Nuclear Engineering and Design 241 (2011) 5295–5307

Contents lists available at SciVerse ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Feasibility study of minor actinide transmutation in light water reactors with various Am/Cm separation efficiencies

Daniell Tincher, Travis W. Knight*

Department of Mechanical Engineering, Nuclear Engineering Program, University of South Carolina, 300 Main Street, Columbia, SC 29208, USA

ARTICLE INFO

Article history:
Received 4 May 2011
Received in revised form 29 August 2011
Accepted 29 August 2011

ABSTRACT

A study was conducted to evaluate the feasibility of minor actinide (MA) transmutation in light water reactors (LWR). The purpose of this work was to provide a guide for future investigations into MA transmutation in LWR. This work considered the effects of various Am/Cm separation efficiencies as well as homogeneous and heterogeneous MA bearing fuel assemblies. The MA content was introduced into the reactor as mixed oxide plus minor actinide (MOX + MA) fuel. Three Am/Cm separation efficiencies were independently considered: 99.9%, 99.0%, and 90.0%. In order to evaluate the feasibility of MA transmutation, the fuel performance of the various assemblies and core designs, as well as their respective safety related parameters, were calculated. The reduction of the burden of high level waste (HLW) motivated the investigation of MA transmutation. It was found that the MA bearing fuel assemblies and their subsequent core designs were able to perform within the safety limits required as well as achieving similar burnups to a UO_2 core. The Am transmutation rates were ~40% for the homogeneous assemblies and up to 68% for the MA targets in the heterogeneous assemblies after the described burnup, however, there was a significant amount of Cm produced during burnup. This Cm production was due to the more favorable neutron capture reaction over fission for Am in the thermal spectrum. Future work should examine the benefits of Am transmutation at the expense of large Cm production rates.

1. Introduction

1.1. Goals

A study was conducted to evaluate the feasibility of minor actinide (MA) transmutation in light water reactors (LWR). The purpose of this work was to provide a guide for future investigations into MA transmutation in LWR. This work considered the effects of various Am/Cm separation efficiencies as well as homogeneous and heterogeneous MA bearing fuel assemblies. In order to evaluate the feasibility of MA transmutation, the fuel performance of the various assemblies and core designs, as well as their respective safety related parameters, were calculated. The reduction of the burden of high level waste (HLW) motivated the investigation of MA transmutation.

1.2. Background

The ultimate disposal of the used nuclear fuel (UNF) produced from U.S. commercial nuclear activities has yet to be determined with the Yucca Mountain license application withdrawal. MA transmutation was considered in an effort to reduce the design requirements of a geological repository by reducing the long-term radiotoxicity and decay heat of HLW. Despite the more favorable transmutation rates in a fast spectrum (IAEA, 2009; Westlén, 2007), MA transmutation in LWR was considered due to the delayed introduction of widespread commercial fast reactors. Two elements, Pu and Am, found in HLW have the greatest contribution to the long term radiotoxicity and decay heat of HLW. Therefore, it is of interest to reduce the inventory of these two elements in a transmutation scheme (Wigeland et al., 2006).

The difficulty associated with the chemical separation of Am from Cm means that some amount of Cm would be carried along with any Am content included in nuclear fuel, therefore it was of interest to examine the effects of varying amounts of Cm content in any fuels containing MA. A study (Li et al., 2010) analyzed the how separation efficiency affected fuel cycle performance. Similar separation efficiencies for Am/Cm separation were considered here. Other potential issues associated with the use of mixed oxide bearing minor actinides (MOX + MA) fuels in LWR include over-pressurization of fuel pins due to increased He production (Fetterman, 2009), positive moderator void coefficient (MVC) values, and pin power peaking.

* Corresponding author. Tel.: +1 803 777 1465; fax: +1 803 777 0106.
E-mail addresses: dtincher@gmail.com (D. Tincher), twknight@sc.edu (T.W. Knight).

0029-5493/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.nucengdes.2011.08.080

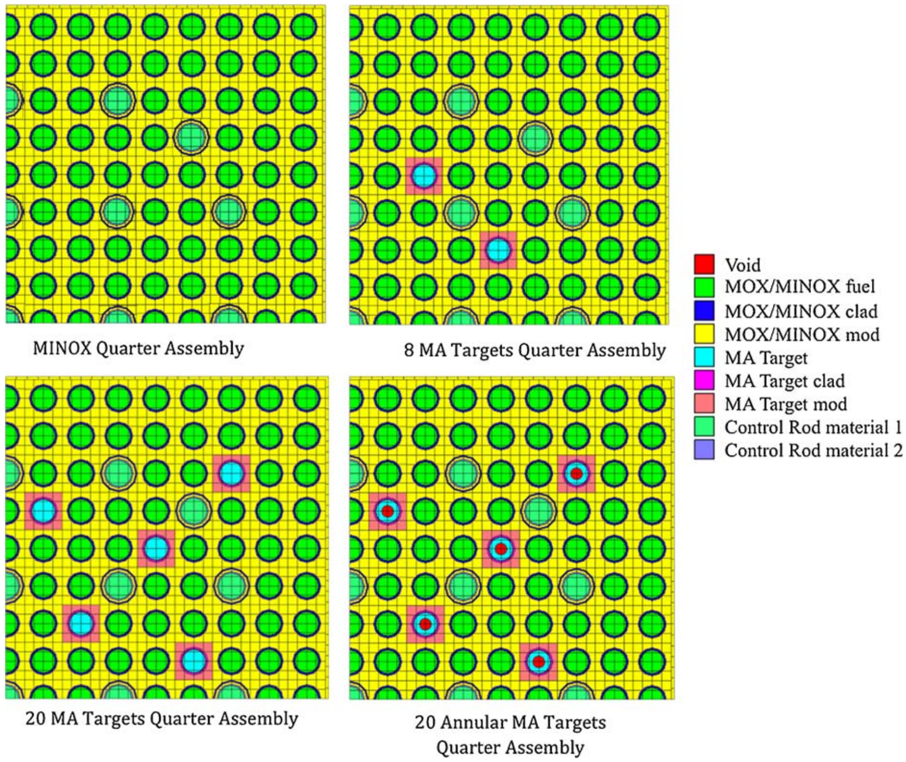

Fig. 1. MA bearing fuel assembly designs, quarter assembly shown.

Table 1
Fuel assembly data for models.

Fuel assembly type	Westinghouse PWR 17 × 17
Assembly pitch	21.6232 cm
Number of fuel rods	264
Number of water rods	25
Cell pitch	1.26 cm
Outer radius of clad for fuel rod	0.4572 cm
Inner radius of clad for fuel rod	0.40005 cm
Fuel pellet radius	0.392176 cm
Inner annular radius	0.196088 cm
Outer radius of water rod for control rod	0.60198 cm
Inner radius of water rod for control rod	0.56134 cm

2. Methods

The analysis of MA transmutation in LWR was carried out to evaluate its feasibility with regard to transmutation efficiency, fuel performance, and safety parameters (Tincher, 2010).

2.1. Fuel assembly models

The fuel assemblies modeled in this study were Westinghouse 17 × 17 Performance+ PWR assemblies as described in Table 1. The UO_2 fuel assemblies that were modeled were nominally enriched to 4.9 wt% (Bryson et al., 2006). The MA content was introduced into the reactor as MOX + MA fuel. The isotopic compositions of the MOX + MA fuel were taken from typical discharged UNF with an assumed burnup of 58 GWD/MTU that had been cooled for 5 years (Coleman and Knight, 2010). The Pu content in the MOX fuel was an assumed 8 wt% and remained constant. Two separate MOX + MA fuel assembly designs were independently considered. A homogeneous minor actinide mixed oxide (MINOX) assembly type with a uniform MOX + MA fuel mixture in each pin was considered. In addition, two heterogeneous designs were considered as well. These assemblies consisted of 8 and 12 discrete target rods that contained MA mixed with depleted uranium (DU). The remainder of the fuel pins in the heterogeneous assembly consisted of MOX fuel only. MA targets of solid and annular pellets were both tested independently. The annular targets were used to accommodate the anticipated increase of fission gas and helium production. For all assembly types the MA content was fixed at 1 wt% of the heavy metal on a fuel assembly basis and consisted only of Am and Cm. This MA concentration was varied only for moderator void coefficient (MVC) calculations to determine a maximum MA loading. Three Am/Cm separation efficiencies were independently considered. The first separation efficiency was 99.9% of Cm removed from Am and was referred to as MA Content Type A. The two others considered were Type B at 99.0% and Type C at 90.0%. Four types of fuel assemblies were considered, and these are described in Table 2 and Fig. 1. Each assembly was burned out to 57.75 GWD/MTHM in three cycles and an assumed 5 year cooling period was considered as shown in Table 3.

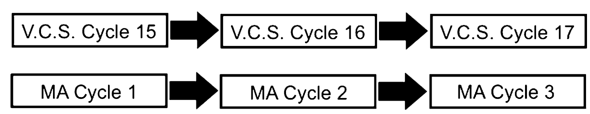

Fig. 2. Correlation between V.C. summer cycles and MA cycles.

2.2. Reactor core models

The reference reactor and cycles for this study were the V.C. Summer Reactor Cycles 15, 16, and 17, each with 157 fuel assemblies and generally three unique burnup zones (Bryson et al., 2006). The loading pattern and shuffling scheme of the V.C. Summer reactor were modeled as described in Bryson et al. (2006), except that in each of the cycles modeled, 16 UO_2 assemblies were substituted with MOX + MA assemblies. The correspondence between the V.C. Summer Cycles 15–17 and the modeled MA Cycles are shown in Fig. 2. By the beginning of the MA Cycle 3, 48 assemblies were MOX + MA, reaching the typical 1/3 core MOX loading. The core