POTENTIAL OF INCINERATION OF LONG-LIFE FISSION PRODUCTS FROM FISSION ENERGY SYSTEM BY D-T AND D-D FUSION REACTORS

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Abstract

The incineration of LLFPs, all of which can not be incinerated with only the fast reactor without isotope separation is studied by employing the DT and DD fusion reactors. The requirement of production of tritium for the DT reactor is severe and the thickness of the blanket should be decreased considerably to incinerate the considerable amount of LLFPs. On the other hand the DD fusion reactor is free from the neutron economy constraint and can incinerate all LLFPs. The pure DD reactor can also show the excellent performance to reduce the first wall loading less than 1 MW/m^2 even for total LLFP incineration. By raising the wall loading to the design limit, the D-D reactor can incinerate the LLFPs from several fast reactors. When the fusion reactor is utilized as an energy producer, plasma confinement is very difficult problem, especially for the D-D reactor compared to the D-T reactor. However, when it is utilized as an incinerator of LLFP, this problem becomes considerably easier. Therefore, the incineration of LLFP is considered as an attractive subject for the D-D reactor.

1. INTRODUCTION

We may accept a long period for using the fission energy before the fusion energy will be put to practical use. When we use the fission energy, the problem of radioactive waste is an inevitable problem. If we try to incinerate them, long-life radioactive materials should be transmuted to stable ones though nuclear reactions, though for short-life fission products we will simply wait until they will decay out. These long-life radioactive materials consist of actinides and LLFPs (long-life fission products). The actinides are fissionable materials and can be incinerated in a fast reactor through fission process[1]. However, the LLFPs are pure neutron absorbers and their incineration will make the criticality of reactor difficult. Incidentally, the fission energy system does not only produce radiotoxic materials but incinerates radiotoxic materials by burning uranium and its daughters[2]. In the present paper we evaluate the toxicity with the unit of incinerated uranium (and its daughters) toxicity.

In the present paper we consider 7 LLFPs: ^{79}Se, ^{93}Zr, ^{99}Tc, ^{107}Pd, ^{126}Sn, ^{129}I and ^{135}Cs. Though the total toxicity of these nuclides is about a half of the incinerated uranium toxicity [2], the incineration is desirable since their chemical characteristics are different from the uranium and its daughters. If we employ isotope separation and only LLFPs are inserted in the fast reactor, it is possible to incinerate them without violating criticality constraint[3,4]. However, the isotope separation is a very difficult technique, and only chemical separation is desired. In the latter case, many stable isotopes are contaminated in the materials to be inserted in the reactor. The conventional sodium-cooled oxide-fuel fast reactor can incinerate only 4 LLFPs: ^{79}Se, ^{99}Tc, ^{126}Sn and ^{129}I. There remains the normalized toxicity of about 0.1[4].

In the present paper we try to incinerate the LLFPs born in the fast reactor by employing a fusion reactor. For the D-T reactor, tritium is produced in the fast reactor blanket. The produced tritium is transferred to the fusion reactor with the LLFP produced at the same time. The neutrons produced from tritium in the fusion reactor core incinerate the LLFPs in the blanket. The neutron balance of the system is studied and the feasibility of this synergic system is evaluated. For the D-D reactor, the neutron economy is not required. Then, the total 7 LLFPs can be incinerated.

2. REACTOR DESIGNS AND FUEL CYCLE SCHEME

The studied fast reactor is a sodium-cooled oxide-fuel fast reactor whose thermal power output is 3000 MW. The design of fusion reactor is made by considering ITER [5]. The standard value of first wall loading is set to be 1 MW/m^2 for each reactor.

The fuel cycle scheme for the system of only fast reactor is shown in Fig. 1. The complicated steps of separation and storage are simplified in this figure. The fission core includes all regions where the neutrons are available. The natural uranium is inserted to the core. In the present study Zr, Tc and Pd are treated as simple metal, and Se, Sn, I and Cs are charged in the blanket as compounds, SeSn, SnO, CsI and Cs_2O. Every material is a stable solid and easier to be treated, but the melting point of CsI is 894K and heat removal becomes important. The removal rate of LLFP from the core is chosen to be 1/2 y^{-1} in the present study.

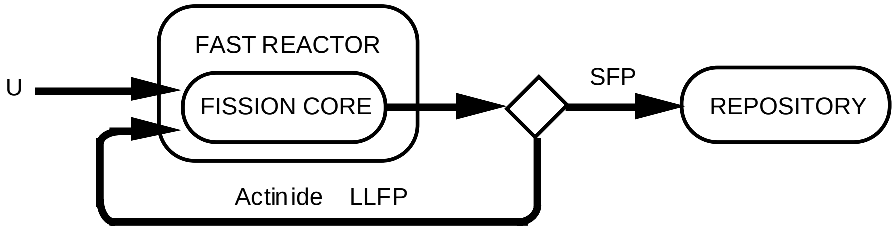

FIG. 1. Fuel cycle scheme of only fast reactor. SFP and LLFP stand for stable and long life FP, respectively. The fission core includes all regions where the neutrons are available.

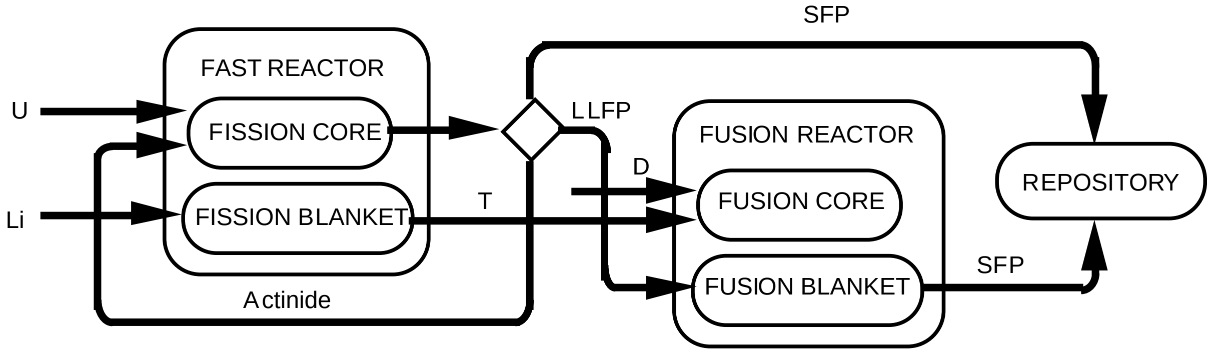

FIG. 2. Fuel cycle scheme using DT fusion reactor. SFP and LLFP stand for stable and long life FP, respectively. The fission blanket is a tritium production region and the fission core is other region where the neutrons are available.

When the DT fusion reactor is employed, the LLFPs are incinerated in the fusion blanket and the tritium used as fuel of the fusion reactor is produced in the fission blanket as shown in Fig. 2. The core and blanket of fast reactor are different from the conventional definitions. The fission blanket is a tritium production region and the fission core is the other region where the neutrons are available. The physical conditions of LLFP are the same as the previous case, and the lithium is oxide. The removal rates of LLFP and tritium are chosen to be same and 1/2 y^{-1}.

When the DD fusion reactor is employed, the fuel for the fusion reactor does not need to be produced by using nuclear reaction. The neutron economy is not a problem for this case. The fuel cycle scheme for this case is shown in Fig. 3. Both catalyzed and pure DD reactor satisfy the similar scheme.

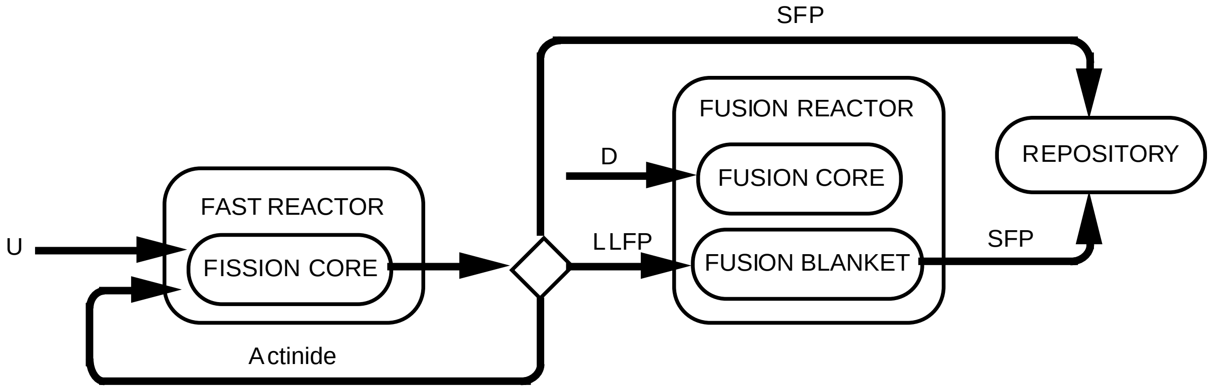

FIG. 3. Fuel cycle scheme using DD fusion reactor. SFP and LLFP stand for stable and long life FP, respectively. The fission core includes all regions where the neutrons are available.

3. CALCULATION METHOD

The neutron transport calculations for fusion reactor blanket and fission reactor blanket are performed with ANISN code[6] for one-dimensional cylindrical geometry. Employed nuclear data are JENDL-3.2 and ENDF/B6, and processed with NJOY code[7]. In the present study 1238 nuclides are treated. One-group constants are generated from obtained neutron spectrum and used for nuclear equilibrium calculation. The calculation of fast reactor core is performed with ECICS code system[8].

4. CALCULATION RESULTS AND CONCLUSIONS

The extensive calculation results are obtained for many calacteristic values associating to safety and neutron economical aspects for the presented calculaton cases. However the spece of the proceedings is not enough and ony some concluding results are presented here.

The incineration of LLFPs, all of which can not be incinerated with only the fast reactor without isotope separation is studied by employing the DT and DD fusion reactors. The incinerated LLFPs for different reactors are shown in Table V. And the required first wall loading for the standard fusion blanket (ITER) volume is shown in Table VI.

TABLE V. INCINERATED LLFPS FOR DIFFERENT REACTORS

		Incinerated LLFP
Fast reactor		^{79}Se, ^{99}Tc, ^{126}Sn, ^{129}I
DT reactor	Standard blanket width	^{79}Se, ^{99}Tc, ^{126}Sn, ^{129}I, ^{135}Cs
	1/2 blanket width	^{79}Se, ^{99}Tc, ^{126}Sn, ^{129}I, ^{135}Cs
	1/4 blanket width	^{79}Se, ^{93}Zr, ^{99}Tc, ^{126}Sn, ^{129}I, ^{135}Cs
DD reactor		^{79}Se, ^{93}Zr, ^{99}Tc, ^{107}Pd, ^{126}Sn, ^{129}I, ^{135}Cs

TABLE VI. REQUIRED FIRST WALL LOADING FOR STANDARD FUSION BLANKET VOLUME

		Req. 1st wall loading (MW/m^2)
DT reactor	Standard blanket width	5
	1/2 blanket width	3
	1/4 blanket width	2
Catalyzed DD reactor		3
Pure DD reactor		0.8

The requirement of production of tritium for the DT reactor is severe and the thickness of the blanket should be decreased considerably to incinerate the considerable amount of LLFPs. On the other hand the DD fusion reactor is free from the neutron economy constraint and can incinerate all LLFPs. The pure DD reactor can also show the excellent performance to reduce the first wall loading less than 1 MW/m^2 even for total LLFP incineration. By raising the wall loading to the design limit, the D-D reactor can incinerate the LLFPs from several number of fast reactors. When the fusion reactor is utilized as an energy producer, plasma confinement is very difficult problem, especially for the D-D reactor compared to the D-T reactor. However, when it is utilized as an incinerator of LLFP, this problem becomes considerably easier. Therefore, the incineration of LLFP is considered as an attractive subject for the D-D reactor.

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