Applied Radiation and Isotopes 125 (2017) 188–195

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

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

The use of MOX caramel fuel mixed with ^{241}Am, ^{242m}Am and ^{243}Am as burnable absorber actinides for the MTR research reactors

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ARTICLE INFO

Keywords:
MTR-22 MW reactor
MOX caramel fuel
Criticality safety
Neutronic parameters
MCNP4C code

ABSTRACT

The MOX (UO_2 & PuO_2) caramel fuel mixed with ^{241}Am, $^{242\,m}$Am and ^{243}Am as burnable absorber actinides was proposed as a fuel of the MTR-22 MW reactor. The MCNP4C code was used to simulate the MTR-22 MW reactor and estimate the criticality and the neutronic parameters, and the power peaking factors before and after replacing its original fuel (U_3O_8-Al) by the MOX caramel fuel mixed with ^{241}Am, $^{242\,m}$Am and ^{243}Am actinides. The obtained results of the criticality, the neutronic parameters, and the power peaking factors for the MOX caramel fuel mixed with ^{241}Am, $^{242\,m}$Am and ^{243}Am actinides were compared with the same parameters of the U_3O_8-Al original fuel and a maximum difference is −6.18% was found. Additionally, by recycling 2.65% and 2.71% plutonium and ^{241}Am, $^{242\,m}$Am and ^{243}Am actinides in the MTR-22 MW reactor, the level of ^{235}U enrichment is reduced from 4.48% to 3% and 2.8%, respectively. This also results in the reduction of the ^{235}U loading by 32.75% and 37.22% for the 2.65%, the 2.71% plutonium and ^{241}Am, $^{242\,m}$Am and ^{243}Am actinides, respectively.

1. Introduction

Research Reactors have a wide range of uses that includes medical applications such as: boron neutron capture therapy and production of cobalt, validation of reactor calculation codes, neutron activation analysis using thermal and epithermal neutrons, cold, thermal and fast neutron radiography. Additionally, these kinds of facilities usually represent the first step in a nuclear technology development plan, contributing in the education and training of scientists, reactor operators and engineers (Liu et al., 2004; IAEA, 2001; Shaaban and Albarhoum, 2015; Shaaban, 2010; Eberhardt et al., 2005; Kaushal, 2005).

In research reactors many types of fuel were used such as: U-A1 alloy, dispersion-type fuels including $UA1_x$-A1, U_30_8-A1, U_3Si_2-Al,U_3Si-Al and U-ZrH_x. Fuels in MNSRs (Miniature Neutron Source Reactors), MTRs (Material Testing Reactors) and TRIGA (Training, Research, Isotopes, General Atomics) reactors are enriched in ^{235}U to about 90% in MNSRs and 20% in MTRs and TRIGA reactors (IAEA, 1992; SAR, 1993; Bretscher and Matos, 1996; IAEA, 1980). As well as, the UO_2 caramel fuel is one of the most promising new types of reduced enrichment fuel. The UO_2caramel fuel has been qualified since 1978 and is commercially available for use in low and medium power research reactors. The UO_2 caramel fuel was used for the OSIRIS and Shipping Port reactors (IAEA, 1980).

As a result of nuclear plants diffusion around the world, the resources of ^{235}U are expected to become limited and very expensive. Therefore many countries decided to re-process the spent fuel to recover the unused uranium and plutonium. Additionally, there is a suggestion to recycle the plutonium together with Minor Actinides (MAs) in Light Water Reactors (LWRs) and fast reactors. This helps in saving energy and enhancing the proliferation resistance of radioactive materials, and reduces the radio-toxicity of the spent fuel on one hand. From the other hand, the minimum fuel enrichment with ^{235}Uis about 20% for most Research Reactors (RRs) except for some reactors which use UO_2 as a fuel (IAEA, 2003; Bergelson et al., 2011; Chang and Zhang, 2009; Chang, 2007; Zhang, 2003; Hsieh et al., 1980). Therefore, it is very important to think of recycling RRs by MOX (UO_2 & PuO_2) fuels with MAs. This suggestion helps in:

1. enhancing the proliferation resistance of the radioactive materials and eliminating their risks,
2. burning the plutonium and the MAs,
3. reducing the volume of spent fuel for storage,
4. redesigning RRs using MOX fuel with and without MAs.

The main objective of this paper is to discuss recycling of the MTR-22 MW reactors(the Egyptian Test Research Reactor No. 2 (ETRR-2*)* as example)with MOX (PuO_2 & UO_2) caramel fuel with $^{(i)}$Am (^{241}Am, ^{242m}Am and ^{243}Am) as burnable absorber actinides without

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http://dx.doi.org/10.1016/j.apradiso.2017.04.026
Received 29 March 2016; Received in revised form 20 April 2017; Accepted 20 April 2017
Available online 25 April 2017
0969-8043/

changing the dimensions of the:

5. Fuel Plate (FP), fuel material and the Fuel Element (FE),

1. reactor core, the beryllium and aluminum cubes surrounding the reactor core,
2. control plates or any component of the reactor.
3. The clad (Al-6061 for the U_3O_8-Al original fuel) was the only material which was changed to Zircaloy-4 for the UO_2 caramel fuel and the MOX (PuO_2 & UO_2) caramel fuel with $^{(i)}$Am actinides, the latter (Zircaloy-4) being used in Power reactor for many reasons of which its small absorption cross section for neutrons its high melting temperature,…etc.

The MCNP4C code (Briesmeister, 2000) was used to simulate the various stages of core conversion from the U_3O_8-A1 original fuel to the UO_2 caramel fuel and then to the MOX (PuO_2 & UO_2) caramel fuel with $^{(i)}$Am actinides of the ETRR-2 reactor. A computer model of the ETRR-2 reactor was used to estimate the criticality and the neutronic parameters of the ETRR-2 reactor, the power distribution in the FEs and to calculate the power peaking factors of the U_3O_8-Al original fuel, the UO_2 caramel fuel and the MOX caramel fuel mixed with $^{(i)}$Am actinides.

2. Methodology

2.1. Description of the ETRR-2 reactor

The ETRR-2 reactor is a Material Testing Reactor (MTR)which uses low enriched MTR fuel elements (19.7% enrichment). The reactor power is 22 MW with high thermal neutron flux (> 10^{14} n/cm^2.s) in the Central Neutronic Trap (CNT). The ETRR-2 reactor is cooled and moderated by light water and reflected by beryllium. The ETRR-2 core consists of 29 positions for fuel elements and one position for CNT as shown in Fig. 1. Table 1 shows the fuels used in the ETRR-2 reactor which are: 7 Standard Fuel Elements (SFE), 8 Fuel Elements Type 1 (FEs

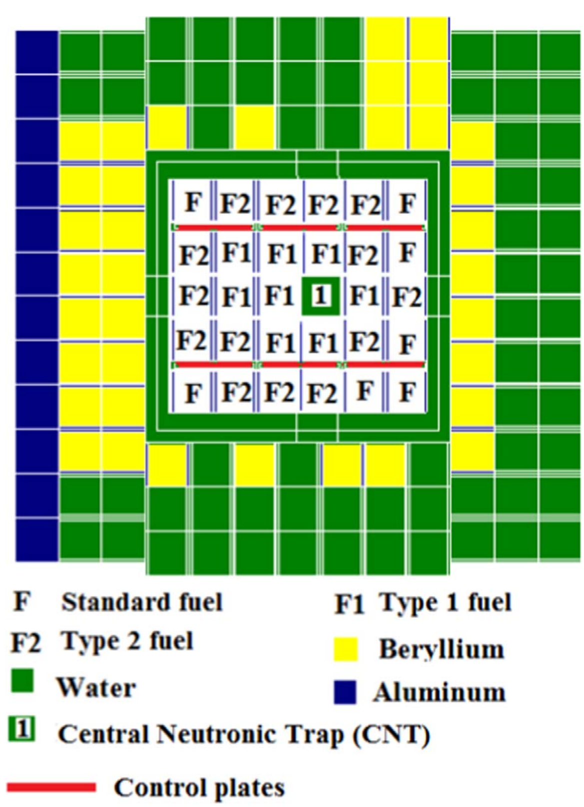

Fig. 1. A cross section of the ETRR-2 core in the plane X–Y with CNT using the MCNP4C code.

Table 1
Composition of the FE in a typical ETRR-2 reactor. Where SFE - is the standard fuel element, FE Type 1 - is the Fuel Elements Type 1 and FE Type 2 - is the Fuel Elements Type 2.

Parameter	Weight percentage %		
	SFE	FE Type 1	FE Type 2
^{235}U	12.377	6.598	8.398
^{238}U	50.450	26.894	34.230
^{27}Al	25.91	60.504	49.730
^{16}O	11.263	6.004	7.642
Density (g/cm^3)	4.802	3.299	3.655

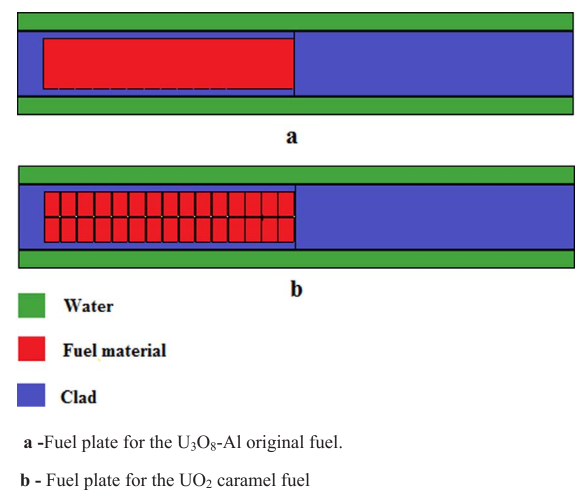

Fig. 2. Schematic representation of the fuel plate in the plane X–Y using the MCNP4C code. **a** -Fuel plate for the U_3O_8-Al original fuel. **b** - Fuel plate for the UO_2 caramel fuel.

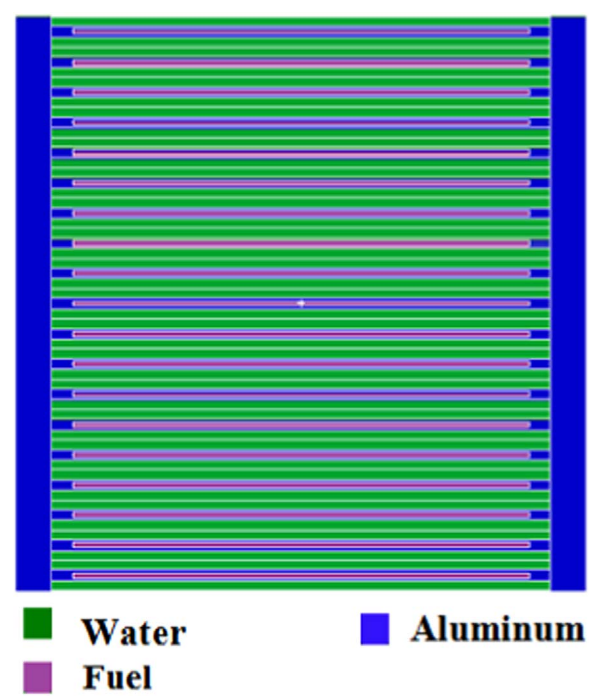

Fig. 3. A schematic horizontal cross section in a plate type fuel element of the ETRR-2 reactor using the MCNP4C code.

Type 1) and 14 Fuel Elements Type 2 (FEs Type 2). The reactor is controlled by 6 plates made of Ag-In-Cd alloy. The general specifications of the fuel material, Fuel Plate (FP), Fuel Element (FE), absorber