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Core characteristics of fast reactor cycle with simple dry pyrochemical processing

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Abstract

Fast reactor core concept and core nuclear characteristics are studied for the application of the simple dry pyrochemical processing for fast reactor mixed oxide spent fuels, that is, the Compound Process Fuel Cycle, large FR core with half of loaded fuels are recycled by the simple dry pyrochemical processing. Results of the core nuclear analyses show that it is possible to recycle FR spent fuel once and to have 1.01 of breeding ratio without radial blanket region. The comparison is made among three kinds of recycle fuels, LWR UO_2 spent fuel, LWR MOX spent fuel, and FR spent fuel. The recycle fuels reach an equilibrium state after recycles regardless of their starting heavy metal compositions, and the recycled FR fuel has the lowest radio-activity and the same level of heat generation among the recycle fuels. Therefore, the compound process fuel cycle has flexibility to recycle both LWR spent fuel and FR spent fuel. The concept has a possibility of enhancement of nuclear non-proliferation and process simplification of fuel cycle.

Keywords: Nuclear fuel cycle; Fast reactor core; Simple dry pyrochemical processing; Compound process fuel cycle; Enhancement of nuclear non-proliferation

1. Introduction

Recently, a new nuclear fuel cycle concept named ‘‘Compound Process Fuel Cycle’’ which utilizes the simple dry pyrochemical processing was proposed and the feasibility of the concept was investigated (Ikegami, 2005, 2006). The concept originally aims to utilize light water reactor (LWR) spent fuels simply and efficiently in fast reactor (FR) core, to suppress the LWR spent fuel pile-up, and to realize smooth evolution from LWR system to FR system.

An outline of the concept of the Compound Process Fuel Cycle (Ikegami, 2006) is briefly described as follows. LWR spent fuels are multi-recycled with only simple dry pyrochemical processing (Goode, 1973; Asquith and Grantham, 1978; Thomas, 1973) before fuel re-fabrication. It is expected that re-fabricated fuel will be reloaded to the FR core in which about 40–50 % of the fuels are recycled LWR spent fuels and remaining 50–60 % of the fuels are FR fuels. The simple dry pyrochemical processing consists of only de-cladding and pulverization processes, and has no chemical separation process of the ordinary reprocessing of mixed oxide (MOX) fuel. Spent fuel pins are oxidized at high temperature (~500 °C) after being cut to small pieces or being hole-punched at cladding. The de-cladding and the pulverization are conducted by the volume expansion of about 30% in oxidation from UO_2 to U_3O_8. Volatile fission products (FPs) are removed at the process. Reduction under the hydrogen added atmosphere enables pulverized U_3O_8 returning to UO_2, in a ready form for re-fabrication. The recycled LWR fuels are taken over, at the simple dry pyrochemical processing, only with cladding replacement but without adding or subtracting any amount of heavy metals, resulting in no Pu enrichment adjustment.

Major results of the previous study (Ikegami, 2006) are as follows. Four to six times of recycling of LWR spent fuels with the burn-up of 300–400 GWd/t can be achieved with almost no increase of minor actinide content. The benefits of this concept are the efficient utilization of nuclear fuel resources, the enhancement of nuclear non-proliferation due to the recycle of all actinides in a lumped state together with the fact that the concept has no radial blanket fuels, the

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reduction of environmental impacts due to reduced high level waste, the reduction of fuel cycle cost through simplified reprocessing procedure, and the suppression of light water reactor spent fuel pile-up.

It is expected that the concept can be applied for both LWR and FR spent fuels, in other words, not only for transient period from LWR to FR but also for FR equilibrium period. Therefore, the feasibility of the concept for FR spent fuels has been studied in this paper focusing strictly on the core nuclear characteristics.

2. Concept of compound process fuel cycle for fast reactor spent fuel

The cycle concept for FR spent fuels is presented in Fig. 1. Two kinds of fuels are loaded in FR core, fresh FR fuels and recycle fuels. The spent fuels from the fresh fuels which have rather low burn-up are fed to the simple dry pyrochemical processing and are loaded to the FR core after fabricated as recycle fuels. On the other hand, the spent fuels from the recycle fuels which have high burn-up are fed to the ordinary FR fuel reprocessing. The recycle fuels were LWR spent fuels in the case of the compound process fuel cycle for LWR fuels in the previous study (Ikegami, 2006). Only volatile FPs are removed at the simple dry pyrochemical processing and heavy metals including minor actinides (MA) with non-volatile FPs are recycled without adjusting Pu enrichment, or with neither adding nor subtracting any amount of heavy metal nuclides. The cladding replacement conducted in this process avoids over irradiation of core material such as cladding and duct for high burn-up of FR fuel. These are very important features of the compound process fuel cycle concept.

Fission product removal rates in the simple dry pyrochemical processing are given in Ikegami (2005).

Process simplification and reduction of high level waste (HLW) compared with the ordinary reprocessing can be expected in the simple dry pyrochemical processing which consists of only de-cladding and pulverization without chemical separation process using solution, although confirmation work through future research and development (R&D) efforts is required.

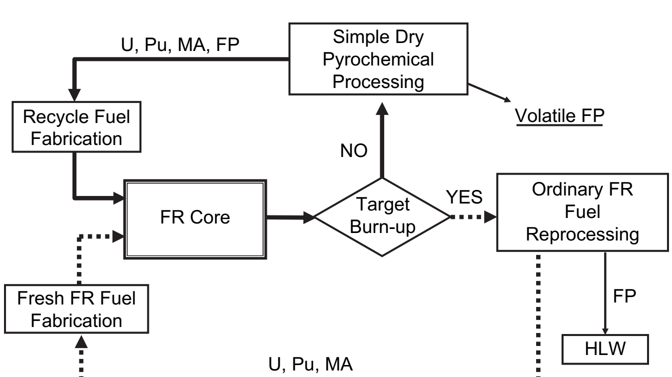

Fig. 1. Concept of compound process fuel cycle for fast reactor spent fuel.

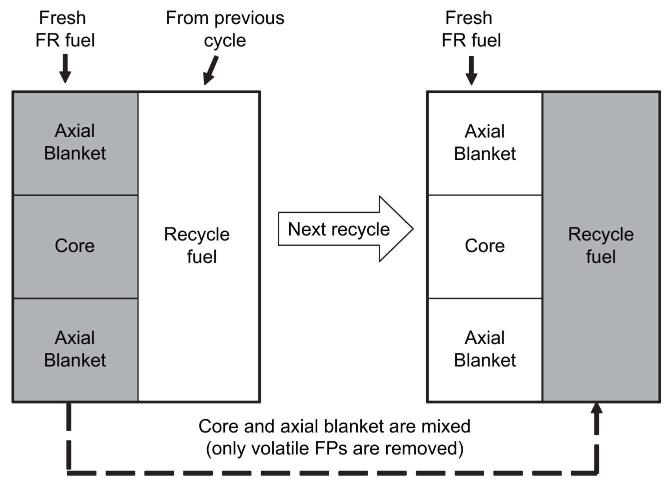

Fig. 2. Fuel flow in the case of fast reactor spent fuel recycle.

Conceptual fuel flow is presented in Fig. 2. It is noteworthy that core and axial blanket of fresh FR fuel are mixed and homogenized in the recycle fuel, resulting in lower Pu enrichment than that of the core region of the fresh FR fuel.

3. Core nuclear calculation

3.1. Calculation method

Core nuclear calculation has been carried out by the CITATION code in two dimensional R-Z geometry using 70 group cross section set JFS3-J3.2R based on the nuclear data library JENDL3.2 (Nakagawa et al., 1995).

Treatment of residual FPs contained in the fuel is very important in this analysis since some amount of FP remains in the recycle fuel. Both of neutron absorption effect and volume effect of FP have been taken into account. More detailed explanation is given in Ikegami (2006).

3.2. Core specification

In order to accommodate two kinds of FR fuels, fresh FR fuels and recycle fuels, a radial heterogeneous core configuration has been adopted as shown in Fig. 3. The number of fuel assemblies in fresh FR fuel region and that in recycle fuel region are identical so as to keep the smooth recycle fuel flow. The R-Z geometry core configuration together with depletion regions is presented in Fig. 4.

Table 1 presents the major core specifications fixed by survey calculations under following limiting conditions. The reactor thermal power is 2400 MWt. The maximum linear heat rate is less than 400 W/cm, taking account of three-dimensional effect margin for the usual design limit of 430 W/cm (Mizuno et al., 2004). The maximum fast neutron fluence is less than $5 \times 10^{27}/m^2$ (Mizuno et al., 2004), supposed design limit of ODS (oxide dispersion strengthened) steel which is expected to be cladding material for future FR. The burn-up reactivity loss is less than 4% dk/kk', following typical FR core design (Mizuno et al., 2004).