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SCIENCE DIRECT

Energy Conversion and Management 47 (2006) 2794–2800

ENERGY CONVERSION & MANAGEMENT

www.elsevier.com/locate/enconman

High temperature helium-cooled fast reactor (HTHFR)

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Available online 4 April 2006

Abstract

Scoping calculations have been performed for a very high temperature (1000 °C) helium-cooled fast reactor involving two distinct options: (1) using graphite foam into which UC (12% enrichment) is embedded into a matrix comprising UC and graphite foam molded into hexagonal building blocks, shown in Fig. 1, and encapsulated with a SiC shell covering all surfaces, and (2) using UC only (also 12% enrichment) molded into the same shape and size as the foam–UC matrix in option 1. Both options use the same basic hexagonal fuel matrix blocks to form the core and reflector. The reflector contains natural uranium only. Both options use 50 μm SiC as a containment shell for fission product retention within each hexagonal block.

The calculations show that the option using foam (option 1) would produce a reactor that can operate continuously for at least 25 years without ever adding or removing any fuel from the reactor. The calculations show further that the UC only option (option 2) can operate continually for 50 years without ever adding or removing fuel from the reactor. Doppler and loss of coolant reactivity coefficients were calculated. The Doppler coefficient is negative and much larger than the loss of coolant coefficient, which was very small and positive. Additional progress on and development of the two concepts are continuing.

Keywords: Helium-cooled; Fast reactors; Hexagonal; Blocks; Uranium carbide

1. Introduction

Under the gas-cooled fast reactor component of the Generation IV Nuclear Energy Systems Initiative, we, at the Georgia Institute of Technology Nuclear Engineering Program, have been conducting scoping calculations for a very high temperature (1000 °C) helium-cooled fast reactor involving two distinct options: (1) using ORNL graphite foam [1] into which UC (12% enrichment) is embedded into a matrix, and (2) using UC only (also 12% enrichment) molded into the same shape and size as the graphite foam–UC matrix in option (1). Both options use the same basic building blocks, Fig. 1, for core and reflector. In the reflector natural uranium

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doi:10.1016/j.enconman.2006.02.012

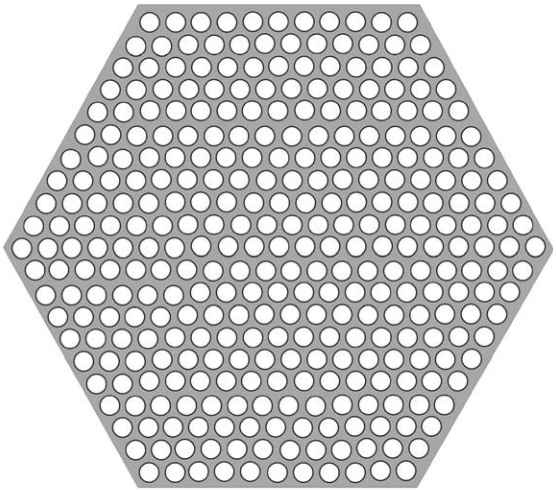

Fig. 1. Hexagonal building block of core and blanket assemblies. Cooling channel = 1 cm in diameter; channel to channel pitch = 1.3 cm; area of hexagonal block: area of one equilateral triangle × 6 triangles in a block; one side of triangle: 13.65 cm; area of triangle: 80.66 cm^2; area of hex block: $6 \times 80.66\ cm^2 = 483.96\ cm^2$; volume fraction of coolant: 53%; volume fraction of UC and foam matrix: 46%; volume fraction of SiC: 1%. © by Ratib A. Karam, 2004.

is used. Each hexagonal block is coated with a 50 μm thick layer of SiC on all surfaces. The 50 μm shell is used to contain the fission products. No metallic material is used in the core.

The main reason for removing the graphite foam from the fuel matrix in option (1) is because it might require significant development to embed the UC in foam and its performance in a fast reactor environment is not known. By using UC only molded in shape (Fig. 1) by relatively low pressure and heat would not require any development. Also, SiC as a containment shell has been used before but not in the geometry envisioned for our reactor concept. Consequently, an experimental program for qualifying the hexagonal block with SiC for extended use in the reactor will be needed.

A third option that is currently being contemplated, but for which no scoping calculations have been made, is to replace the SiC shell in option (2) with a carbon–carbon composite as the containment shell. The "UC only" material stays as in option (2). Carbon–carbon composite material is strong, has thermal conductivity comparable to aluminum, remains strong at temperatures of 2500 °C, and may have desirable nuclear characteristics in that it helps produce a slightly softer spectrum.

In a previous paper [2], we reported that a very high temperature (1000 °C) helium-cooled fast reactor using uranium carbide (UC 12% enrichment) embedded in a graphite foam [1] that has a density of 0.5 g/cm^3 and encapsulated with a 50 μm SiC shell, operating at 1000 psi (68 bar) pressure in a direct cycle mode and producing 1000 MWe of power was indeed feasible. Furthermore, it was reported that this reactor fuel cycle can go 10 years continuously with no need for refueling. Our recent work has evolved to decreasing the foam density (from 0.5 g/cc to 0.3 g/cc) with all other parameters kept the same as before.

2. Design details

The basic element of the core and blanket material structure and assembly is a hexagonal block approximately 24 cm flat-to-flat distance, containing 10 rings of coolant channels, each channel is one centimeter in diameter, and channel-to-channel pitch is 1.3 cm. A sketch of the hexagonal block is shown in Fig. 1.

The design options in which the graphite foam density was lowered from 0.5 g/cc to 0.3 g/cc had two core regions and one reflector region. All three regions were comprised of the hexagonal blocks, shown in Fig. 1 and stacked together radially and axially to form nearly a right cylinder. The reflector's hexagonal blocks contained natural uranium carbide embedded in the graphite foam. The core regions contained 12% enriched UC in the same graphite foam. The enrichment in both core regions was the same. The only difference was that the central region contained the burnable poison, B-10, in the concentration of 4.1×10^{-4} atoms/b-cm. The outer radius of