Available online at www.sciencedirect.com
ScienceDirect
Journal of Nuclear Materials 377 (2008) 298–306
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Irradiation damage to the beam window in the 800MWth accelerator-driven system

Kenji Nishihara *, Kenji Kikuchi

Nuclear Transmutation Technology Group, Basic Nuclear Technology and Reactor Engineering Unit, Nuclear Science and Engineering Directorate, Japan Atomic Energy Agency, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan

Abstract

Irradiation damage to the beam window in the concept of 800MWth accelerator-driven system is evaluated. Heat produced in the window is also evaluated. Transport of proton and neutron up to 3.0 GeV is calculated by both PHITS that is the Monte Carlo code for particles and heavy ions and TWODANT that is two-dimensional deterministic transport code. The beam window is irradiated at the center of the accelerator-driven system with 20 MW proton beam power and neutron from the core during 300 full power days. Heat, displacement per atom, production rate of hydrogen and helium isotopes, and neutron and proton fields are estimated, assuming the Gaussian and flat beam profiles.

1. Introduction

An accelerator-driven system (ADS) is proposed to transmute minor actinide (MA) to ease the burden of high level waste disposal. In particular, one of the most key components in the ADS is a beam window. In a design of Japan Atomic Energy Agency (JAEA) [1] the beam window positions above the lead–bismuth eutectic (LBE) target and is cooled by LBE. The beam window is not only subjected to the hot LBE under high LBE pressure and thermal stress but also damaged by high energy protons and neutrons. In the ADS design, proton beam energy and criticality mainly affect the amount of irradiation damage. The damage, that is displacement per atom (DPA) and production of hydrogen and helium, is evaluated in the present report. Heat generated in the window is also evaluated.

For the evaluation, flux of the proton and neutron is calculated by the PHITS [2] (particle and heavy ion transport code system) and TWODANT [3] (two-dimensional diffusion-accelerated neutral-particle transport code system). Displacement by proton and neutron above 150 MeV and production of hydrogen and helium by high energy particle above 20 MeV are also calculated by PHITS. DPA cross section below 150 MeV is calculated by processing LA-150 by NJOY code [4]. Cross sections in a library of DCHAIN-SP [5] are available for production of hydrogen and helium by neutron below 20 MeV.

The damage to the window is calculated for the ADS with several parameters those are proton beam energy, criticality, window material and beam shape. The approximate expressions of the damage are induced as functions of these ADS parameters. Then, result of the survey for effects of the ADS parameters to the damage are discussed.

2. ADS design parameter

The proposed ADS is 800MWth, LBE-cooled, tank-type reactor as shown in Fig. 1 and Table 1. The spallation target is also LBE. The core is composed by MA nitride fuel with zirconium nitride to dilute the fuel. The plutonium is added to the fuel only at the initial loading of the first cycle to reduce the burn-up swing of reactivity (Fig. 2). Although in the reference core design [1], two-zone fuel loading is adopted to decrease the power peaking, a

* Corresponding author. Tel.: +81 29 282 5059; fax: +81 29 282 5671.
E-mail address: nishihara.kenji@jaea.go.jp (K. Nishihara).

0022-3115/$ - see front matter
doi:10.1016/j.jnucmat.2008.02.045

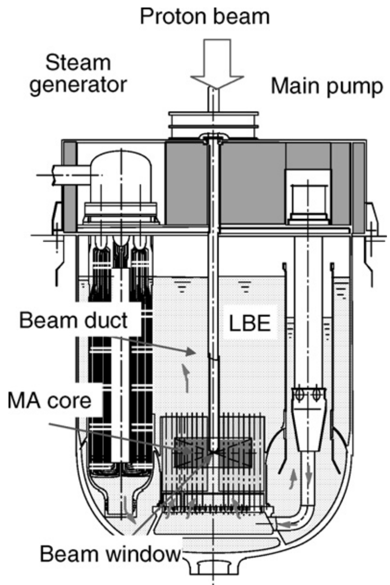

Fig. 1. Conceptual design of 800MWth ADS plant.

Table 1
ADS plant specification

Power (MWth)	800
Cycle length (FPDs)	600
Number of batch	1
k (min/max)	0.94/0.97
Active core diameter (mm)	2343
Active core height (mm)	1000
Coolant temperature (in/out)	300/407
Maximum coolant flow rate (m/s)	2.0
Beam duct diameter (mm)	450
Thickness of beam window (mm)	2
Accelerator type	Proton linac
Beam energy (GeV)	1.5
Beam current (min/max) (mA)	9.6/21

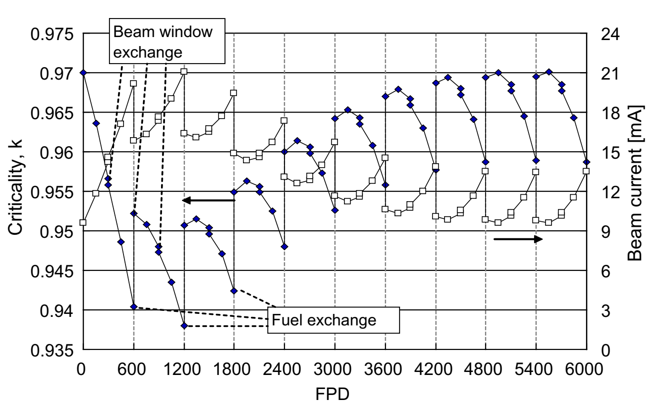

Fig. 2. Swing of criticality and beam current.

single-zone fuel loading is adopted in the present study to simplify the ADS design. The burn-up swing of criticality (*k*) and proton beam current are almost similar between the single and two-zone fuel loading. However, the low energy neutron from the single-zone MA core to the window material is larger than that from two-zone fuel because the power near the window is higher in the single-zone core than two-zone core.

All the fuel in the core is simultaneously to be unloaded at every 600 full power days (FPDs), while the beam window is to be exchanged at every 300 FPDs by an operation scenario.

The proton beam energy is set at 1.5 GeV. The beam current changes between 9.6 and 21 mA according to criticality swing as shown in Fig. 2. The window is the most irradiated during 900–1200 FPDs.

The detail design around the window is described in Ref. [6]. The target region is separated by a wall from the MA fuel to keep the cooling performance of the MA fuel. The flow control nozzle is positioned under the target to cool the window effectively. When 20 mA proton beam with energy of 1.5 GeV is induced, the heat density at the center was 700 W/cm^3 according to Ref. [6]. The window was designed under the most severe condition, 700 W/cm^3, because the proton beam current is the strongest at 20 mA. The outer surface temperature at center of the window was 450 °C. The maximum temperature was found at the peripheral region, and its value was 490 °C. The maximum velocity of LBE along the window was 1.8 m/s.

3. Calculation method

Flux and cross section of proton and neutron are necessary to evaluate the damage to the window. For the flux of proton and high enrgy neutron above 10 MeV, PHITS is used. PHITS is also available for neutron below 10 MeV using MCNP-4C, however, TWODANT is used for neutron because it is difficult to precisely estimate the flux from the MA core to such small area as the window. TWODANT is suitable because it is determinstic.

The heat cross section is calculated by PHITS for whole energy region of proton and neutron. The DPA cross section for proton and neutron above 150 MeV is calculated by PHITS and that for neutron below 150 MeV is calculated by NJOY with LA150 as descrived in Ref. [4]. The production cross section of hydrogen and helium for proton and neutron above 20 MeV is calculated by PHITS and that for neutron below 20 MeV is obtained from a libraly of DCHAIN-SP, which is a calculation code for irradiation and decay. The library of DHCAIN-SP contains 150 groups cross sections for various reaction of neutron below 20 MeV such as (n,p), (n,np), (n,d), (n,α), and, etc. Those cross sections are collected from EFF-2.4, ADL-3.0, JEF-2.2, JENDL-3.2, etc.

4. Induced expressions for the damage

4.1. Parameters

Four parameters are chosen for parametric survey. Those are energy of proton beam (E_p), core criticality (k), material of the window (M) and beam shape (S) as shown