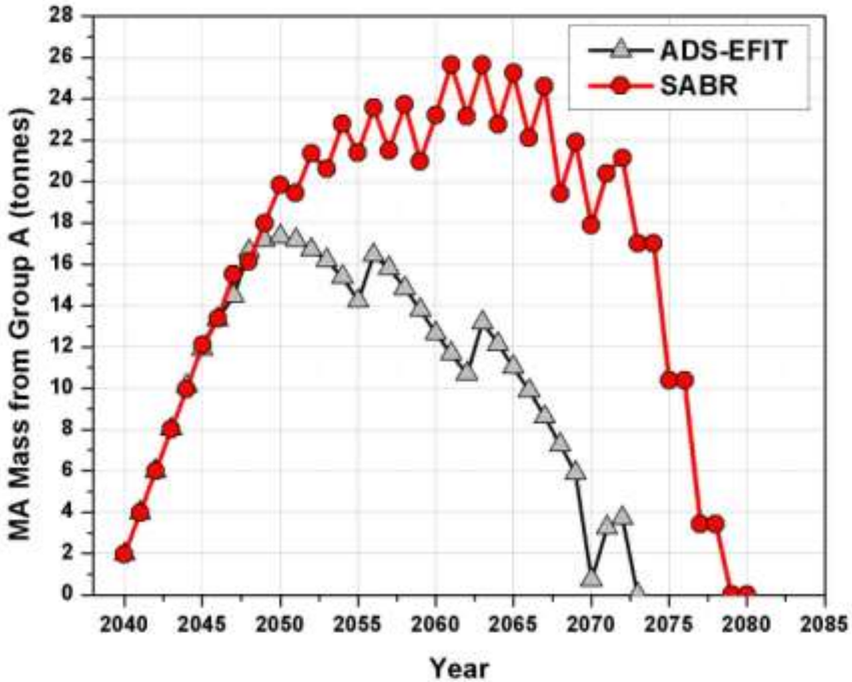
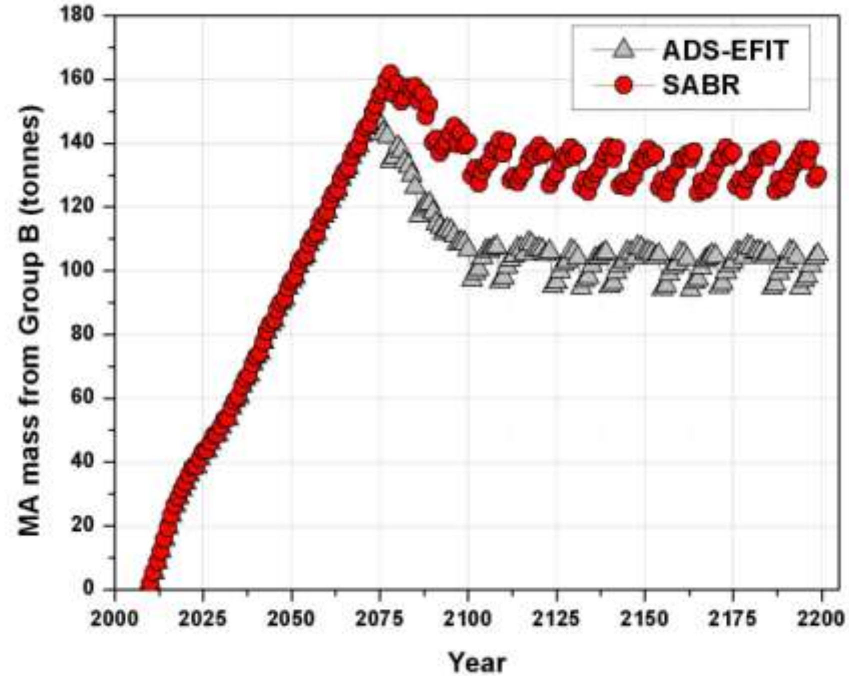
Scenario Simulation Results - MA Stocks evolution vs. time





Minor differences in performances *(in particular in Am-241 burning rate)* cause that MA from Group A are completely transmuted by ADS-EFIT ca. 6 years earlier.

A slightly higher SABR yearly energy production is required in order to stabilize MA of Group B.

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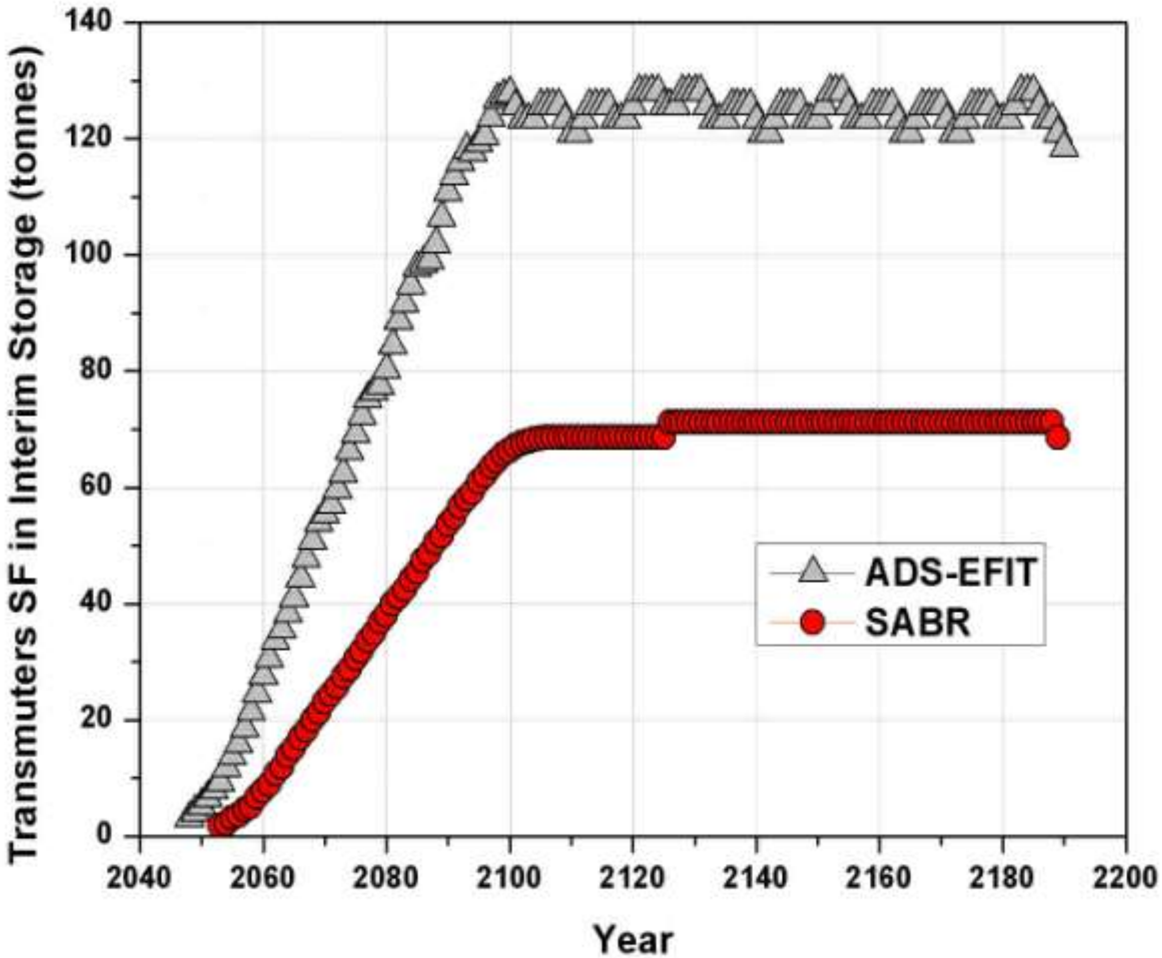
Scenario Simulation Results - Spent Fuel (SF) Interim Storage



SF Interim storages mass ratio in accord with transmuters fuel burnup (78,000 MWd/t for ADS-EFIT, 184,000 MWd/t for SABR)

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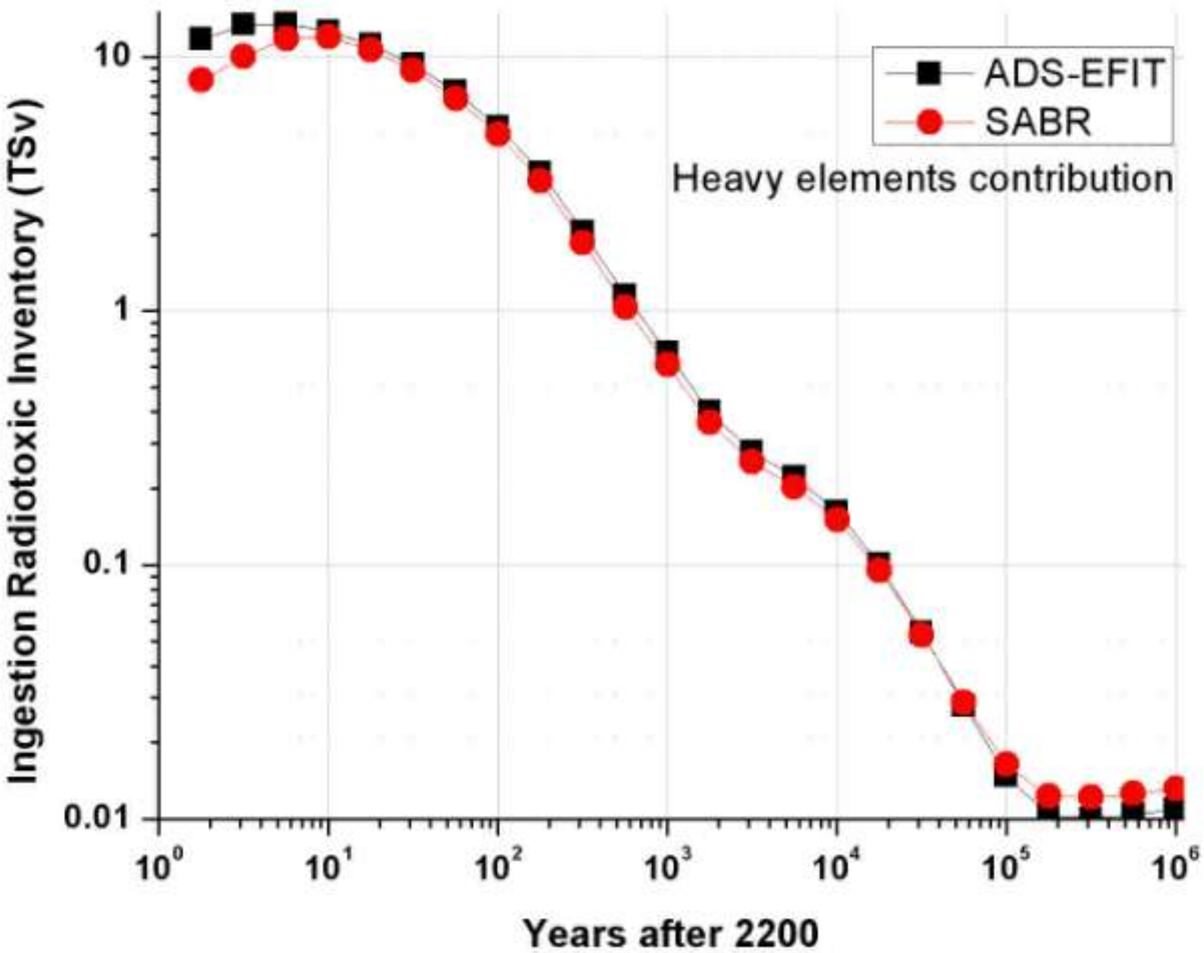
Transmuters Radiotoxic Inventory Comparison



Only heavy elements contribution evaluated

Very similar trend vs. time

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Conclusions

- A preliminary comparison between an ADS (ADS-EFIT) and a Fusion-Fission Hybrid reactor (SABR), both used as waste burners, has been performed

- Both systems were loaded with the same fuel composition, with a MA/Pu ratio ~1.2

- Design differences (coolant type, burn-up, power density, etc.) can explain relatively small differences in burning rates. As an example, neutron spectrum differences in the two systems, result in some differences in MA burning rates *(in particular Am-241).* However the overall transmutation performances are very similar

- In a regional scenario context, where the final goal is *a)* to transmute the TRU of nations with stagnant or even phase-out nuclear energy policy and *b)* to stabilize MA inventory of countries with a continuing nuclear energy development, the two transmuters show a similar performance

- Both ADS-EFIT and SABR proved to be well suited in principle for nuclear waste management issues

- Further work is foreseen in this field, in particular comparison with other transmuting systems and impact on fuel cycle