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Journal of Nuclear Materials 373 (2008) 407–414
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Prediction of TRISO coated particle performances for a one-pass deep burn

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Received 26 August 2006; accepted 10 July 2007

Abstract

In the present studies, TRISO coated particle performances have been investigated for incinerating plutonium and minor actinides by the Gas Turbine-Modular Helium Reactor, whose fresh fuel is fabricated after the uranium extraction (UREX) process applied to Light Water Reactors irradiated fuel. The analyses divide into two parts: in the first part, the latest design of the reactor core proposed by General Atomics, which takes advantage of four fuel rings, has been modeled in deep details by the Monte Carlo MCNP code and a burnup process has been simulated by the MCB code. In the second part, the TRISO coated particle performances have been investigated by the PANAMA code with the goal of verifying the design constraints proposed by General Atomics. During burnup, the refueling and shuffling schedule followed the one-pass deep burn concept, where the fuel is utilized, since fabrication for the Gas Turbine-Modular Helium Reactor, without any reprocessing until the final disposal into the geological repository. During the reactor operation, the fast fluence on all TRISO particles layers has been evaluated and the production of the key fission products monitored. During an hypothetical reactor accident scenario, the TRISO particle failure fraction has been estimated.

1. Introduction

The Gas Turbine-Modular Helium Reactor (GT-MHR) [1], conceived by General Atomics (GA), has the capability to incinerate plutonium and minor actinides coming from the uranium extraction (UREX) process applied to Light Water Reactors (LWRs) irradiated fuel. Within this context, the plutonium and minor actinides burnup is often referred as 'deep burn' to emphasize that transuranic isotopes deplete more than 50%. In previous studies, two alternative scenarios have been investigated: the first one where the three years irradiated plutonium and minor actinides triple isotropic (TRISO) coated particles are reprocessed to manufacture fresh fuel TRISO coated particles (referred as two-pass deep burn to emphasize the reprocessing of the TRISO coated particles) [2] and the second one where the plutonium and minor actinides TRISO coated particles remain in the core until their final disposal into the geological repository (referred as one-pass deep burn to emphasize no reprocessing of the TRISO particles occurs) [3]; the two different options have shown transmutation rates of 94% and 83% for the key isotope ^{239}Pu. Since in both cases an accumulation of curium isotopes has been observed, the present studies focused on the transmutation of only neptunium, plutonium and americium by a one-pass deep burn. The major goal of the present analyses is the verification of the GA design constrains for the integrity of TRISO particles. Consequently, the analysis consists of two parts: in the first part the reactor burnup has been simulated by a Monte Carlo transport code and in the second part the results of the Monte Carlo transport code have been used as input in a thermo-chemical-mechanical code for evaluating TRISO coated particle performances.

2. The GT-MHR Monte Carlo modelling

The latest design of the GT-MHR, which exhibits four fuel rings, as shown in Fig. 1, has been described in a detailed 3D model by the Monte Carlo N-Particle (MCNP)

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0022-3115/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnucmat.2007.07.001

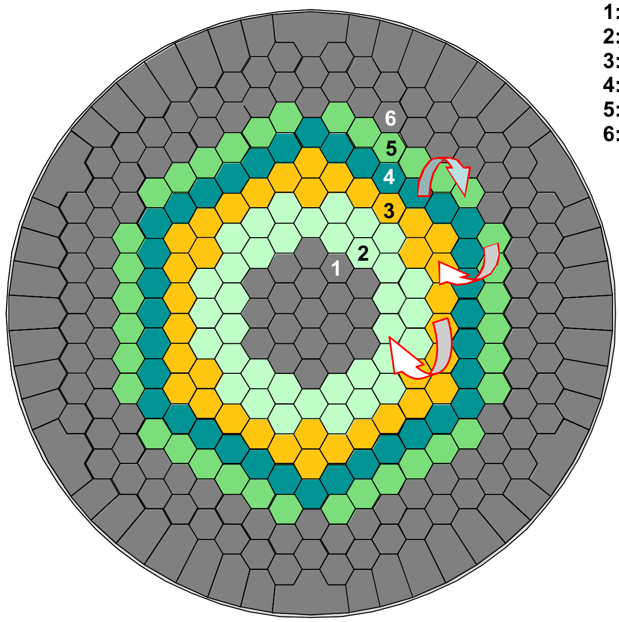

Fig. 1. Horizontal section of the GT-MHR core.

transport code [4]; that has cost a 5500–10000 lines input (for the fresh and irradiated reactor core, respectively). Fig. 2 illustrates the fuel hexagonal block, which allocates 108 coolant channels and 216 fuel pins; the latter ones have been modeled as graphite cylinders filled by a body centered cubic lattice of TRISO particles. Fig. 5 of previous studies [2] illustrates the structure of the TRISO particles and their disposal inside the fuel pins, as represented in the Monte Carlo geometry model. Tables 1 and 2 report the geometry and material data, respectively, of the present core. In the present core configuration all control mechanisms (e.g. burnable poison or control rods) have been neglected.

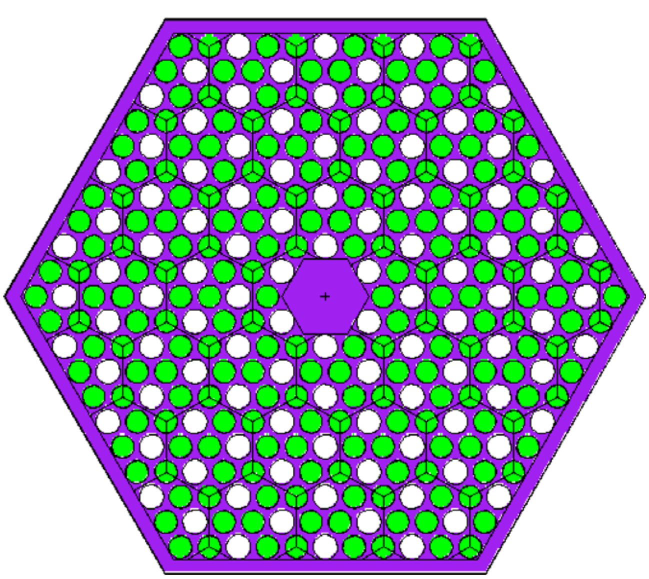

Fig. 2. Horizontal section of the fuel hexagonal block.

Table 1
Geometry data of the GT-MHR

Core-radius [cm]	385
Core-height [cm]	1030.885
Hexagonal fuel blocks – number	36 × 4
Hexagonal fuel blocks – apothem [cm]	17.9984
Hexagonal fuel blocks – height [cm]	793
Hexagonal fuel blocks – interstitial gap [cm]	0.1016
Hexagonal fuel blocks – fuel pins number	216
Hexagonal fuel blocks – coolant channels number	108
Hexagonal fuel blocks – fuel pins radius [cm]	0.6223
Hexagonal fuel blocks – fuel pins pitch [cm]	1.8796
Hexagonal fuel blocks – fuel pins hole radius [cm]	0.635
Hexagonal fuel blocks – coolant channel radius [cm]	0.79375
Hexagonal fuel blocks – fuel pins height [cm]	793
TRISO particles – kernel radius [μm]	100
TRISO particles – width porous graphite layer [μm]	150
TRISO particles – width inner pyrocarbon layer [μm]	35
TRISO particles – width SiC layer [μm]	35
TRISO particles – width outer pyrocarbon layer [μm]	40
TRISO particles – packing fraction [%]	20

The burnup calculation has been carried out by the Monte Carlo Continuous Energy Burnup MCB code [5–9], version 2 beta, which is an extension of the MCNP code; the MCB transport code has been equipped with a nuclear data library based on JEFF-3 and extended with: JENDL-3.3, ENDF\B-6.8 and DLC200, which has been used just for the evaluation of the scattering function $S(\alpha,\beta)$ of graphite. The Monte Carlo method allows to handle the triple heterogeneity of the GT-MHR without any spatial homogenization and to treat the neutron energy over a continuous domain; however, to reduce statistical fluctuations the number of simulated neutrons is so high that