A Preliminary Study of P&T Scenario on a Sustainable Energy System in China

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Abstract. Fast breed reactor has two important mission in China: the first mission is to increase the utilization ratio of uranium resource sharply; another one is to minimize long life radioactive waste by recycling all the TRU in FBR. Firstly, the radioactive harmfulness of the spent fuel was studied. In order to ensure the harmfulness of spent fuel being smaller than that of uranium mine level in one thousand year, the object of reprocessing partition ratio of some nuclides was shown in the paper. Secondly, the study of the capability of MA burning in 600 MWe FBR shows that FBR could burn more MA produced in six PWR with same capacity. Lastly, a 400GWe nuclear energy system scenario was studied ,and the study balance of MA in the system shows that 500 tons MA would be produced by the system, including PWR and FBR with Pu fuel. In 2050, the quantity of MA would reach the peak value. Lots of MA was transported into fast transmutation reactor and only a small part was burnt in FBR. After 2070, there would be about 70 tons MA in the NES, most of which exist in FBR core and its reprocessing facilities. In summary, for a sustainable nuclear energy system in China, FBR should be commercially operating before 2035, and P&T strategy should be implemented before 2050.

Key Words: FBR, transmutation, NES Scenario.

1. Introduction

The need of energy will become more and more large in China, with the economic developing sharply. Because of the big stress of low carbon emissions, China has a huge demand for nuclear power. Calculated in accordance with China's nuclear power to reach the world average level, the total capacity will reach 400GWe by 2050.

But PWRs has a very small uranium utilization ratio, which is not more than 1%, and the long time risk of spent fuel storage must to be considered. In this case, China had planned a consistent closed fuel cycle policy in 1980's, and devote country's energies to develop the fast breeder reactor and its fuel cycle.

Fast breeder reactor has two missions in China. The first one is to breed the fissile fuel with U-Pu fuel cycle, to realize the sustainability of nuclear energy system. The second one is to burn the MA from the PWR spent fuel after fuel reprocessing. At the same time, all the actinide in fast reactor spent fuel will recycle, thus the total MA will be keep in a acceptable level.

2. The Harmless of PWR Spent Fuel

The Long term goal of fast reactor is one kind of integrate fuel cycle. The only high radioactive waste, which needs to be disposal, is the fission products after reprocessing and some other cladding waste. But there will be 20~30kg MA per GW•a in PWR spent fuel, beside 160kg industrial plutonium, according the spent fuel burn-up. Increasing decay time, more and more ^{241}Pu will decay to ^{241}Am.

The radioactivity level of PWR spent fuel was studied, Fig1 shows the radioactivity of primary nuclides in one ton PWR spent fuel with a burn-up of 45,000MWd/tHM, calculated by ORIGEN2 code. Furthermore the dose of these nuclide was shown in Fig2.

The goals of partition and transmutation by IAEA:

- In the long (>300 years) time scales, reduce the harmfulness of the waste produced by NPPs, by decreasing Pu and MA.
- Reducing the time, in which radioactive harmfulness will be as low as the reference level, by recycling the TRU.
- Reducing the volume of spent fuel, by partition and recycle the uranium in spent fuel. Making full use of disposal capacity.

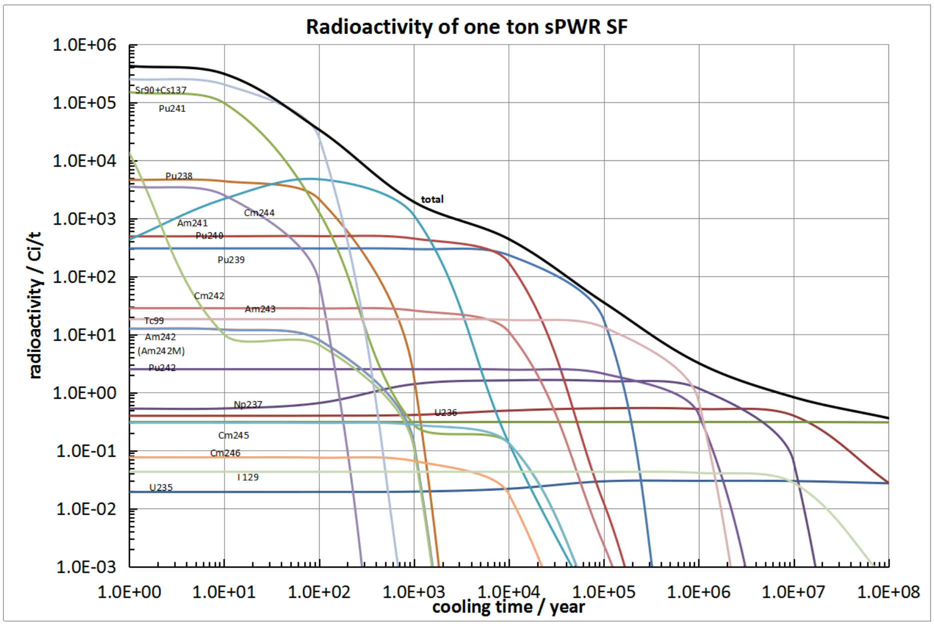

FIG. 1. The radioactivity of PWR spent fuel

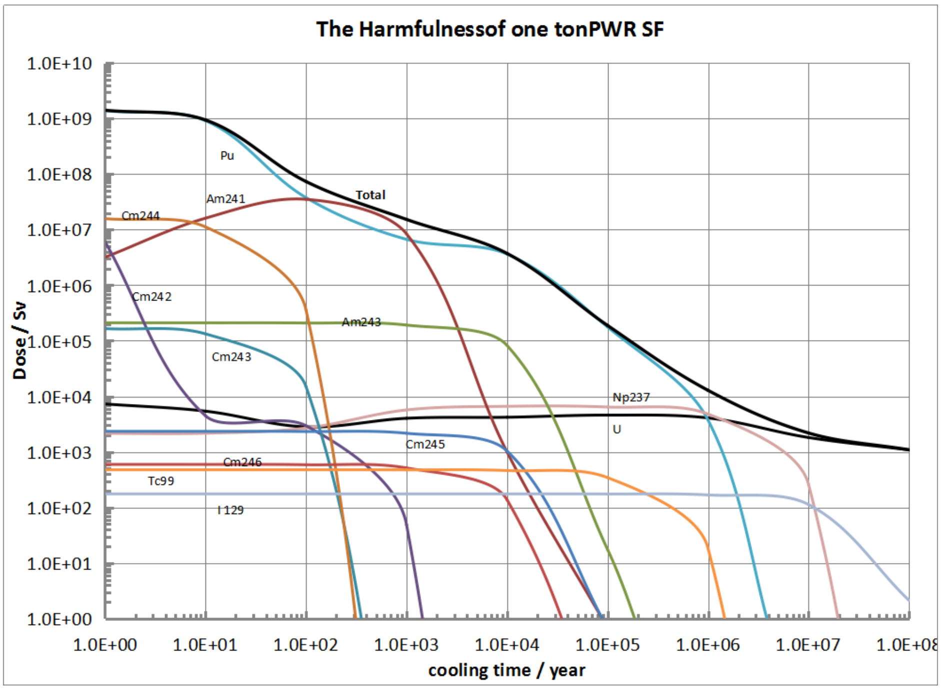

FIG. 2.The dose of PWR spent fuel.

In this case, if it was hoped that the harmfulness level of spent fuel could be as low as that of the uranium mine level in no more than 1,000 years, all the plutonium isotope, ^{237}Np, ^{241}Am, ^{243}Am, ^{245}Cm, ^{129}I and ^{99}Tc should be partitioned and transmuted. And the partition ratio was shown in table1.

TABLE I: THE OBJECT OF PARTITION RATIO

NUCLIDES	**By radioactivity**	**By dose**
^{237}Np	6	14
^{241}Am	4,580	20800[1]
^{243}Am	105	476
^{242}Cm	/[2]	/
^{244}Cm	/	/
^{245}Cm	/	5
^{246}Cm	/	/
PU	3,040	16600
^{99}Tc	74	/
^{129}I	/	/

3. Transmutation Capacity of FBR

In general a middle size fast would be more suitable as a transmutation fast reactor. CFR600 would be the demonstration fast reactor in China, besides the breeder reactor core, a specialized core for burning MA with 5% MA in MOX fuel was studied. To compare the transmutation capacity between Np and Am, the two elements was calculated individual, results shown in table1.

More than 10kg MA per GW•a will produced in this kind of 600MWe fast reactor without any MA in MOX fuel. And the transmutation capacity will be more than 200kg MA per GW•a, what over with 5% Np or Am in MOX fuel. It mean that one 600MWe fast transmutation reactor could deal with enough MA produced by six time equivalent capacity PWR.

TABLE I: MA CHANGE IN 600MWe FBR， kg/GWe•a

Nuclide	**MOX fuel FBR**	**MOX fuel FBR with 5% Np**	**MOX fuel FBR with 5% Am**
^{237}Np	3.20	-201	
^{241}Am	-8.88	/	-182
^{243}Am	9.00	/	-25.6

1 ^{241}Pu decays to ^{241}Am with a T1/2 of 14.1 years, thus the partition ratio should refer to ^{241}Pu. And the partition ratio would be changed, depends on the decay time of spent fuel.

2 It means that the harmfulness level would be low than uranium mine level after 1,000 years.

^{242}Cm	5.58	/	
^{244}Cm	1.19	/	
^{245}Cm	0.0792	/	
^{246}Cm	0.00242	/	

The large commercial size fast breeder reactor with Pu fuel would produce more MA than PWR, if there is not any MA in fuel. But the start fuel of fast reactor come from PWR spent fuel. If the TRU in PWR spent fuel was recycle together in fast reactor, the result of MA will be different completely. A commercial size fast breeder reactor, named CFR1000, was studied, which used TRU come from PWR spent fuel as the first cycle fuel, than recycled it fuel and blanket. Table2 shows that, only a little change about Pu composition happened, the portion of ^{238}Pu doubled and the portion of ^{241}Pu reduced sharply. The fraction of MA in fuel reduced negligibly, except the composition of MA, shown in fig3.

TABLE II: FUEL COMPOSITION CHANGE IN CFR1000

Number of cycle	**Pu**					**MA/HM**
	^{238}Pu	**^{239}Pu**	**^{240}Pu**	**^{241}Pu**	**^{242}Pu**	
1	4.06%	62.54%	21.93%	7.03%	4.44%	1.500%
2	5.70%	64.05%	21.95%	4.19%	4.11%	1.492%
3	6.57%	64.72%	22.05%	3.02%	3.64%	1.492%
4	6.99%	64.84%	22.08%	2.68%	3.40%	1.485%
5	7.20%	64.99%	22.18%	2.53%	3.10%	1.483%
10	7.34%	65.43%	22.48%	2.47%	2.28%	1.477%
15	7.36%	65.57%	22.56%	2.48%	2.03%	1.476%
20	7.37%	65.63%	22.55%	2.48%	1.96%	1.475%
23	7.38%	65.65%	22.55%	2.48%	1.94%	1.475%

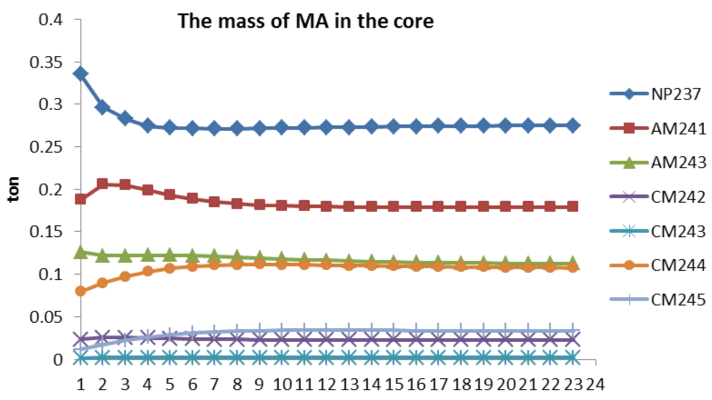

FIG. 3.MA changing in CFR1000 core.

According the result of CFR1000, 1.5% MA in fuel may be the balance fraction in this kind fast reactor. That mean that, a fast reactor with more than 1.5% MA in fuel will be a kind of transmutation reactor, otherwise it will produce more MA than that burn in core.

4. A Scenario Study of P&T in China

Although nuclear power in China started lately and MA accumulation in the short term is limited, the overall nuclear power development expected large scale, total demand for transmutation is very large. Fig4 shows an assumption nuclear energy system scenario in China. 200GWe PWR is expected in the near future, and than MOX fuel fast breeder reactor is expected to deploy. After 2050, the metal fuel fast reactor with TRU cycle should be deployed.

In the scenario, there were some key point:

- 200GWe PWR will produce about 400 ton MA during the 60 years life. The peak amount MA is 5.5 ton annually.
- Before 2050, there is no more than 100 ton MA after reprocessing in the nuclear energy system, including produced by PWR and FBR with MOX fuel. It was the reason why the transmutation capacity is not urgent.
- FBR with MOX fuel will produce 110 ton MA from 2030 to 2075.
- After 2050 the capacity of NPPs remain 400GWe. So the fast reactor should reduce is high breed ratio to a little great than 1.0. Or the Pu came from FBR could use as PWR fuel in innovative water coolant reactor.
- Reducing the volume of spent fuel, by partition and recycle the uranium in spent fuel. Making full use of disposal capacity.

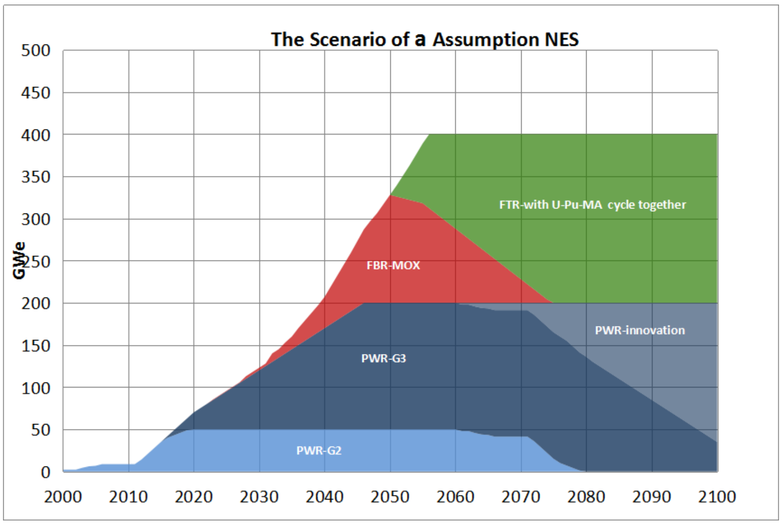

Fig 4 A scenario of assumption nuclear energy system in China

Fast reactor using TRU cycle could use metal fuel with 5% MA will provide a strong support to transmute MA. The balance of MA in the nuclear energy system was shown in fig5.

- 200GWe FBR could burn about 30 ton MA each year. The transmutation ability is much great than the MA produce in other type reactor.

- During the early time of deploy fast transmutation reactor, the MA in storage reduced sharply. But it was not transmuted indeed, most of them was transport into the fast reactor core.
- When the capacity of fast transmutation reactor reaches 110GWe in 2060, most of MA in storage was put into the fast reactor core. After that, the problem comes to that, how to manage the TRU fuel cycle in fast reactor.
- The MA amount in fast reactor core will reduce to 70 ton, and the portion of MA in fuel will be nearly 1.5%. Then there will remain 70 ton MA in NES.

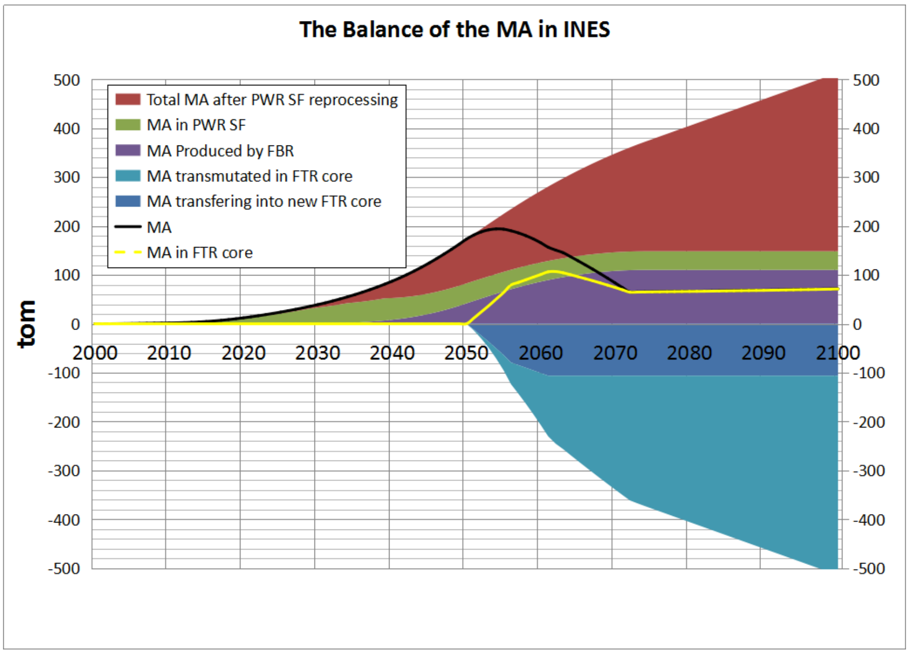

Fig5 The Balance of the MA in INES

5. Conclusion

A closed fuel cycle based on fast reactor and thermal reactor is an important way to realize the sustainable nuclear energy system for China. High breed ratio fast reactor with the U-Pu cycle is the first step of the FBR strategy, in order to rise the NPPs capacity. Then integrate fuel cycle for fast reactor, with TRU recycled, will deploy before 2050. FBR could provide enough transmutation ability to dell with the MA, and keep the amount of MA in a acceptable level.

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