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Optimization study on accelerator driven system design for effective transmutation of Iodine-129

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A B S T R A C T

The transmutation of Iodine-129 in accelerator driven system (ADS) is studied. The sodium iodide assembly loadings inside the core of ADS and in the surrounding core region are considered. The introduced concept of ADS with a power of 800 MWt is able to transmute 250 kg/y of minor actinides (MAs) and 46 kg/y of Iodine-129 that supports ten PWRs. The initial loading masses of MAs and I-129 in ADS were equal to 3810 kg and 824 kg, respectively.

1. Introduction

Safety, non-proliferation and environmental protection concerns arise in the long-term storage of long-lived fission products (LLFPs) such as Iodine-129 and technetium-99. Transmutation of such LLFPs under neutron flux in nuclear power plant is one of solution of these problems and promises considerable reduction of the total radiotoxicity of nuclides. Transmutation is the process of artificial transformation their into stable or short-lived nuclides, in particular: I-129 transmutes to stable Xe-130 and Tc-99 to stable Ru-100.

Research and development of iodine and technetium transmutation aims at to minimize the risks of radiotoxicity and environmental hazard. Various theoretical and experimental studies on LLFP transmutation in power plants were conducted in prior to. For example, in Europe, Konings (1996, 1999) carried out a collaborative program "Experimental Feasibility of Targets for Transmutation" (EFTTRA) with purpose to test of Tc, NaI, CeI_3 and PbI_2 and clarification its irradiation properties. In the US, the transmutation efficiency of NaI in the fast flux test facility (FFTF) was estimated. Yang et al. (2004) performed a systematic study to define an optimal strategy for LLFP transmutation in critical and subcritical systems. In Japan, fundamental research on LLFP transmutation in accelerator driven system (ADS) and fast-breeder reactor (FBR) was done by Nishihara et al. (2001, 2008), Tachi et al. (2009), Yokoyama et al. (2009). As a result, important experimental data were accumulated through all of these activities in due course.

The goal of earlier studies in relations to transmutation of LLFPs (I-129 and Tc-99) in critical and subcritical systems was to achieve a value of support factor at the range of one or more; where as power systems were required to transmute only amount of I-129 or Tc-99 annually produced by corresponding nuclear plant.

Kloosterman and Li (1994) attempted to increase the support factor for technetium by considering transmutation of Tc-99 in heavy water reactor (HWR), light water reactor (LWR) and FBR plants with thermal power of 3 GW. As a result, the support factor of 5–7 depending on system was achieved successfully.

Simultaneous transmutation of minor actinides (MAs) and LLFPs in ADS was studied in Korea Atomic Energy Research Institute (KAERI) on hybrid power extraction reactor (HYPER) of 1 GW thermal power by Song et al. (2004); and in Argonne National Laboratory on Accelerator Transmutation of Waste System (ATW) of 840 MWt power by Yang et al. (2004).

HYPER could perform simultaneous transmutation of transuranium (282 kg/y), I-129 (7 kg/y) and Tc-99 (27 kg/y) that conforming to support factor of 1 plant for iodine and technetium and 10 plants for MAs.

To simultaneously transmute TRU, I-129 and Tc-99 with support factor of 3.2 for such plant was feasible in ATW of ANL.

The present study engages an optimization of the ADS parameters for effective transmutation of I-129 simultaneously with MAs aiming to achieve support factor of 10 PWRs.

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2. Outline of the reference ADS for Iodine-129 transmutation

The ADS is a hybrid system that consists of a high intensity proton accelerator, spallation target and subcritical reactor. The present study is based on the work of Nishihara et al. (2001), which shows that the type of ADS of Japan Atomic Energy Agency (JAEA) can simultaneously transmute MAs and LLFPs. Accordingly, the computational model represents a simplified cylindrical geometry for all components (spallation target, homogeneous active core and homogeneous LLFP blankets). The LLFP blankets in this concept contained the homogenized mixture of iodide (NaI or CuI), moderator, cladding material and coolant.

Figs. 1 and 2 illustrate hexagonal calculation geometry of the present study that is modified from the cylindrical model of the reference ADS. There are axial and radial blanket regions for transmutation of the LLFP and sizes are determined in this study. The radial blanket is not shown in the planar layout in Fig. 2. The main characteristics, taken from the latest design work by JAEA (Nishihara et al., 2008), are presented in Table 1.

Criticality coefficient value in ADS at 0.97 per latest study (Nishihara et al., 2008) was used, although in previous work (Nishihara et al., 2001) it was at 0.95. Initial proton beam energy was equal to 1.5 GeV and beam current was kept at value corresponding to 800 MWt of system thermal power. The abidance of such conditions implies that system can transmute 250 kg of MAs annually (300 days of irradiation).

As for the fuel composition, the following reprocessing scheme is considered for the origin of MAs. The spent PWR fuel of 45 GWd/t burn-up was reprocessed after 7 years of cooling, and MAs were recovered. Before fabrication of the ADS fuel, an additional 3-year period after recovery of MAs is assumed. Isotopic composition of MA and Pu (wt.%) is presented in Table 2. The average fission energy of such fuel is 210 MeV (Croff, 1980). For the blanket fuel the mono-nitride of MAs is used with a pellet density of 95% theoretical density (TD) and a smear density of 80% TD. The mass of MA inventory was 2625 kg. Zirconium-nitride (ZrN) is applied with the fuel as an inert matrix.

The volume fractions in the core region are equal to 0.29, 0.098, and 0.597 for fuel, structure material, and coolant, respectively. This coolant volume ratio corresponds to the ratio of fuel pin pitch to fuel pin diameter (P/D) of 1.5.

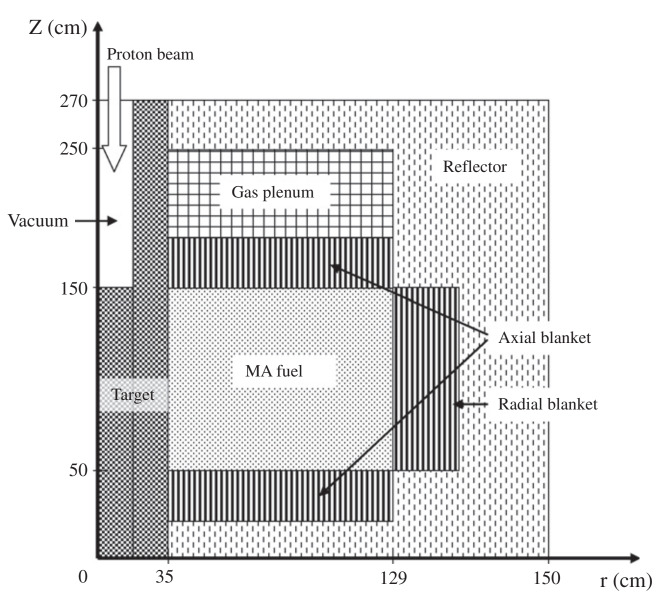

Fig. 1. Design of reference ADS for simultaneous transmutation of MAs in fuel zone and LLFPs in radial and axial blankets.

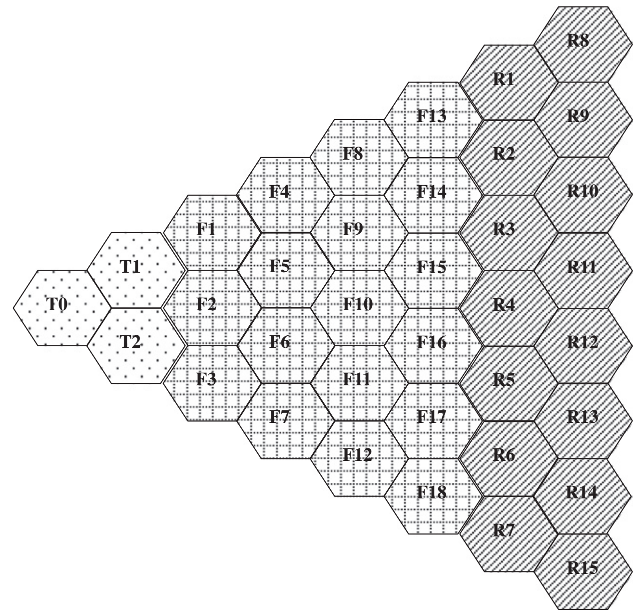

Fig. 2. The 1/6 of planar layout of base ADS for MAs transmutation, where T – target assembly (T0 – central), F – fuel assembly and R – reflector.

Table 1
Characteristics of base case ADS for MA transmutation.

Thermal fission power (MWt)	800
Coolant	Pb–Bi eutectic
Coolant velocity in fuel zone (m/s)	2.0
Active core height (mm)	1000
Assembly pitch (mm)	233.9
Number of fuel pins/tight rods per assembly	391/6
Number of fuel assemblies	84
Number of target assemblies	7
Pin diameter (mm)	7.65
Pin pitch (mm)	11.48
Pitch to diameter ratio	1.5
Cladding thickness (mm)	0.5
Fuel (MA/Pu in initial)	Nitride (MA60% + Pu40%)
Inert matrix	ZrN (volume ratio ~ 65%)
Total heavy metal inventory (kg)	4375
Transmutation of actinide (kg/300 days)	250
Proton beam energy (GeV)	1.5
Proton beam radius (cm)	20.2
Proton beam profile	Flat

Table 2
Isotopic composition of MA and Pu (wt.%).

Isotope	MA	Pu
^{234}U	–	0.04
^{236}U	–	0.01
^{237}Np	49.65	–
^{238}Pu	–	2.38
^{239}Pu	–	54.47
^{240}Pu	0.32	24.19
^{241}Pu	–	10.85
^{242}Pu	–	6.96
^{241}Am	32.10	1.09
^{242m}Am	0.06	–
^{243}Am	13.37	–
^{243}Cm	0.03	–
^{244}Cm	4.04	–
^{245}Cm	0.39	–
^{246}Cm	0.04	–