Annals of Nuclear Energy 85 (2015) 613–620

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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

Absolute burnup measurement of LEU silicide fuel plate irradiated in the RSG GAS multipurpose reactor by destructive radiochemical technique

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ARTICLE INFO

Article history:
Received 2 April 2015
Received in revised form 1 June 2015
Accepted 8 June 2015
Available online 23 June 2015

Keywords:
Absolute burnup measurement
Destructive radiochemical technique
U-235
Cs-137
Silicide LEU fuels
RSG GAS

ABSTRACT

Absolute burnup measurements of a sample taken from the IDA0045 fuel plate of RI-SIE2 low enriched uranium, silicide, experimental fuel element irradiated in the Reaktor Serba Guna G.A. Siwabessy (RSG GAS; previous name MPR-30) multipurpose reactor were conducted using destructive radiochemical technique. The destructive burnup measurement effort is an important part of the continuing efforts related to the post irradiation examination (PIE) project of the Indonesian National Nuclear Energy Agency. The amount of U-235 fissile material left and the Cs-137 fission product in the sample were selected as the burnup indicator for the present work. The measured burnup values of the sample were 72.4 ∓ 4.5% loss of U-235 and 78.6 ∓ 5.0% loss of U-235 based on the amount of U-235 fissile material and Cs-137 fission product, respectively. The burnup value based on the measured Cs-137 showed an overestimation since it was assumed that all fissions originated from U-235 thermal fissions. Numerical burnup verification was also conducted using the SRAC2006 code system with a PIE dedicated detail burnup chain and a SRAC library based on the JENDL-3.3 nuclear data. The verification results, combined with the previous nondestructive burnup measurement results on the plate wise and axial distributions of the Cs-134/Cs-137 activity ratio, produced burnup value of 75.0 ∓ 5.0% loss of U-235 which agreed well with the measured values.

1. Introduction

In our previous work (Liem et al., 2013) we have reported the results of nondestructive burnup measurement using gamma-ray spectrometry method on the low enriched uranium (LEU) silicide fuel plates which had been irradiated in the Reaktor Serba Guna G.A. Siwabessy (RSG GAS; previous name MPR-30) multipurpose reactor, operated by the Indonesian National Nuclear Energy Agency. In the nondestructive burnup measurement, the plate wise and axial distributions of the Cs-134/Cs-137 activity ratio were measured and numerical burnup verification was also conducted. Following the nondestructive burnup measurement, in this paper the destructive radiochemical analysis results for a sample taken from the same fuel plate are reported and discussed. The RSG GAS and the related post irradiation examination (PIE) project of the Agency are briefly explained.

RSG GAS is a Be-reflected, light-water-moderated and -cooled, 30 MWth (max.) multipurpose reactor. The reactor main data (the reactor was commissioned in 1987) are shown in Table 1. Originally, the core used material testing reactor (MTR) type low enriched uranium (LEU; 19.75 w/o U-235 enrichment) oxide fuel elements (FEs). On the 10 × 10 core grid positions there are 40 standard FEs (each consisting of 21 fuel plates as depicted in Fig. 1), 8 control elements (CEs, each consisting of 15 fuel plates as depicted in Fig. 2) initially loaded with 250 and 178.6 g U-235 respectively, Be reflector elements, and other irradiation facilities. This fuel loading corresponds to a uranium meat density of 2.96 g U/cm^3. The original nominal core cycle is 25 days or equivalent to 750 MWD per cycle. The equilibrium core is divided into seven burn-up classes with an average burn-up step of approximately 8% loss of U-235.

At the end of 90's, the core conversion program from oxide to silicide fuels with higher U-235 loading per FE was initiated to optimize the reactor utilization. The optimized equilibrium silicide cores with a new fuel management strategy for U-235 loading up to 350 g U-235/FE (equivalent to a uranium meat density of 4.15 g U/cm^3) were found (Liem et al., 1998), and the transition core design to reach such equilibrium cores were established (Liem and Sembiring, 2010). At present, the former oxide core has been completely converted into new silicide cores using the

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http://dx.doi.org/10.1016/j.anucene.2015.06.016
0306-4549/

Table 1
Reactor main design data of RSG GAS (present silicide core).

General	
Reactor type	Pool type
Fuel element type	LEU silicide MTR
Cooling system	Forced convection Down flow
Moderator/coolant	H_2O
Reflector	Be & H_2O
Nominal power (MWt)	30
Core characteristics	
No. of fuel elements	40
No. of control elements	8
No. of fork type absorber (pairs)	8
Nominal cycle length (fpd)	25
Ave. burn-up at BOC (% loss of U-235)	23.3
Ave. burn-up at EOC (% loss of U-235)	31.3
Ave. discharge burn-up at EOC (% loss of U-235)	53.7
Fuel/control elements	
Fuel/control element dimension (mm)	$77.1 \times 81 \times 600$
Fuel plate thickness (mm)	1.3
Coolant channel width (mm)	2.55
No. of plate per fuel element	21
No. of plate per control element	15
Fuel plate clad material	$AlMg_2$
Fuel plate clad thickness (mm)	0.38
Fuel meat dimension (mm)	$0.54 \times 62.75 \times 600$
Fuel meat material	U_3Si_2Al
U-235 enrichment (w/o)	19.75
Uranium density in meat (g/cm^3)	2.96
U-235 loading per fuel element (g)	250
U-235 loading per control element (g)	178.6
Absorber meat material	Ag–In–Cd
Absorber thickness (mm)	3.38
Absorber clad material	SUS-321
Absorber clad thickness	0.85

same uranium fuel loading (250 g U-235/FE) under the new fuel management strategy. The present silicide core and reflector configuration is shown in Fig. 3.

The above mentioned core conversion program is being coordinated and fully supported by a similar program conducted in the Agency's Nuclear Fuel Element Center (NFEC) for acquiring and establishing the technology to fabricate U_3Si_2 dispersion fuel. As one important milestone, the silicide FEs with uranium fuel loading of 250 g U-235/FE supplied to the RSG GAS are all in-house manufactured from the first lot. Experimental mini and full scale silicide fuels with higher fuel loading are also being manufactured, irradiated in RSG GAS, and nondestructive as well as destructive PIE tests are being conducted in the Agency's Radio-Metallurgy Installation (RMI) for fuel characterization and licensing purposes.

This paper focuses on the absolute burnup measurement results by destructive radiochemical technique obtained from the above-mentioned continuing efforts. It is worthily noted that this activity is the first attempt at the Agency in this particular field, and it is expected to lay the technical and engineering foundations for future similar efforts. The target of the absolute burnup measurement is the experimental silicide FE (identified as RI-SIE2) which was in-house manufactured in the early phase of the program by the NEFC. The experimental silicide FE has been irradiated in the RSG GAS for six consecutive core cycles up to a burnup level of approximately 50% loss of U-235. As for the absolute burnup measurement method, the amount of U-235 isotope and Cs-137 FP were adopted as the burnup indicator, while for the numerical burnup verification, the SRAC2006 code system (Okumura et al., 2007) with a PIE dedicated detail burnup chain and a SRAC library based on the JENDL-3.3 nuclear data (Shibata et al., 2002) was used.

The paper is organized as the following. In Section 2, the absolute burnup measurement by destructive radiochemical technique is explained. Section 3 discusses the absolute burnup measurement results. In Section 4, the detail burnup analysis based on the irradiation history of the targeted FE is explained. The present absolute burnup measurement, previous nondestructive burnup measurement and the burnup analysis results are compared and discussed in Section 5, while the last section, Section 6, provides the concluding remarks of the present work.

2. Destructive radiochemical technique adopted for the absolute burnup measurement

The destructive and nondestructive analytical techniques are commonly used for research reactor spent fuel samples examination for obtaining reference measurements. The nondestructive methods refer to, among others, gamma-ray spectrometry methods namely scanning of FEs or fuel plates such as the one reported in our previous work (Liem et al., 2013). The gamma-ray spectrometry is widely known for assessing the relative (spatial) distributions of fission products (FPs) in irradiated FEs by measuring complete gamma-ray spectra. For MTR type FEs like in the present work, the relative distributions of FPs may depend on the axial, transversal, and lateral (or plate wise) positions (IAEA, 1992). After proper corrections are applied on the position dependent gamma-ray spectra, the information of the FP distributions can be correlated to the relative burnup distributions of the targeted FE.

On the other hand, the isotopic composition and concentration of the spent fuel samples can also be measured using a destructive radiochemical technique which is the main subject of the present work. Destructive radiochemical analysis is considered the most reliable method for isotopic composition and concentrations of the samples, however, it demands expensive professional laboratories equipped by hot cells and other sophisticated equipments and measuring instruments, i.e. for chemical separation of the samples and various spectrometry measurements, respectively. Based on the existing facilities available in the Agency, the PIE for the present destructive radiochemical analysis consists of several separate steps shown in Fig. 4 and is discussed below.

In the present work, there are two isotopes targeted to be analyzed by the destructive method, namely, U-235 and Cs-137. In the in-core fuel management of research reactors, since the main fissile material is U-235, the burnup of a FE is commonly expressed in the% loss of initial U-235. Therefore, the measured amount of U-235 left in the spent FE can be used directly for predicting the burnup. The amount of Cs-137 isotope may also be correlated to the fuel burnup in the unit of % loss of initial U-235 if other fissile materials' thermal fission contribution is small and can be neglected. Since we used nearly 20% enriched uranium, the Pu-239 thermal fissions contribution is neglected as in our previous nondestructive measurements (Liem et al., 2013). The Cs-137 FP is also selected because of its long half life (30.1 years) which allows PIE to be conducted many years after the fuel irradiation finished such as in the present case.

2.1. Sample preparation

The destructive radiochemical analysis was conducted around 17 years after the targeted RI-SIE2 FE was discharged from the reactor. A spent fuel sample for the present destructive radiochemical analysis was cut from 20th fuel plate of RI-SIE2 FE (identified as IDA0045 fuel plate) using a micro-cutter in the hot cell equipped with manipulators. The dimension of the sample was 3.0 mm × 3.0 mm × 1.37 mm (weight 0.036 g) while the location of the sample is depicted in Fig. 5. The specification and the burnup history of the RI-SIE2 FE are discussed later.