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COMPARISON BETWEEN TWO GAS-COOLED TRU BURNER SUBCRITICAL REACTORS: FUSION-FISSION AND ADS

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ABSTRACT

This work shows a preliminary comparative study between two gas cooled subcritical fast reactor as dedicated transuranics (TRU) transmuters: using a spallation neutron source or a D-T fusion neutron source based on ITER. The two concepts are compared in terms of a minor actinides burning performance. Further investigations are required to choose the best partition and transmutation strategy. Mainly due to geometric factors, the ADS shows better neutron multiplication. Other designs, like SABR and lead cooled ADS may show better performances than a Gas Coolead Subcritical Fast Reactors and should be investigated. We noticed that both designs can be utilized to transmutation. Besides the diverse source neutron spectra, we may notice that the geometric design and cycle parameters play a more important role.

Key Words: Transmutation, ADS, Fusion, Subcritical, Gas Cooled Fast Reactor.

1. INTRODUCTION

Partitioning and transmutation apply to the nuclear fuel cycle the general principles, adopted by the most sustainable industries, of classification (partitioning) and recycling (transmutation) of the components that are useful or dangerous for the population or the environment. The main objective of partitioning and transmutation (P&T) is to eliminate, or at least substantially reduce, the amount of long-lived radionuclides that will go to a deep geological repository for final disposal, increasing, in this way, the repository capacity [16].

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The investigation on P&T methods of spent nuclear fuel long-lived radionuclides has increased in the 1990ies. These studies are strongly focused on Accelerator Driven Hybrid Systems for incineration of spent nuclear fuel [11, 18], since it is a politically acceptable research even in countries with a negative political nuclear landscape. Recently, the interest on fast reactors to incinerate spent nuclear fuel increased and the concept of P&T was incorporated in the Generation IV [10] and INPRO [9] iniciatives.

The possibility of using a tokamak as a neutron source for transmutation had been investigated in few works during the 1990ies [6–8]. Due to the fission core neutron multiplication, the requirements of a tokamak to drive a transmutation reactor are lower than those to drive a pure fusion reator for eletricity generation [12].

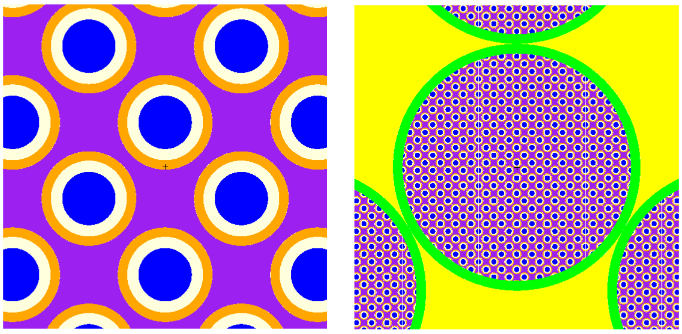
Over the past decade, the group at Georgia Tech has examined [4, 5] the application of a tokamak D-T fusion neutron source, which is based on the physics and technology of ITER, driving a sub-critical fast transmutation (burner) reactor fueled with transuranics (TRU) from spent nuclear fuel (SNF). The purpose of such a reactor would be to stabilize the accumulation of TRU being discharged from LWRs by fissioning this TRU to significantly reduce the required number of high-level-waste storage repositories. In this research, two types of nuclear reactors have been considered, both driven by essentially the same tokamak neutron source: gas-cooled reactors operating on a burn and bury deep-burn non-reprocessing fuel cycle with TRISO TRU fuel (GCFTR) [1–3] and liquid metal cooled reactors (SABR, FTWR) operating on a reprocessing fuel cycle with TRU metallic fuel.

Considering the studies performed at Georgia Tech, we propose here a spallation-accelerator driven subcritical reactor based on the GCFTR reactor. The performance of the two systems, concerning transmutation capability, fuel consumption, source strength were compared. The same fuel element was utilized on both systems. The two reactors are modelled on MCB code [13–15] and the fuel cycles were simulated until the equilibrium. An out-to-in fuel shuffling scheme was adopted. In the section 2, the description of the GCFR subcritical concepts is done. In section 3, the calculational methods are detailed and in section 4 some preliminary results are present.

2. GCFR SUBCRITICAL CONCEPTS

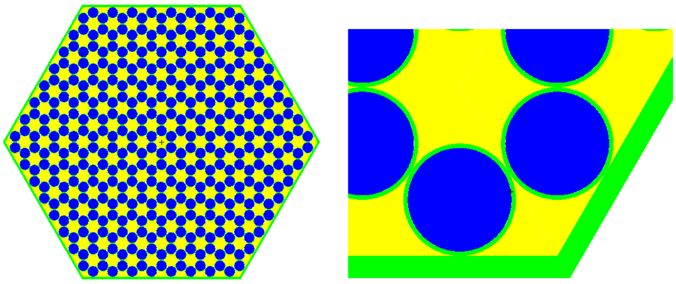
The GCFR was designed to use TRISO or BISO particles and to achieve deep burnup. A different particle from those proposed by the Georgia Tech group was considered. The particle used for the both systems studied in this work has a TRU oxide kernel, surrounded by a SiC porous buffer intermediate zone and a SiC shell disperse in a SiC matrix. The particle's $(TRU)O_{1.7}$ inner radius is $165\,\mu m$, while the porous intermediate zone and the external SiC shell are $69\,\mu m$ and $58\,\mu m$ thick, respectivelly. The TRU oxide volume fraction of the matrix is 8.1% and the packing fraction of the particles is 0.40. The fuel pins are filled by the SiC matrix cladded by HT-9 steel. It has an inner radius of $0.703\,cm$, an outer radius of 0.763, and a lenght of $300\,cm$. These fuel pins are arranged in a hexagonal block of 384 fuel pins and apothem of $18.6125\,cm$, the same fuel configuration proposed by the Georgia Tech group. Figures 1 and 2 illustrate the fuel particles, the fuel pins and the fuel element.

The fusion reator uses a similar configuration proposed by the Georgia Tech group, with 245 fuel elements surrounding the tokamak. Fig. 3 shows the one quarter XY and the XZ views of



(a) FuelParticles in the Matrix. (b) Fuel Pin.

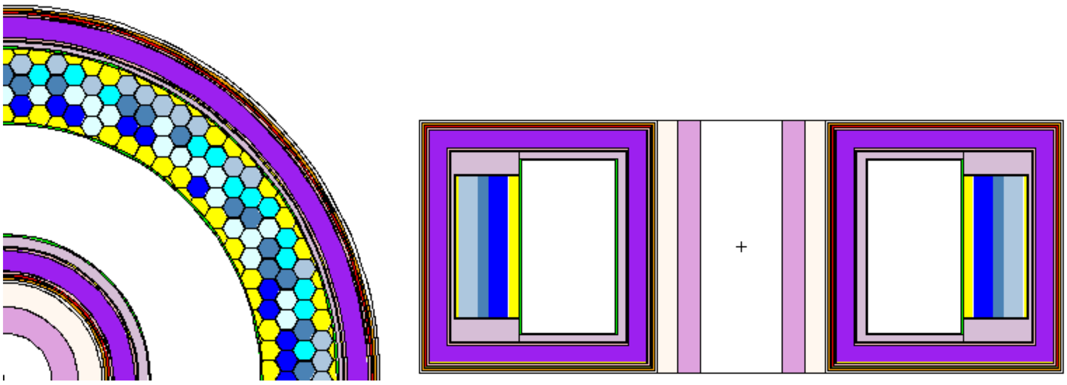
Figure 1: Fuel Pins and the Fuel Particles.



(a) Fuel Element. (b) Fuel Element Detail.

Figure 2: Fuel Element.

the fusion core. For the ADS, a void surrounded by 72 fuel elements was created to accomodate the spallation target and the accelerator tube for the 1 GeV proton beam. A reflector of Ba_2Pb was utilized in the ADS to improve the neutron efficiency. Fig. 4 shows the XY and XZ views of the Accelerator driven GCFR core.



(a) 1/4 XY view. (b) XZ view.

Figure 3: XY and XZ views of the fusion driven GCFR.

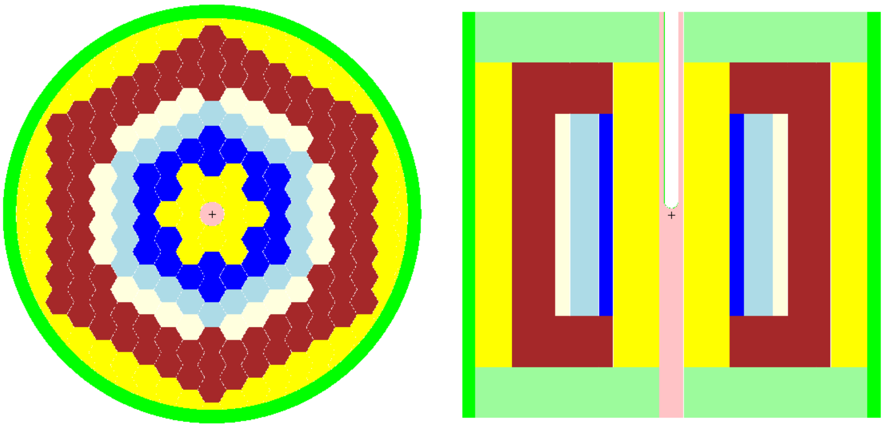

(a) XY view. (b) XZ view.

Figure 4: XY and XZ views of the Accelereator driven GCFR core.

The initial fuel is the same in both concepts: $(TRU)O_{1.7}$ with the TRU Plutonium atom fraction of 89%. In the refuelling, the fresh fuel has the Plutonium fraction increased to pushup the reactivity, compensating the burnup. For the fusion reator, the Plutonium atom fraction used in subsequent cycles are 95, 96, 97 and 98 %, while for the ADS the Pu enrichment of the fresh fuel in each cycle are 95 and 97%. Table I organizes the main cycle parameters for fusion and ADS reactors.

3. METODOLOGY

Both reactors are detailed modelled in MCB, a continuos energy Monte Carlo code which is a patch of MCNP that allows burnup calculations. The neutron source was explicitily modelled in the MCB code. The fusion source is assumed isotropic and homogeneous at the plasma region, with the typical D-T spectrum. The spallation source was modelled in MCNPX and the spatial and energetic distributions were used as input of the MCB calculation. To speedup the calculation, only the neutrons scapping the plasma towards the fission blanket are sampled, so the plasma source to produce $3000 MW_{th}$ on the blanket should be correct by a geometric factor. No homogenization has been done in the transport calculation, i.e. the fuel particles, inert matrix and fuel pins were modeled explicitily, as showed in Figures 1 and 2. The only homogenization that has been done was in the burnup calculation, where the fuel elements have been set in zones that burn homogeneously. In the fusion reactor, five zones has been defined, and in the accelerator driven, three zones. In this analysis, for simplicity, the axial burnup profile has not taken into account.

The point-wise neutron data library was based on ENDFB6.8 except for the Curium isotopes, taken from JEF2.2. For the MCNP analyses, the temperature was assumed to be constant and equals to $1200\,K$ in the reactors cores. Before and after each burn step, a KCODE calculation was performed to evaluate the effective multiplication factor k_{eff}. The burnup time-step was set to 150 days.

Table I: Main Parameters

Parameters	Fusion	ADS
Fission Power MW_{th}	3000	800
TRU fuel mass tonnes	33.9	10
Number of EC	245	72
Cycle duration days	600	350
Cycles to equilibrium	5	3
Fuel residence time in years	8.2	2.9
Plutonium/TRU mass BOC	0.89	0.89
TRU transmutation rate (kg/yr)	1091	280
MA transmutation rate (kg/yr)	149	54
Pu transmutation rate (kg/yr)	942	226

4. RESULTS

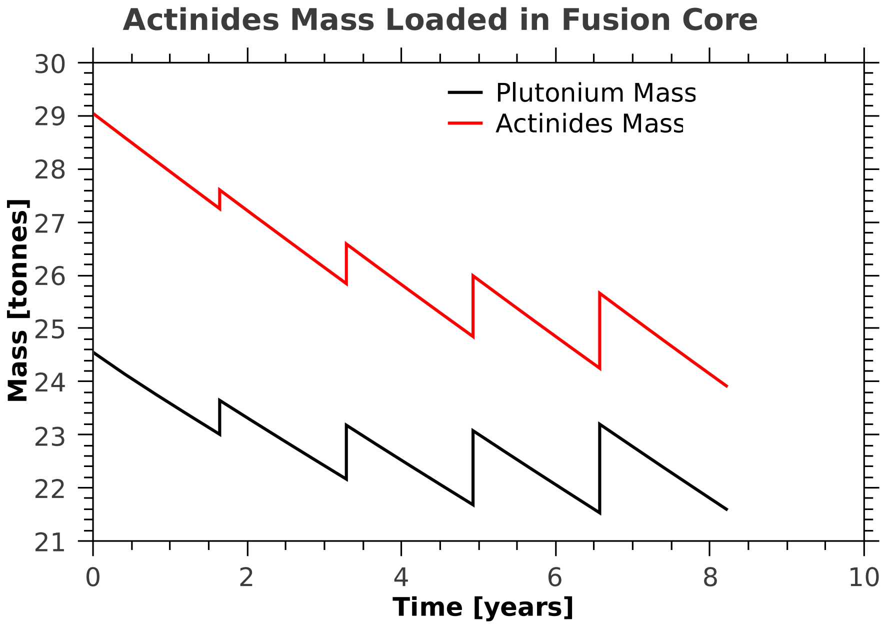
Figure 5 shows the total Actinides and Plutonium mass loaded in the Fusion and ADS cores. The discontinuities in the curves are related with the refuelling scheme.

Figure 6 show the source multiplication factor k_{src} and k_{eff} for fusion and ADS cores. We may note that for the ADS, k_{src} are closer to k_{eff} than for the fusion neutron source, and slight greater than k_{eff}. This suggest that in the ADS core is more efficient in neutron multiplication, probably due to a better geometrical and material configuration to avoid neutron leakage.

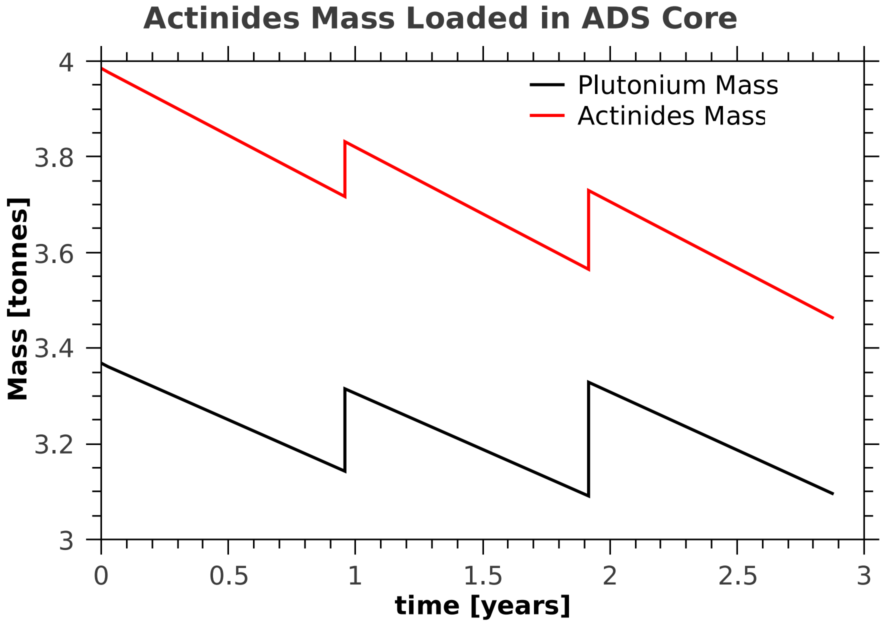
The flux distribution in the fusion core at BOC is showed in Fig. 7. The thermal analyses, using computational fluid dynamics of the hot channel has been done in another paper in preparation. The results obtained by us show that is feasible to remove heat from this systems.

5. CONCLUSIONS

This work shows that both sources could be used to perform transmutation of long-lived nuclides from spent nuclear fuel. Performance differences between the two sources are mainly due to geometrical and design reasons than due to neutron source spectrum differences. The trans-



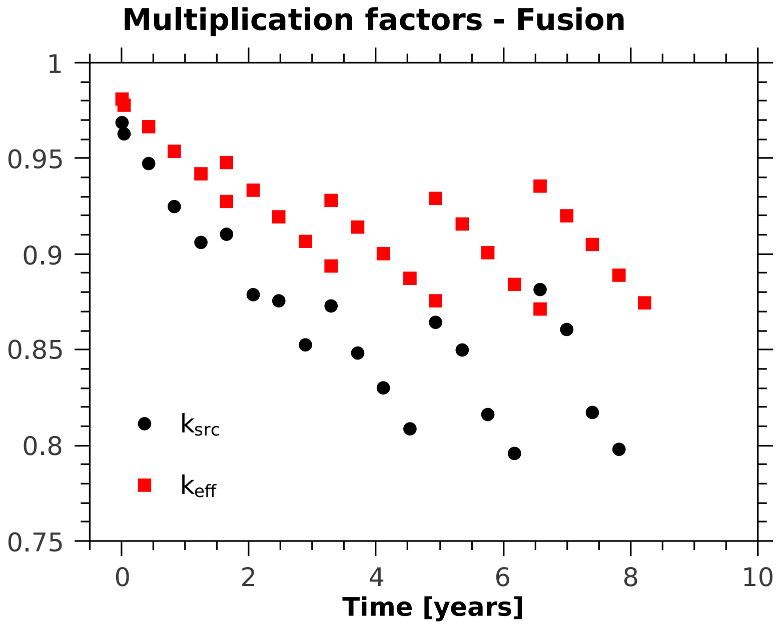
(a) Fusion.



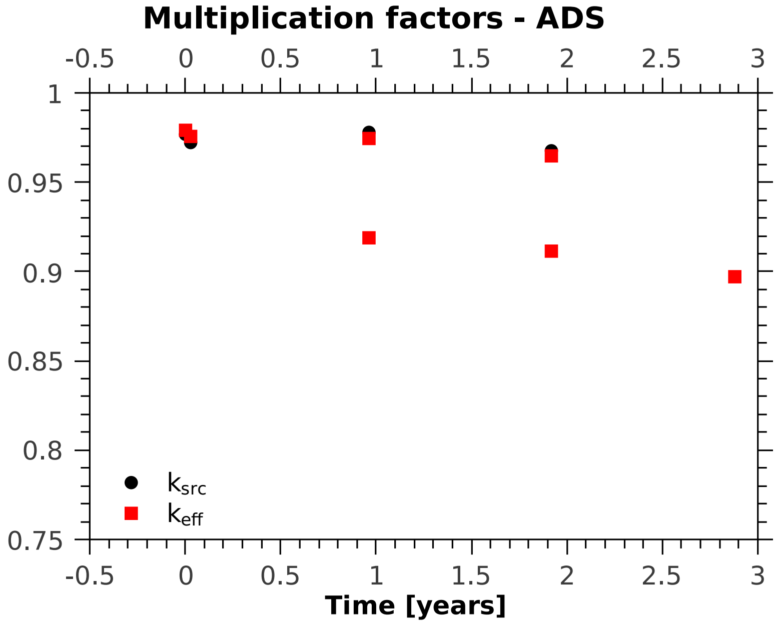
(b) ADS.

Figure 5: Actinide Mass in fusion and ADS cores.

mutation rate is more related with the system power than with source neutron spectrum, since only a small fraction of the neutrons avaliable for transmutation comes directly from the source k_{eff} 0.80. The ADS design shows a better neutron economy while the fusion shows a greater transmutation rate due to the greater power. The ratio between the transmutation rate in the



(a) Fusion.



(b) ADS.

Figure 6: Multiplication factors for fusion and ADS cores.

two systems is 3.90 while the ratio between their power is 3.75, which can be explained by the higher Pu content in the fusion refuelling. The huge mass content of the fusion reactor allow a bigger cycle length and a smaller reativity swing from the BOC and EOC.

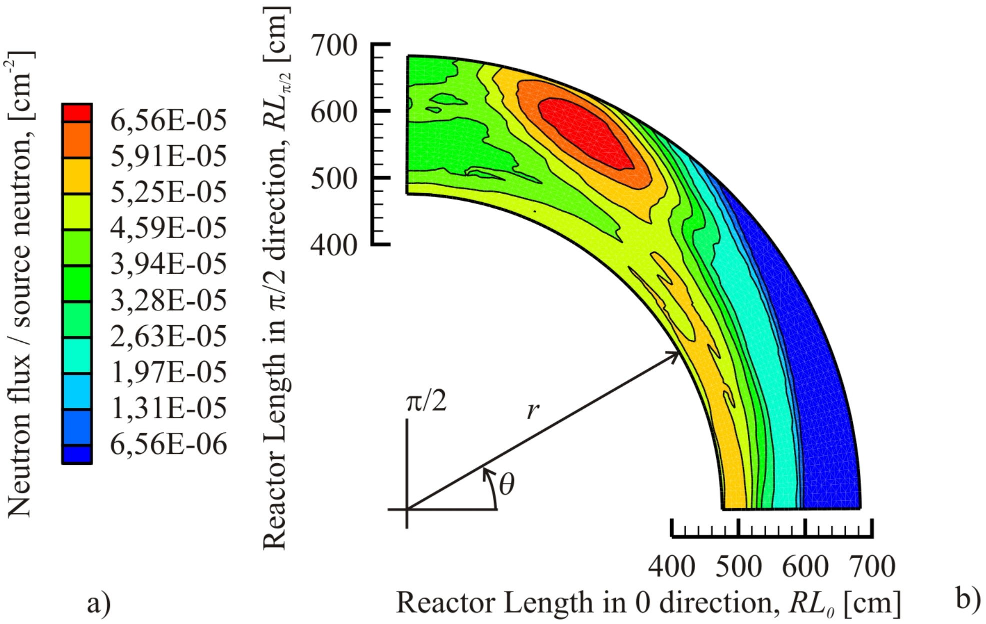


Figure 7: Flux distribution - Fusion.

The Gas Cooled Source Driven reactor can achieve a large burnup without reprocessing, however it could be not the best choice for the dedicated burners reators. Liquid Metal Cooled concepts and Molten Salt subcritical reactors should be analysed. This work do not intent to analyse the economical aspects of the two neutron sources, as done in [17], however it can be usefull in this task, supplying this study with better neutronics analyses. The R& D level of the two neutron sources are quite different and probably the ADS will be available first than the fusion transmutation reactor. However both would play an important role in future, as dedicated burner reactors in a two strata fuel cycle.

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