Nuclear Engineering and Design 331 (2018) 11–23

Contents lists available at ScienceDirect

Nuclear Engineering and Design

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

Conceptual design study of beam window for accelerator-driven system with subcriticality adjustment rod

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ARTICLE INFO

Keywords:
Accelerator-driven system (ADS)
Beam window
Coupled analysis
Burnup analysis
Particle transport analysis
Thermal hydraulics analysis
Structural analysis

ABSTRACT

The design of the beam window of the spallation target is one of the critical issues in the accelerator-driven system (ADS) design. This study aims to perform the coupled analysis for the feasible beam window concept. To mitigate the design condition, namely to reduce the necessary proton beam current, subcriticality adjustment rod (SAR) was installed to the ADS core. The burnup analysis was performed for the ADS core with SAR and the results indicated that the maximum proton beam current during the burnup cycle was reduced from 20 to 13.5 mA.

Based on the burnup analysis result, the coupled analysis; particle transport, thermal hydraulics and structural analyses, was performed. As the final result, the most robust beam window design; the hemisphere shape, the outer radius = 235 mm, the thickness at the top of the beam window = 3.5 mm and the factor of safety for the buckling = 9.0, was presented. The buckling pressure was 2.2 times larger than the previous one and more feasible beam window concept was presented through this study.

1. Introduction

To reduce the burden of the geological disposal of the high-level radioactive waste (HLW), partitioning and transmutation (P&T) technology of the HLW is supposed to be a promising technology (Oigawa et al., 2011). The Japan Atomic Energy Agency (JAEA) has investigated a liquid lead-bismuth eutectic (LBE) cooled accelerator-driven system (ADS) to transmute minor actinides (MAs) which will be partitioned from the HLW. The ADS consists of a high intensity proton accelerator with 1.5 GeV beam energy, an LBE spallation target and a subcritical core with 800 MW thermal power. The spallation target is placed at the center of the subcritical core and the proton beam is injected into the target. The subcritical core is driven by the spallation neutrons generated in the target. The subcritical core can transmute about 250 kg MAs per year (Tsujimoto et al., 2004).

One of the critical issues for the realization of the ADS is a design of a beam window which is a boundary between the accelerator and the spallation target. Fig. 1 shows a schematic view of the ADS and the beam window. The LBE flows into the target region from the bottom of the core and out to the upper region of the core with being heated up by the proton beam. The beam window should be tolerant to (a) external pressure by the LBE (accelerator side is vacuum), (b) heat generation by the proton beam, (c) creep deformation at high temperature, (d) corrosion in the LBE and (e) irradiation damage by protons and neutrons.

In the previous study (Sugawara et al., 2010), the investigation for a feasible beam window concept was performed by changing a proton beam profile with the consideration of (a), (b) and (d). Through a coupled analysis of particle transport, thermal hydraulics and structural analyses, the following beam window concept was presented as the feasible one: the ellipse shape with the outer radius of 235 mm and the thickness of 2.0 mm at the top of the beam window. The design achieved a factor of safety (FS) of 4.1 for the buckling. It was also confirmed that all three beam profiles considered in the previous study, i.e. Gaussian, parabolic and flat, were acceptable for this design. On the other hand, it was supposed that the ellipse shape was not suitable from the viewpoint of design and fabrication. A more feasible concept with a simple shape has been required from the viewpoint of its fabrication and reliability. To realize more feasible beam window concept, a new core concept to relieve design condition of the beam window was investigated and the beam window concept was re-evaluated.

The most important factor for the beam window design is the heat generation by the proton beam. If the required proton beam current to maintain the same core power is reduced, the design condition for the beam window is mitigated. In the ADS operation, the neutron effective multiplication factor decreases by the burnup, then it will be necessary to increase the proton beam current to maintain the same core power. If it is available to keep the effective multiplication factor at the same value during the operation, the proton beam current is also kept as the

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https://doi.org/10.1016/j.nucengdes.2018.02.011
Received 6 September 2017; Received in revised form 30 January 2018; Accepted 4 February 2018
Available online 28 February 2018
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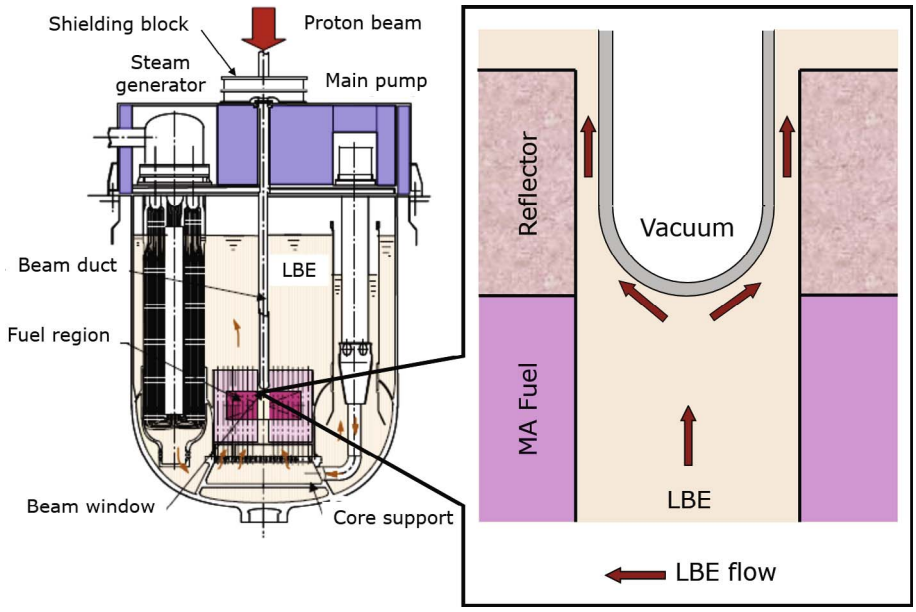

Fig. 1. Schematic view of LBE cooled ADS and its beam window.

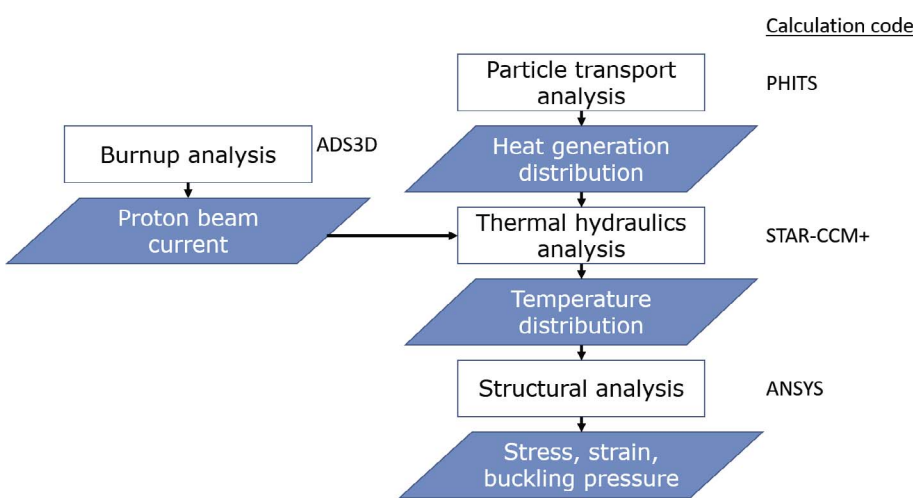

Fig. 2. Calculation flow.

constant. To achieve such condition, a subcriticality adjustment rod (SAR) which is a B_4C control rod is investigated in this study.

At first, the burnup analysis was performed for the ADS core with SAR to decide a new proton beam condition. Then, by using the new proton beam current condition, the coupled analysis of the particle transport, the thermal hydraulics and the structural analyses was performed to present a more feasible beam window concept.

Section 2 introduces the calculation methodology and assumptions in this study. From Sections 3–6, the calculation conditions and results for the burnup, the particle transport, the thermal hydraulics and the structural analyses are described, respectively. Section 7 concludes this study.

2. Methodology and assumptions

2.1. Calculation flow and codes

Fig. 2 presents the calculation flow of this investigation. First, the burnup analysis is performed by ADS3D code (Sugawara et al., 2016), which can calculate the transport of neutrons, the burnup calculation and the fuel exchange for an ADS in three-dimensional calculation model. This analysis aims to get a feasible ADS core concept which should satisfy the boundary conditions such as a maximum temperature of the cladding tube surface (details are described below). As one of the outputs, the proton beam current during the burnup cycle is obtained.

Table 1
Main parameters of the reference ADS.

Plant	Thermal power	800 MW
	Coolant and spallation target	LBE
	Inlet temperature	300 °C
	Coolant velocity	2.0 m/s
	Maximum k_{eff}	0.97
	Operation period	600 EFPDs*1
	Transmutation amount	250 kgMA/ 300 EFPDs
Accelerator	Type	Superconducting linac
	Proton beam energy	1.5 GeV
	Maximum proton beam current	20 mA
	Maximum proton beam power	30 MW
	Beam profile	Gaussian

*1 Effective Full Power Days

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