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Original Article

RECYCLING OPTION SEARCH FOR A 600-MWE SODIUM-COOLED TRANSMUTATION FAST REACTOR

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ABSTRACT

Four recycling scenarios involving pyroprocessing of spent fuel (SF) have been investigated for a 600-MWe transmutation sodium-cooled fast reactor (SFR), KALIMER. Performance evaluation was done with code system REBUS connected with TRANSX and TWODANT. Scenario Number 1 is the pyroprocessing of Canada deuterium uranium (CANDU) SF. Because the recycling of CANDU SF does not have any safety problems, the CANDU-Pyro-SFR system will be possible if the pyroprocessing capacity is large enough. Scenario Number 2 is a feasibility test of feed SF from a pressurized water reactor PWR. The sensitivity of cooling time before prior to pyro-processing was studied. As the cooling time increases, excess reactivity at the beginning of the equilibrium cycle (BOEC) decreases, thereby creating advantageous reactivity control and improving the transmutation performance of minor actinides. Scenario Number 3 is a case study for various levels of recovery factors of transuranic isotopes (TRUs). If long-lived fission products can be separated during pyroprocessing, the waste that is not recovered is classified as low- and intermediate-level waste, and it is sufficient to be disposed of in an underground site due to very low-heat-generation rate when the waste cooling time becomes >300 years at a TRU recovery factor of 99.9%. Scenario Number 4 is a case study for the recovery factor of rare earth (RE) isotopes. The RE isotope recovery factor should be lowered to ≤20% in order to make sodium void reactivity less than <7$, which is the design limit of a metal fuel.

1. Introduction

Currently, one of the most important issues in the nuclear industry is the safe and reliable management of high-level radioactive wastes (HLWs), such as spent fuel (SF). In Korea, SF is stored at the power plants temporarily, but the storage capacity will be full in about 10 years' time. Under the same conditions of the world, research into identifying methods for SF incineration has been actively pursued in the past number of decades. As one of the methods, SF should be recycled for reuse as a fuel for the sodium-cooled fast reactor (SFR) [5].

The Korea Atomic Energy Research Institute (KAERI) has redesigned a Gen-IV SFR, the KALIMER (Korea Advanced LIquid MEtal Reactor) reactor, as a dedicated transmutation reactor

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for recycling with pyroprocessing [1]. For SF to be recycled by the recycling process called “pyroprocessing”, as much of the impurities as possible should be first removed from the SF, thereby recovering materials that can be used for fuel and reusing the recovered materials for recycling. Pyroprocessing is a technology involving electrochemical treatment on SFs >500°C using a molten salt medium and electricity. Because of its processing characteristics, plutonium cannot be separated individually, and thus the proliferation resistance is high. This is why the pyroprocessing can be being developed in Korea. Although pyroprocessing technology is an advanced method and SFR has been actively studied, unexpected results still occur if a back-end fuel cycle is made by combining SFR with pyroprocessing. This is because pyroprocessing research aims to increase the recovery factor of transuranics and uranium while removing as many impurities as possible, whereas the direction of SFR research is focused on increasing safety and operation performance. As such, these two technologies have been developed separately with different directions. Furthermore, various variables, including the recovery factor of nuclides, are not yet finalized in pyroprocessing and no studies have been performed on the influence of options that can be changed during the recycling system process using a KALIMER reactor core for transuranic isotope (TRU) transmutation. Thus, SFR performance needs to be evaluated according to options that can be changed during pyroprocessing.

In this study, we aimed to design an SFR for TRU transmutation using the design parameters of KALIMER developed by the KAERI, and examine the design feasibility in advance by identifying the nuclear characteristics of reactor cores caused by various parameters in the material flow scheme of SF recycling. To achieve this goal, various achievable scenarios feasible in Korea have been tested to compare and evaluate the impact on nuclear safety of SFR core and TRU transmutation efficiency.

2. Concept of the reference core design

The reactor core to be evaluated in this study was designed with reference to the design parameters of the KALIMER-600 [1,3] TRU Burner Report, which was an SFR for transmutation developed by the KAERI. The code used for the design and evaluation was the TRANSX [6]/TWODANT [7]/REBUS-3 [8] code system, which is used for nuclear design in the KAERI; the nuclear data were obtained from the ENDF/B-VII-based KAFAX library, which was recently modified by the KAERI. In addition, the ORIGEN2 code was used to compute the heat-generation rate and specific activity.

Fig. 1 shows (A) a cross-sectional diagram of KALIMER-KHU, which is a newly designed SFR for transmutation in Kyung Hee University, Gyeonggi-do, Korea and (B) an R-Z cross-sectional diagram for the computation of TWODANT. Table 1 shows the design variables of the KALIMER-600 TRU Burner that were referred to for designing the KALIMER-KHU. The assumptions applied when designing the reactor core are as follows: (1) the coolant/structure volume ratios of the handling socket and the nosepiece are 0.6/0.4 and 0.7/0.3, respectively; (2) a wire wrap is assumed to be wound three and half times around the wheel at the active core height; (3) Mod.HT-9 was used as the material for all structures such as cladding and ducts; (4) the in-vessel storage (IVS), which is a part of KALIMER-600, was removed because it was considered to have an insignificant influence on reactor core computation; and (5) the control rod follower was ignored.

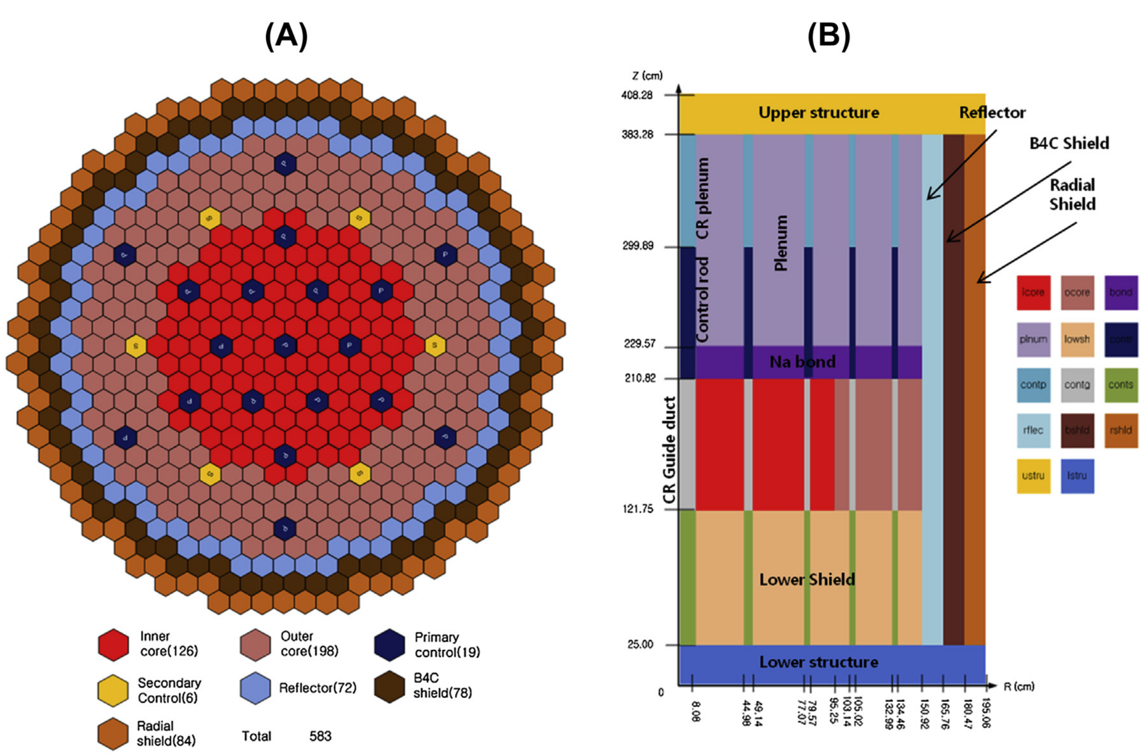

Fig. 1 – Radial and axial configuration of the KALIMER-KHU.